UDK 33(082) (0.034.2)

Volume 4, No. 1, 2026

COLLECTION OF PAPERS
NEW ECONOMY

NEW HORIZONS:
DIGITAL ECONOMY AND RESPONSES TO A CHANGING WORLD



4

Oikos Institute - Research Center Bijeljina
Bosnia and Hercegovina

OIKOS INSTITUTE
Research Center Bijeljina

COLLECTION OF PAPERS
NEW ECONOMY

NEW HORIZONS: DIGITAL ECONOMY AND RESPONSES TO A CHANGING WORLD

Volume 4, No. 1, 2026

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

oikos INSTITUTE

UDK 33(082) (0.034.2)

ISSN 2831-1736

772831 172003

Bijeljina
September 2026.

EDITOR IN CHIEF
PhD Adis Puška

PUBLISHED BY
“Oikos Institute - Research Center” Bijeljina

FOR THE PUBLISHER
PhD Zoran Mastilo

LECTURER
Željka Nedić

TECHNICAL EDITOR
Kokan Janković

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

33(082)(0.034.2)

TRADITIONAL scientific conference on the subject "Digital economy and responses to a changing world" (14 ; 2026)
Collection of papers [Elektronski izvor] : New economy / XIV Traditional scientific conference on the subject "Digital economy and responses to a changing world", 2026 ; [Editor in Chief Adis Puška]. - Onlajn izd. - El. zbornik. - Bijeljina : Oikos Institute – Research center, 2026. - (Collection of papers New economy (Online) : printed, ISSN 2831-1736)

Način pristupa (URL): https://conference.oikosinstitut.org/#papers. - Насл. са насл. екрана. - Опис извора дана 9.09.2026. - Ел. публикација у ПДФ формату опсега 370 стр. - Библиографија уз радове.

ISBN 978-99997-959-2-0

COBISS.RS-ID 144774145

COLLECTION OF PAPERS
NEW ECONOMY

Vol. 4, No. 1, 2026

ISSN 2831-1728 (Print)
ISSN 2831-1736 (Online)

EDITOR IN CHIEF: PhD Adis Puška - **Bosnia and Herzegovina**

ASISTANT EDITORS IN CHIEF:
PhD Dragana Radičić – **United Kingdom**
PhD Zoran Mastilo - **Bosnia and Herzegovina**

CO-EDITORS:
Dejan Mastilo - **Master of Economics, Faculty of Business Economics, Bijeljina, Bosnia and Herzegovina**
Sara Drakul - **PhD Candidate, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia**
Andrea Mastilo - **University of Westminster, London, United Kingdom**

EDITORIAL BOARD:
Bosnia and Herzegovina: PhD Bojan Baškot, PhD Mladen Rebić, PhD Goran Popović, PhD Armina Hubana, PhD Jamila Jaganjac, PhD Slobodan Subotić, PhD Ognjen Erić, PhD Andrijana Mrkaić – Ateljević, PhD Zdravko Todorović, PhD Branislav Mašić, PhD Željko Račić, PhD Zoran Mastilo

INTERNATIONAL BOARD:
Israel: PhD Gil S. Epstein, PhD Andrey Kudryavtsev; **Greece:** PhD Phoebe Koundouri, PhD Konstantinos N. Malagas, PhD Constantinos Challoumis, PhD Andreas Papatheodoru; **Poland:** PhD Andrzej Niemiec, PhD Piotr Wisniewski; **Japan:** PhD Taro Abe; **New Zealand:** PhD Mohammad Saud Khan, PhD Tauisi Taupo; **Republic of China:** PhD Hamid Khurshid, PhD Tafazal Kumail, PhD Zhou Bin; **United States:** PhD Jason Patalinghug, PhD Tom Gillpatrick, PhD Leland Buddress, PhD Roofia Galeshi, PhD Jason Caudill, PhD Hugh J. Ault, PhD Richard J. Fast, PhD Cevat Tosun; **Serbia:** PhD Nikola Fabris, PhD Petar Vrgović, PhD Kristijan Ristić, PhD Snežana Milićević, PhD Drago Cvijanović, PhD Snežana Radukić, PhD Zorana Kostić; **Brasil:** PhD Arcione Ferreire Viagi, PhD Fabio Albergaria de Queiroz; **Germany:** PhD Willy Legrand, PhD Tristan Nguyen; **Australia:** PhD Alberto Posso; **South Korea:** PhD Bipithalal Balakrishnan Nair; **Taiwan:** PhD Shu Lung Kuo; **Canada:** PhDIqtidar Shah; **United Kingdom:** PhD Christopher Hartwell, PhD Denis Hyams-Ssekasi, PhD Lorenzo Trapani, PhD Tarek Abdel Fattah**; Switzeralnd:** PhD Isabelle Collet; **Austria:** PhDAhu Genis – Gruber, **Singapore:** PhD Zsuzsa Reka Huszar; **Spain:** PhD Elena De la Poza, PhD Maria – Dolores Guillamon; PhD Francisco Jose Garcia Gonzalez; **Portugal:** PhD Joao Paulo Vieito; **Italy:** PhD Ubaldo Comite, PhD Marco Valeri, PhD Leslie Fadlon, PhD Alberto Celani, PhD Gianluca Mattarocci, PhD Marcello Signorelli; **Ukraine:** PhD Semenenko Tetiana, PhD Olha Komelina, PhD Liudmyla Yurchyshena, PhD Katerina Kovtoniuk, PhD Ellana Molchanova, PhD Tetiana Paientko, PhD Iryna Lytvynchuk, PhD Viktor Koziuk, PhD Oleksandr V. Dluhopolskyi; **Hungary:** PhD Andrea Szalavetz; **Scotland:** PhD Kieran James; **Sweden:** PhD Christer Thornqvist; **Finland:** PhD Spyros Hirdaris Ceng FRINA; **Czech Republic:** PhD Lucie Andreisova, PhD Martina Blaškova; **Cyprus:** PhD Eirini Daskalaki; **Turkey:** PhD Huseyin ISIKSAL, PhD Metin Toprak, PhD Zeki Atil Bulut, PhD Feden KoC, PhD Zafer Oter, PhD Emrah Gulay; **Slovakia:** PhD Ivan Brezina; **Russia:** PhD Elena A. Okunkova, PhD Oleg Roy, PhD Perepelkin Vyacheslav; **Bulgaria:** PhD Venelin Terziev, PhD Julia Stoyancheva Stefanova,PhD Marin Petrov Georgiev; **India:** PhD Ray Titus, PhD Rudrarup Gupta; PhD Sandeep Kumar, PhD Brijendra Singh Yadav, PhD Raul Villamarin Rodriguez, **Oman:** PhD Mythili Kolluru, PhD Vidya Suresh; **Romania:** PhD Alexadru Nedelea, PhD Rocsana B. Manea Tonis, PhD Manuela Rozalia Gabor; **Croatia:** PhD Zoran Wittine, PhD Anita Čeh Časni, PhD Kosjenka Dumančić, PhD Lorena Škuflić; **Montenegro:** PhD Boban Melović, PhD Milivoje Radović, PhD Rade Ratković, PhD Ivo Županović; PhD Darko Lacmanović, PhD Anđelko Lojpur; **Macedonia:** PhD Predrag Trpeski; **Moldova:** PhD Corina Gribincea, PhD Marica Dumitrasco; **South Africa:** PhD Sanja Bauk; **Saudi Arabia:** PhD Bashar Almansour; PhD Yassin Eltahir; PhD Abu Umar Faruq Ahmad; PhD Melfi Alrasheedi; **Slovenia:** PhD Andrej Raspor, PhD Marjana Merkac Skok, PhD Marija Bogataj; **Iran:** PhD Gholamreza Jandaghi; **Algeria:** Isak Kherchi; **Belarus:** PhD Oksana Koshulko; **Sri Lanka:** PhD Ahamed Lebbe Mohamed Aslam, PhD Nisanttha Kurukulasooriya A.; **Indonesia:** PhD Teguh Sugiarto; **Egypt:** PhD Ahmed Mohamed Elbaz; PhD Azza Mohamed Kamal; **Uganda:** PhD Micahel Okoche; **Morocco:** PhD Fouzi Belmir; **Ethiopia:** PhD Dereje Teklemariam; **Bahrain:** PhD Adel M. Sarea, PhD Naji Mansour Nomran; **Nigeria:** PhD Bhola Khan; **The United Arab Emirates:** PhD Ana Stranjančević, PhD Ulas Rao, PhD Jelena Janjušević; **Pakistan:** PhD Ali Ahmad Bodla; **Republic of Uzbekistan:** PhD Dang Rui; **Republic of Cameroon:** PhD Alain Aime Ndedi; **Jordan:** PhD Bashar Almansour; **Fiji:** PhD Ranasinghe Amaradasa; **Albania:** PhD Brilanda Bushati, PhD Elidiana Bashi; **Tailand:** PhD Napat Harnpornchai

ADRESS OF THE EDITORIAL BOARD:
Neznanih junaka 9-11
76300 Bijeljina
Republic of Srpska, Bosnia and Herzegovina
e-mail: economics.oikos.institut@gmail.com
Web site: https://www.conference.oikosinstitut.org/

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

CONTENTS

CLOUD-ENABLED ACCESS MANAGEMENT IN SMART PORTS: A BUSINESS MODEL FRAMEWORK FOR SECURITY, EFFICIENCY AND GOVERNANCE 1
Maria Rosilene Sabino, Marcela Castro, Shervin Shahidi, Ana Mendes, Tiago Pinho

ARTIFICIAL INTELLIGENCE, IT INFRASTRUCTURE AND CYBERSECURITY IN LABOUR MARKET TRANSFORMATION: BRIDGING THE GAP IN UNDERSTANDING DIGITAL INEQUALITY IN THE EUROPEAN UNION 27
Mariusz Łazarski, Patrycja Zmysłowska-Łazarska

THE STRUCTURE OF SOCIAL TRUST: THE ISSUE OF INSTITUTIONAL HETEROGENEITY ACROSS COUNTRIES 41
Viktor Koziuk, Yuriy Hayda, Oleksandr Dluhopolskyi, Oksana Liashenko, Oksana Shymanska

LABOR MARKET CHALLENGES IN BUSINESS TRANSFORMATION BY AI: EMPIRICAL EXPERIENCE OF SELECTED EUROPEAN COUNTRIES 61
Snežana Radukić, Zorana Stanković, Žarko Popović

BEYOND TECHNICAL COMPLIANCE: NXTPORT AND THE GOVERNANCE OF NEUTRAL DATA INTERMEDIATION IN THE PORT OF ANTWERP-BRUGES 75
Lucas Freitas

ICT SERVICES TRADE, DIGITAL ADOPTION, LABOUR PRODUCTIVITY AND EMPLOYMENT IN ADVANCED AND DEVELOPING ECONOMIES: A PANEL DATA ANALYSIS 85
Andrii Oliinyk, Tetiana Melnyk, Liudmyla Huliaieva, Liudmyla Sierova, Olena Kravchenko, Yuliia Tunitska

DESIGN AND IMPLEMENTATION OF A MULTI-MODEL AI-BASED CONTENT MODERATION SYSTEM IN A PRODUCTION ENVIRONMENT 105
Maksym Nenashev

PREDICTORS OF EMPLOYEE PSYCHOLOGICAL ADAPTATION TO AI SYSTEMS IN IT ORGANIZATIONS 113
Oleksii Nahorniak, Vasyl Osodlo

SUSTAINABILITY AT MARITIME MOBILITY: COMPARING OPEN DATA ECOSYSTEMS AND COLLABORATIVE MARITIME PLATFORMS 127
João Marreiros, Tiago Pinho, Nelson Carriço, Ana Mendes, Marcela Castro

SUSTAINABILITY AS A COMPETITIVE ADVANTAGE IN LUXURY GASTRONOMY: EVIDENCE FROM EASTERN EUROPE 153
Noémi Tordai (Pál), Flavia Dana Oltean

INSTITUTIONAL AND ECONOMIC FRAMEWORKS FOR ESTABLISHING A GREEN ENERGY ZONE IN AZERBAIJAN: EVIDENCE, CHALLENGES, AND DEVELOPMENT PROSPECTS 175
Mahabbat Mammadov, Turkan Hasanova, Oksana Krivoruchko, Ruhangiz Aliyeva, Gunel Imamquluyeva

OPEN INNOVATION AS A COORDINATION MECHANISM IN PORT ECOSYSTEMS: A COMPARATIVE ANALYSIS OF EUROPEAN SEAPORTS 185
Maria Rosilene Sabino,Marcela Castro, Ana Mendes, Tiago Pinho

PSYCHOSOCIAL DETERMINANTS OF ORGANIZATIONAL CONFLICT IN A DIGITAL WORK ENVIRONMENT: A NARRATIVE REVIEW 219
Nino Paresashvili, Teona Edzgveradze

ECONOMIC MECHANISM FOR AGRICULTURAL E-COMMERCE DEVELOPMENT IN KAZAKHSTAN 231
Azamat Zhanseitov

ARTIFICIAL INTELLIGENCE, ALGORITHMIC GOVERNANCE AND CULTURAL VALUE IN THE DIGITAL ECONOMY: TRANSFORMING CREATIVE LABOR AND CINEMA 241
Yelda Özkoçak

REIMAGINING CAREER GUIDANCE IN BOSNIA AND HERZEGOVINA: ALIGNING NATIONAL POLICIES WITH THE REALITIES OF THE GLOBAL DIGITAL ECONOMY 261
Andrijana Mrkaić Ateljević, Anđelka Štilić, Sara Drakul

DIGITAL TWIN RESILIENCE IN PORTUGUESE ATLANTIC CORRIDOR PORTS: A STAKEHOLDER STUDY 273
Carlos Batista, Ana Barroso, Tiago Pinho

BLOCKCHAIN IN THE AGENT ECONOMY: IDENTITY, AUTHORIZATION, AND MACHINE-TO-MACHINE SETTLEMENT 287
Krzysztof Bochenek, Jarosław Bochenek

DIGITAL TRADE, GOVERNMENT POLICY, AND ECONOMIC GROWTH: THE CASE OF AZERBAIJAN 299
Ramil Huseyn, Aykhan Gadashov

HUNTING TOURISM POLICIES AND THE ROLE OF DIGITALIZATION: A COMPARATIVE PERSPECTIVE ON ROMANIA AND HUNGARY 313
Tatar Beata, Pal (Tordai) Noemi, Moga Alexis- Monica, Oltean Flavia Dana

LAND CONSOLIDATION IN POLAND: CONTEMPORARY BARRIERS TO SUSTAINABLE RURAL DEVELOPMENT 333
Bartosz Mickiewicz, Katsiaryna Volkava

AI-ENABLED STRATEGIC TRANSFORMATION: ORGANIZATIONAL CAPABILITIES AND COMPETITIVE ADVANTAGE IN A CHANGING BUSINESS ENVIRONMEN 347
Sara Drakul

MANAGING INDUSTRY 4.0 COMPETENCIES FOR THE DIGITAL ECONOMY: INDUSTRIAL ROBOTICS AND UNIVERSITY-INDUSTRY COLLABORATION IN ENGINEERING EDUCATION 359
Dawid Piotr Gądkowski

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

CLOUD-ENABLED ACCESS MANAGEMENT IN SMART PORTS: A BUSINESS MODEL FRAMEWORK FOR SECURITY, EFFICIENCY AND GOVERNANCE

Maria Rosilene Sabino[1,2*], Marcela Castro[1,3,4], Shervin Shahidi[1], Ana Mendes[1,2], Tiago Pinho[1,2]

Received 07.03.2026. | Send to review 29.03.2026. | Accepted 04.08.2026.

Original Article

BY NC ND

[1] Instituto Politécnico de Setúbal, Escola Superior de Ciências Empresariais, Campus do IPS - Setúbal, Portugal

[2] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Portugal

[3] LASI - Laboratório Associado de Sistemas Inteligentes, Guimarães, Portugal

[4] NECE - Research Centre for Business Sciences, Department of Management and Economics, Faculty of Human and Social Sciences, Universidade da Beira Interior, Covilhã, Portugal

***Corresponding Author:**
Maria Sabino

Email:
mr.sabino@campus.fct.unl.pt

JEL Classification:
O31, O32, L86, L91, R40, M15

Doi: 10.61432/CPNE0401001s

UDK: 004.738.5:351.824.11

ABSTRACT

Smart ports increasingly rely on secure, interoperable, and scalable digital infrastructures to manage complex flows of cargo, vehicles, people, and information. Access management has therefore evolved from an operational security function into a strategic component of governance, cybersecurity, regulatory compliance, and logistics efficiency. This study proposes a cloud-enabled access management framework for smart port ecosystems. It adopts an exploratory, design-oriented methodology combining a Scopus-based literature review, benchmarking of 22 cloud-based access control systems, consultations with nine stakeholders, and value proposition analysis. The findings identify key technological, organizational, and regulatory requirements, including modular integration, multi-factor authentication, role- and zone-based access controls, interoperability with existing port systems, auditability, and compliance with data protection and information security standards. Stakeholder consultations further reveal recurring challenges, such as biometric reliability, entry delays, fragmented access control, high staff turnover, and continued reliance on manual procedures. The proposed framework links these challenges to value-creating mechanisms, including automated scheduling, remote management, API integration, alternative authentication methods, real-time monitoring, and non-compliance management. The study contributes to smart port research by conceptualizing cloud-enabled access management as both a governance and business model innovation capable of strengthening security, operational efficiency, and resilience across port ecosystems.

Keywords: *Smart ports, cloud-enabled access management, port governance, cybersecurity, business model innovation, maritime logistics, digital transformation, access control*

1. INTRODUCTION

Ports are undergoing a profound digital transformation. Once viewed primarily as physical interfaces between maritime and inland transport, they have evolved into complex cyber-physical ecosystems in which cargo flows, vehicle movements, personnel access, regulatory procedures, security requirements, and data infrastructures are closely interconnected. This transformation has increased the demand for secure, interoperable, and scalable systems that support both operational efficiency and infrastructure protection.

Access management is a critical yet underexplored component of this transition. In port environments, it extends beyond gate entry and credential verification to the governance of differentiated access rights across users, zones, schedules, operational roles, and security levels. Workers, contractors, drivers, inspectors, crews, passengers, technology providers, and public authorities may all require distinct combinations of physical and digital access. Access management therefore constitutes a strategic function for security, operational continuity, regulatory compliance, and logistics coordination.

Many legacy access control systems are poorly suited to these requirements. They often rely on static card-based mechanisms, fragmented databases, manual validation, and limited integration with wider port infrastructures. These limitations are particularly problematic in environments characterised by high personnel turnover, multiple access points, differentiated security zones, and the need for real-time visibility. Cloud-enabled access management offers a more flexible alternative through remote administration, multi-factor authentication, role- and zone-based permissions, modular integration, audit trails, dashboards, and interoperability with existing systems.

The empirical context of this study is a cloud-enabled access management prototype developed for port and logistics environments. The prototype provided a design-oriented basis for examining how access control, security, and surveillance functions can be integrated into a scalable digital architecture. The analysis considered anonymised requirements relating to physical and logical authentication, mobile and non-intrusive verification, entry and exit records, operational dashboards, failed authentication events, and integration with physical barriers and terminal devices. Broader issues, including service-based deployment, compatibility with logistics systems, and market acceptance, were also examined.

The study does not present the prototype as a commercial product or disclose operationally sensitive details. Instead, prototype-based evidence is used to develop a general analytical framework. The research question is therefore: How can cloud-enabled access management support the transition from legacy access systems to smart port governance in complex maritime logistics environments?

To address this question, the study adopts an exploratory, design-oriented approach combining a Scopus-based literature review, market benchmarking, stakeholder consultations, and value proposition analysis. The empirical design includes 61 scientific articles, 22 cloud-based access control systems, and nine consultation meetings involving six experts in port operations, security, logistics, and information technology. The paper contributes by conceptualising access management as a governance issue, linking cloud-based access control to cybersecurity, interoperability, and compliance, and proposing a framework that connects stakeholder challenges, technological enablers, and value-creation mechanisms.

The remainder of the paper is organised as follows. Section 2 presents the theoretical background. Section 3 describes the methodology. Section 4 reports the findings from the literature review, market benchmarking, stakeholder analysis, and framework development. Section 5 discusses the theoretical and practical implications, while Section 6 concludes with the main contributions, limitations, and directions for future research.

2. THEORETICAL BACKGROUND

2.1. SMART PORTS, DIGITAL TRANSFORMATION AND PORT OPERATIONAL GOVERNANCE

Ports are increasingly understood as digitally enabled, interconnected, and multi-actor systems rather than purely physical infrastructures for cargo handling. The transition towards smart ports reflects the wider digital transformation of maritime logistics, char-

acterised by the integration of data infrastructures, automation, the Internet of Things, cloud computing, artificial intelligence, and cyber-physical systems (Barasti et al., 2021; Nguyen et al., 2023; Pham, 2023). This transformation affects not only terminal productivity and cargo flows, but also security, stakeholder coordination, regulatory compliance, and operational governance.

Smart ports use advanced digital technologies to improve efficiency, transparency, sustainability, and connectivity across port ecosystems (Sarabia-Jacome et al., 2020; Tijan et al., 2021; Nguyen et al., 2026). However, smart port development extends beyond technology adoption and requires the reconfiguration of organisational processes, governance structures, and stakeholder relationships. Port Community Systems and logistics single windows illustrate this shift by enabling information exchange and coordinating port and hinterland operations (Carlan et al., 2016).

This governance dimension is particularly important because no single actor controls all flows of people, cargo, vehicles, information, and regulatory procedures within a port. Port authorities provide strategic direction and oversight, while terminal operators, logistics companies, security providers, technology vendors, and public agencies manage interdependent operational processes. Access management therefore forms part of a broader governance architecture. It involves defining who may access specific zones, systems, resources, and procedures, under which conditions, and with what degree of traceability (de Langen et al., 2020; Tijan et al., 2021).

Digitalisation also creates new vulnerabilities by increasingly linking physical and digital security (Marjohan et al., 2026). Cyber incidents may disrupt cargo handling, gate operations, identity verification, surveillance, customs procedures, and logistics coordination (Dimakopoulou & Rantos, 2024; Mileski et al., 2018; Senarak, 2021). Cloud-enabled access management can thus support smart port governance, but its effectiveness depends on interoperability, cybersecurity, data protection, stakeholder acceptance, and alignment with operational requirements, rather than on remote administration and real-time monitoring alone (Hu et al., 2020; Parkinson & Khan, 2023).

2.2. CLOUD-BASED ACCESS CONTROL AND CYBERSECURITY IN CRITICAL INFRASTRUCTURES

Access control is a foundational element of security management in critical infrastructures. In digitally connected environments, it increasingly combines physical security, identity management, authentication, authorisation, monitoring, data protection and auditability (Ferrari, 2010; Mohamed et al., 2022; Parkinson & Khan, 2023). This evolution is particularly important in ports, where operational spaces bring together employees, contractors, truck drivers, customs officers, ship crews, passengers, security personnel, and service providers.

Legacy access control systems often rely on static credentials, local databases, fixed permissions and hardware-dependent configurations. Such systems are less suited to port ecosystems characterised by temporary access needs, multiple entry points, differentiated security zones and changing operational schedules (Aksentijevic et al., 2021; Garzia et al., 2009; Koliousis, 2020). Cloud-based access control systems respond by shifting part of the infrastructure from local, hardware-bound environments to cloud-enabled platforms that support centralised oversight, scalable user management, automated backups, remote configuration and integration with mobile or web-based interfaces (Dubey & Rai, 2021; Hu et al., 2020).

Cybersecurity is central to the transition towards cloud-enabled access management. Although cloud-based systems can improve visibility, scalability, and responsiveness, they

also introduce risks related to data privacy, unauthorised access, insecure APIs, credential compromise, vendor dependence, cloud misconfiguration, and cyber-physical vulnerabilities (Chauhan & Shiaeles, 2023; Sun, 2019). Their design should therefore follow core security principles, including least privilege, multi-factor authentication, encryption, timely access revocation, continuous monitoring, incident response, and compliance with recognised information security standards (El Kafhali et al., 2022; Hu et al., 2020).

Attribute-Based Access Control enables permissions to be assigned according to user characteristics, roles, location, time, context, and operational requirements (Hu et al., 2020; Mohamed et al., 2022). This is particularly relevant in ports, where access rights vary across professional functions, security zones, schedules, and operational conditions. Attribute-based encryption and fine-grained access controls can further protect sensitive cloud-based data (Ding et al., 2020; Namasudra, 2019). Blockchain and distributed ledger technologies may also enhance auditability, tamper resistance, and decentralised verification, although their use is most appropriate where distributed trust or verifiable records are required (Agyekum et al., 2022; Yang et al., 2020).

Biometric authentication, mobile credentials, and multi-factor authentication provide additional security layers. However, biometric systems also raise concerns regarding reliability, privacy, data protection, and user acceptance (Parkinson & Khan, 2023; Sun, 2019). Port access management should therefore be treated as a cyber-physical governance challenge involving technologies, rules, responsibilities, data flows, permissions, and accountability mechanisms.

2.3. BUSINESS MODEL INNOVATION AND VALUE PROPOSITION DESIGN IN PORT ECOSYSTEMS

The adoption of cloud-enabled access management in ports represents not only a technological advancement but also a business model innovation. Unlike traditional hardware-intensive access control systems, cloud-based solutions support Software-as-a-Service (SaaS), subscription models, modular deployment, remote maintenance, scalable user management, and integration-based value creation (Chauhan & Shiaeles, 2023; Hu et al., 2020; Marinov & Lisenyi, 2024).

This innovation is particularly relevant in port ecosystems, where value is co-created by multiple stakeholders. Cloud-enabled access management can improve governance and compliance for port authorities, workforce management for terminal operators, operational efficiency for logistics providers, and traceability for regulators. Such a multi-stakeholder perspective aligns with ecosystem-based approaches to maritime value creation, in which performance depends on coordination rather than on isolated organisational decisions (De Martino, 2021; Tsvetkova & Hellström, 2022; Mussina et al., 2026).

Value Proposition Design provides a useful framework for linking stakeholder needs with technological capabilities (Osterwalder et al., 2014). Common challenges in port access management include entry delays, fragmented access controls, unreliable biometric authentication, high staff turnover, manual authorisation procedures, limited interoperability, and the management of temporary users. These challenges translate into requirements such as API integration, automated scheduling, continuous operation, role-based access, reduced manual intervention, and alternative authentication methods.

Regulatory compliance constitutes a further element of the value proposition. Because ports process sensitive personal, operational, and commercial data, cloud-based access management must comply with data protection and information security standards, including the GDPR and ISO/IEC 27001, 27017, and 27018. Compliance not only satisfies legal requirements but also strengthens trust among port authorities, service providers, regulators, and users.

Accordingly, cloud-enabled access management should be viewed as a socio-technical governance innovation that integrates technological capabilities, stakeholder requirements, regulatory compliance, and operational processes. This perspective underpins the analytical framework developed in the following sections, where cloud-enabled access management is examined through three complementary dimensions: technological infrastructure, governance, and business model design.

3. METHODOLOGICAL APPROACH

This study adopts an exploratory, design-oriented approach to develop a cloud-enabled access management framework for smart port ecosystems. The research addresses the intersection of smart port transformation, cloud-based access control, cybersecurity, operational governance, and business model innovation. Given the emerging and multidisciplinary nature of the topic, the study integrates multiple sources of evidence rather than testing predefined hypotheses.

The methodology comprises four stages: literature review, market benchmarking, stakeholder consultation, and value proposition and framework development. Exploratory research is appropriate for examining emerging phenomena, synthesising heterogeneous evidence, and developing frameworks for subsequent empirical validation (Creswell, 2009; Saunders et al., 2023). The design-oriented component draws on research traditions that develop artefacts, models, and frameworks in response to practical problems while also contributing to theoretical knowledge (Hevner et al., 2004; Peffers et al., 2007).

The empirical basis includes project documentation and prototype-oriented design materials generated within a port innovation context. These materials were used to identify requirements, stakeholder concerns, and design relationships. Because some contain operational, consortium-related, or commercially sensitive information, they are not cited directly. Findings derived from them are therefore presented in aggregated and anonymised form.

The methodological design and the role of each evidence source are summarised in Table 1.

Table 1. Research design and evidence integration

Methodological stage	Evidence source	Procedure	Analytical purpose	Output
Literature review	Scopus and selected academic literature	Broad search, refined query, citation-based selection and contextual searches	Identify conceptual foundations and research gaps	Final analytical corpus of 61 articles
Market benchmarking	22 cloud-based access control systems	Comparative analysis across six functional dimensions	Identify technological, deployment and business model patterns	Market-informed system requirements
Stakeholder consultations	Six stakeholders across nine meetings	Semi-structured consultations, online and in-person meetings, and recorded sessions	Capture operational pain points, expectations and implementation constraints	Stakeholder requirements and value-creating mechanisms
Value proposition development	Integrated stakeholder and market evidence	Pain-point/gain mapping, mind maps and Business Model Canvas	Connect operational needs with system capabilities	Structured value proposition
Framework development	Integrated multi-source evidence	Cross-source synthesis and BPMN-oriented process modelling	Relate drivers, enablers and governance outcomes	Three-layer analytical framework

Source: Authors' elaboration

3.1. LITERATURE REVIEW

The first stage consisted of an exploratory literature review designed to identify conceptual foundations, relevant research streams and application-oriented evidence related to cloud-enabled access management in smart port environments. Literature reviews are appropriate for organising fragmented knowledge, identifying conceptual patterns and clarifying emerging research domains (Snyder, 2019; Tranfield et al., 2003). The review focused on the intersection of cloud computing, access control, cybersecurity, smart ports, port digitalisation, business model innovation and maritime logistics.

The review began with a broad exploratory search in the Scopus database using combinations of terms related to *cloud* and *access control*. The initial search, covering the period from 1988 to 2025, retrieved approximately 7,800 documents. This broad search was used to assess the field's scale and evolution and to identify the need for a more focused search strategy.

The search was subsequently refined using the expression: TITLE-ABS-KEY("cloud computing" AND "access control" AND "Security"), with restrictions applied by publication period, document type and subject area. The refined search produced 1,701 documents. From this set, the 50 most-cited publications were used as an initial analytical core to capture influential contributions to cloud computing, access control and security.

To explore innovation at the nexus of business models and ports, two additional searches were carried out:

- TITLE-ABS-KEY("cloud computing" AND "access control" AND "Security") AND TITLE-ABS-KEY("BUSINESS MODEL")
- TITLE-ABS-KEY("cloud computing" AND "access control" AND "Security") AND TITLE-ABS-KEY("SEAPORT" OR "PORT" OR "MARITIME" OR "SHIP")

The initial analytical core and the supplementary searches were consolidated into a final corpus of 61 articles considered relevant to the study's analytical scope. The literature was subsequently examined comparatively to identify recurring conceptual and application-oriented themes relevant to cloud-enabled access management. These themes informed the interpretation of access security, privacy and data governance, connected infrastructures, auditability, interoperability and cloud governance, and were later compared with evidence from market benchmarking and stakeholder consultation.

3.2. MARKET BENCHMARKING

The second stage consisted of market benchmarking of cloud-based access control systems. The purpose was to identify technological trends, deployment models, authentication mechanisms, integration requirements, operability features and business model patterns relevant to logistics and port environments.

An initial screening identified 22 systems with potential relevance to the research problem. Rather than comparing or ranking individual suppliers, the analysis extracted functional and strategic characteristics that could inform the proposed cloud-enabled access management framework.

The evidence was organised around six dimensions: use type, authentication, deployment, access and management, features and operability, and pricing. These parameters were used to identify requirements such as multi-factor authentication, mobile credentials, QR codes, RFID, biometric options, cloud and hybrid deployment, browser and mobile access, remote permissions, CCTV, real-time alarms, automatic backups, interoperability, lockdown functions, freemium models, volume-based pricing and flexible subscription options.

The benchmarking evidence was analysed comparatively to identify recurring requirements rather than vendor-specific advantages. Attention was given to modularity, interoperability, scalability, remote management, compatibility with legacy infrastructures and the implications of alternative deployment and pricing models. These findings were subsequently compared with stakeholder evidence and used to support the value proposition and the development of the framework.

3.3. STAKEHOLDER CONSULTATIONS

The third stage involved semi-structured stakeholder consultations designed to identify operational requirements, implementation constraints, and system expectations not fully captured by the literature review or market benchmarking. A purposive sampling approach was used to involve participants with direct expertise in port operations, access security, logistics, and information technology.

Six participants contributed: one Information Systems and Business Support Manager from the Port of Sines, two representatives associated with Port Facility Security Officer functions, one logistics or terminal operator representative, and two IT specialists. Their roles provided complementary perspectives on access procedures, security requirements, systems integration, and technological implementation.

Data were collected through nine consultation meetings. Six meetings with the IT specialists were conducted online via Microsoft Teams and recorded. Two meetings with Port of Sines representatives were held in person, while one meeting with the logistics or terminal operator representative was conducted online. Repeated consultations with the IT specialists supported the progressive clarification of technical requirements, authentication options, integration constraints, system architecture, and cloud, on-premises, and hybrid configurations.

A semi-structured interview guide was used with port and terminal stakeholders. It covered user categories, access authorisation volumes, communication channels, authentication methods, control points, hardware configurations, validation systems, biometric technologies, and access to sensitive data. The format ensured consistency across core topics while allowing participants to elaborate on context-specific issues.

The consultation evidence included recordings, transcripts, meeting notes, mind maps, and structured technical premises. These materials were organised around recurring themes, including authentication reliability, biometric limitations, access delays, workforce variability, differentiated access zones, interoperability, remote management, credential lifecycle management, and non-compliance monitoring.

The data were analysed through iterative thematic synthesis. First, recurring operational problems and requirements were identified. Second, related issues were grouped into three categories: stakeholder pain points, system requirements, and value-creating mechanisms (Chenail, 2016; Miles et al., 2013). Finally, these categories were compared with the findings from the literature review and market benchmarking. The aim was analytical integration rather than statistical generalisation, supporting the development of the proposed design-oriented framework.

3.4. VALUE PROPOSITION AND FRAMEWORK DEVELOPMENT

The fourth stage translated evidence from the literature review, market benchmarking, and stakeholder consultations into a structured value proposition and analytical framework. Value Proposition Design was used to link stakeholder pain points with expected gains, system requirements, and value-creating mechanisms (Osterwalder et al., 2014).

The synthesis followed three steps. First, recurring operational challenges were identified, including biometric reliability issues, access delays, high workforce turnover, fragmented credential management, differentiated access requirements across port zones, and limited interoperability. Second, these challenges were matched with potential system responses derived from market benchmarking and technical consultations, such as multimodal authentication, remote permission management, API integration, automated scheduling, credential lifecycle management, dashboards, and alternatives to biometric verification.

Third, the resulting relationships were organised through visual and process-oriented tools. Mind maps consolidated stakeholder concerns and expected outcomes, while the Business Model Canvas supported the integration of value propositions, user requirements, service configuration, and business model considerations. BPMN-based process modelling, supported by draw.io, was used to represent the activity flows for user registration, identity validation, authentication, access authorisation, permission management, exception handling, and access logging.

These analytical artefacts helped integrate heterogeneous evidence and clarify the relationships among operational challenges, technological capabilities, governance requirements, and business model implications. The resulting three-layer framework comprises: adoption drivers, including security, efficiency, scalability, and compliance; cloud-enabled capabilities, including APIs, interoperability, multi-factor authentication, fallback mechanisms, auditability, dashboards, and monitoring; and governance outcomes, including traceability, zone-based access, reduced manual control, interoperability, and operational resilience.

The framework is presented as a design-oriented analytical contribution rather than a universally validated model. It is intended to support future empirical testing, pilot implementation, and comparative assessment across different port environments.

3.5. METHODOLOGICAL SCOPE AND LIMITATIONS

The methodological approach has several limitations that should be considered when interpreting the findings.

First, the study is exploratory and design-oriented. It develops a framework by integrating evidence from the literature review, market benchmarking, stakeholder consultations, and prototype-oriented material, but it does not provide a longitudinal evaluation of a fully deployed cloud-enabled access management system.

Second, the literature review was designed to support conceptual integration and framework development rather than to function as a fully systematic review or meta-analysis. The initial selection of highly cited studies strengthened coverage of influential contributions, but it may also favour established research over emerging work. Supplementary contextual searches were therefore used to broaden the corpus towards business model and maritime-port applications.

Third, the market benchmarking was used to identify recurring capabilities, deployment patterns and business model characteristics rather than to compare or rank commercial providers. The findings should therefore be interpreted as market-informed requirements rather than as evidence of relative supplier performance.

Fourth, the stakeholder evidence is based on a purposively selected group of six participants across nine consultation meetings. Although these participants provided complementary expertise in port operations, security, logistics and information technology, the sample is not statistically representative of the wider population of port actors. The findings should therefore be interpreted as analytically useful evidence for framework development rather than as generalisable quantitative results.

Finally, the proposed framework emerged from a specific port-innovation context and the integration of multiple evidence sources. Although this strengthens its practical relevance, its transferability to other ports depends on factors such as port scale, governance model, technological maturity, regulatory context and existing infrastructure. Future research should therefore test and refine the framework through comparative case studies, pilot implementations and longitudinal evaluation.

4. RESULTS

4.1. LITERATURE-BASED ANALYTICAL THEMES

The literature review showed that cloud-enabled access management is positioned at the intersection of several interconnected research domains, including cloud computing, access control, cybersecurity, privacy, Internet of Things technologies, fine-grained authorisation, auditability and digital governance. Across the reviewed studies, five recurring analytical themes were particularly relevant to the development of the proposed framework (Hu et al., 2020; Sun, 2019).

The first theme concerns cloud security and access management. Research in this area emphasises the need for scalable identity management, secure authorisation and context-sensitive access decisions in distributed digital environments. Cloud-based access systems can support centralised oversight, remote administration, and flexible permission management, but they also raise concerns about cloud misconfiguration, credential compromise, insecure APIs, and shared responsibility (Chauhan & Shiaeles, 2023; Hu et al., 2020; Sun, 2019). In port environments, these issues are particularly relevant because access decisions may involve heterogeneous users, multiple security zones and operationally critical infrastructures.

The second theme concerns privacy and data governance. Access management systems process identities, credentials, access histories and, in some cases, biometric data. The literature therefore emphasises privacy protection, data minimisation, secure processing, accountability, and controlled access to sensitive information (Ding et al., 2020; Namasudra, 2019; Sun, 2019). For smart ports, this theme is important because personal and operational data may circulate across organisational boundaries involving port authorities, terminal operators, logistics firms, technology providers and public agencies.

The third theme concerns IoT and cyber-physical integration. Smart port environments increasingly connect gates, sensors, mobile devices, surveillance systems and operational platforms. This integration creates opportunities for real-time visibility and coordinated access management, but also expands the attack surface and increases the complexity of identity, permission and device governance (Nguyen et al., 2023; Sarabia-Jacome et al., 2020). Access management should therefore be understood as part of a broader cyber-physical infrastructure rather than as an isolated gate-control function.

The fourth theme concerns auditability and distributed verification. The literature identifies growing interest in secure logging, traceable permission changes, verifiable records and, in specific contexts, blockchain-based mechanisms for distributed trust and tamper-resistant audit trails (Agyekum et al., 2022; Appleyard & Yuthas, 2022; C. Yang et al., 2020). However, blockchain is not treated in this study as a universal solution. Its relevance depends on whether the governance context requires cross-organisational verification, distributed trust or enhanced resistance to record manipulation.

The fifth theme concerns interoperability and cloud governance. Secure cloud adoption requires more than authentication mechanisms. It also involves integration with existing systems, allocation of responsibilities, incident response, risk management, data-sharing rules and compatibility with legacy infrastructures (Chauhan & Shiaeles, 2023; Dimako-

poulou & Rantos, 2024; Senarak, 2021). In port ecosystems, interoperability is especially important because access management may need to interact with Port Community Systems, logistics platforms, human resource databases, contractor systems and surveillance infrastructures.

The literature-based themes are summarised in Table 2.

Table 2. Main analytical themes identified in the literature and their relevance for cloud-enabled access management in ports

Analytical theme	Main concepts	Interpretation	Relevance for smart ports
Cloud security and access management	Cloud computing; access control; authentication; authorisation	Focuses on secure and scalable management of identities and permissions	Supports flexible and context-sensitive access decisions
Privacy and data governance	Data privacy; secure processing; data minimisation; accountability	Highlights protection and governance of sensitive personal and operational data	Relevant for identity, credential and biometric data
IoT and cyber-physical integration	IoT; connected devices; sensors; surveillance; mobile systems	Addresses integration and security across connected physical and digital infrastructures	Relevant for gates, devices, mobile credentials and real-time monitoring
Auditability and distributed verification	Logging; traceability; blockchain; verifiable records	Focuses on accountability, secure records and conditional distributed trust	May support multi-actor verification and incident investigation

Source: Authors' elaboration based on the reviewed literature

Taken together, these themes indicate that access management is evolving from a predominantly technical concern with authentication and authorisation towards a broader discussion involving cybersecurity, data governance, connected infrastructures, interoperability and organisational responsibility. From a smart port perspective, this suggests that access management should be understood as part of port digital governance rather than as an isolated security subsystem.

The literature also reveals a continuing fragmentation between highly technical research on cloud security and access control and more application-oriented studies on smart ports and port digitalisation. The specific intersection between cloud-enabled access management, port governance, business model innovation and stakeholder value creation remains comparatively underdeveloped. This gap provides the rationale for complementing the literature review with evidence from market benchmarking and stakeholder consultations in the following sections.

4.2. MARKET BENCHMARKING OF CLOUD-BASED ACCESS CONTROL SYSTEMS

The market benchmarking complemented the literature review by examining how cloud-based access control capabilities are configured in practice. The analysis showed that market offerings differ not only in technical features, but also in deployment architecture, management logic, interoperability, and business model design. These dimensions are particularly relevant to smart ports, where access systems must accommodate heterogeneous users, critical infrastructure, and legacy digital environments.

Six benchmarking dimensions were identified: use type, authentication, deployment, access and management, features and operability, and pricing and business model configuration.

The first dimension, use type, distinguishes systems designed for domestic, office, industrial, or application-specific contexts. Port environments require more complex configurations because they combine critical infrastructure protection, logistics operations, workforce and contractor access, ship-related activities, and public–private coordination. Access systems must therefore support multiple user groups, security levels, and physical zones (Pham, 2023; Sarabia-Jacome et al., 2020; Tijan et al., 2021).

The second dimension concerns authentication. The benchmarked systems supported combinations of PIN codes, multi-factor authentication, mobile credentials, QR codes, RFID, smart devices, and biometrics. This diversity suggests that smart ports require configurable, multimodal authentication adapted to different user categories and operational conditions (Bast & Yeh, 2024; Parkinson & Khan, 2023).

The third dimension relates to deployment architecture. On-premises, cloud-based, and hybrid configurations were identified. While cloud deployment offers scalability and remote administration, hybrid solutions may be necessary to ensure compatibility with legacy infrastructure and operational continuity. The findings therefore support a gradual transformation pathway based on interoperability, governance, and risk management (Chauhan & Shiaeles, 2023; Sun, 2019).

The fourth dimension covers access and management capabilities, including browser, desktop, and mobile access, guest permissions, customised restrictions, and remote administration. These functions are important in ports, where authorisation may depend on role, location, time, task, and security level. Remote management is especially valuable for temporary credentials, operational changes, and exceptional access requests.

The fifth dimension concerns features and operability. Relevant capabilities included CCTV integration, real-time alarms, mass notifications, automatic backups, lockdown functions, interoperability, and hardware integration. These features indicate that access control is evolving from isolated entry management towards integrated security and operational platforms linked to surveillance, incident response, compliance, and continuity planning (Dimakopoulou & Rantos, 2024; Senarak, 2021).

The sixth dimension addresses pricing and business model configuration. The systems employed subscription, freemium, volume-based, modular, and trial-based models. Although these approaches may reduce initial investment and improve scalability, they also raise concerns regarding cost predictability, service continuity, cybersecurity responsibilities, and vendor dependence (Marinov & Lisenyi, 2024; Osterwalder et al., 2014).

Across these dimensions, five capabilities emerged as particularly relevant to smart ports: multimodal authentication, modular deployment, configurable remote management, interoperability, and flexible service models. However, technological functionality alone does not guarantee successful adoption. Operational value also depends on compatibility with existing infrastructure, regulatory requirements, organisational routines, and stakeholder expectations. The benchmarking findings were therefore treated as market-informed inputs to the proposed framework rather than as evidence of technological determinism.

The benchmarking dimensions and their relevance to smart port access management are presented in Table 3.

Table 3. Market benchmarking criteria and relevance for smart port access management

Benchmarking criterion	Main elements identified	Relevance for smart ports
Use type	Domestic, office, industrial and application-specific settings	Highlights the need for configurations adapted to critical infrastructure and multi-actor port operations
Authentication	PIN, multi-factor authentication, mobile credentials, QR codes, RFID, smart cards and biometrics	Supports differentiated access procedures across heterogeneous user groups
Deployment	On-premises, cloud-based and hybrid configurations	Enables progressive transition from legacy systems while preserving continuity and compatibility
Access and management	Browser, desktop and mobile applications, guest access, customised permissions and remote administration	Supports role-, zone-, time- and task-based access management
Features and operability	CCTV, video/audio, alarms, notifications, backups, lockdown and interoperability	Connects access control with surveillance, incident response and operational continuity
Pricing and business model	Trials, freemium, subscriptions, volume-based and modular arrangements	Supports alternative service models while raising cost, dependency and governance considerations

Source: Authors' elaboration

The market benchmarking, therefore, confirms that cloud-enabled access management should be evaluated against both technological and organisational criteria. In smart port ecosystems, the value of access management systems depends not only on authentication and surveillance features, but also on interoperability, progressive deployment, governance compatibility and the capacity to adapt to heterogeneous operational requirements. This finding provides the basis for the stakeholder analysis in the next section, where market capabilities are compared with operational pain points and user expectations.

4.3. STAKEHOLDER PAIN POINTS AND SYSTEM REQUIREMENTS

The stakeholder consultation process identified key operational concerns not fully addressed by the literature review or market benchmarking. Participants in nine meetings highlighted that the shift from legacy access control to cloud-based management is primarily motivated by the need to resolve ongoing issues such as authentication reliability, access delays, workforce variability, fragmented permissions, and system interoperability.

The first group of concerns involved identity verification and the reliability of authentication. Participants noted challenges with biometric recognition, card readers, and reliance on single authentication methods. Biometric systems can be affected by device issues, environmental factors, and changes in user appearance, while physical cards may be lost or poorly tracked. The evidence suggests a need for multimodal authentication that combines various methods, such as physical and mobile credentials, multi-factor authentication, biometric verification, and fallback procedures, highlighting the importance of diverse and context-sensitive access mechanisms in complex environments (Bast & Yeh, 2024; Parkinson & Khan, 2023).

The second group concerns operational delays and fragmented validation procedures. Participants highlighted scenarios in which manual checks, redundant registration processes, distinct validation systems, and generic credentials can create bottlenecks at access points. In port environments, such delays extend beyond mere administrative inconveniences, as these access points are intrinsically linked to workforce movements,

vehicle flows, and logistics coordination. Consequently, the consultation findings indicated a need for solutions such as automated scheduling, remote permission management, pre-registration, self-service procedures, and digital records to reduce the need for repeated manual intervention.

The third group was concerned with workforce variability and credential lifecycle management. Port and logistics environments often involve temporary workers, subcontractors, and external service providers, resulting in rapidly changing access rights. This creates an operational burden in managing credentials across various systems. Therefore, automated user lifecycle management, quick permission updates, expiration controls, and traceable revocation procedures are crucial. Cloud-enabled access management can deliver value by facilitating flexible administration of diverse, time-sensitive user profiles.

A fourth group of concerns related to differentiated access across roles, zones, and operational conditions. The consultations showed that port access cannot be reduced to a binary entry decision. Permissions may depend on professional role, organisational affiliation, security clearance, access zone, time period, operational task, document validity, and specific authorisation conditions. Participants therefore emphasised the need for configurable and granular access rules, consistent with Attribute-Based Access Control and fine-grained authorisation models (Hu et al., 2020; Mohamed et al., 2022).

A fifth concern involved limited interoperability with existing systems. Ports typically operate multiple platforms, devices, databases, and operational procedures, requiring access management to interact with Port Community Systems, logistics platforms, contractor databases, human resource systems, surveillance technologies, and legacy access-control infrastructure. The findings therefore highlight the importance of API-based integration, legacy-system compatibility, and hybrid deployment. Rather than complete system replacement, participants generally favoured gradual integration that preserves operational continuity.

The consultations also stressed the importance of monitoring, non-compliance management, and auditability. Key requirements included detecting suspicious behaviour, recording failed authentication attempts, monitoring access events, and maintaining traceable permission histories. These concerns translated into demands for real-time alerts, dashboards, non-compliance modules, and audit trails, particularly in environments where physical security, cybersecurity, and operational continuity are closely interconnected (Dimakopoulou & Rantos, 2024; Senarak, 2021).

Finally, the consultation process revealed that data governance and privacy are integral to access management design. Discussions on biometric data, personal information and external system integration raised questions about data storage, access authorisation, permission management, and the distribution of responsibilities among port organisations, technology providers, and users. This emphasises the importance of integrating data minimisation, role clarity, access logging, and privacy-oriented governance into cloud-enabled architectures from the outset, rather than as afterthoughts.

A synthesis of the main pain points, their operational interpretation and the corresponding system requirements is presented in Table 4.

Table 4. Stakeholder pain points and cloud-enabled system requirements

Stakeholder pain point	Operational interpretation	Cloud-enabled system requirement	Expected value creation
Biometric reliability issues	Authentication may be affected by device, environmental or user-related conditions	Multi-modal authentication; biometric alternatives; fallback procedures	Improves continuity and reliability of access decisions
Card reader issues and non-personalised cards	Physical credentials may be lost, shared or insufficiently traceable	Individualised credentials; mobile credentials; digital access records	Strengthens accountability and traceability
Entry delays and fragmented validation	Manual and repeated procedures create bottlenecks	Automated scheduling; self-service registration; remote permissions	Reduces congestion and administrative burden
High staff turnover and temporary users	Credentials require frequent creation, modification and revocation	Automated lifecycle management; rapid updates; expiration and revocation controls	Supports flexible workforce management and reduces security gaps
Role and zone complexity	Permissions vary by function, location, time and operational purpose	Role-, zone-, time- and attribute-based access rules	Enables granular and context-sensitive access management
Multiple systems and limited interoperability	Fragmented platforms and legacy infrastructure constrain coordination	API integration; hybrid deployment; compatibility with existing systems	Improves data flow, scalability and progressive transformation
Suspicious behaviour and non-compliance	Limited visibility reduces detection and accountability	Real-time monitoring; non-compliance modules; audit trails	Enhances prevention and traceability
Data governance and privacy concerns	Personal and biometric data involve multiple actors and responsibilities	Role-based data access; logging; consent and permission management; privacy-oriented controls	Strengthens trust, accountability and regulatory alignment

Source: Authors' elaboration

The consultation findings highlight that the value of cloud-enabled access management goes beyond advanced technology. Features like authentication, interoperability, and data governance are only valuable when they address specific operational issues. This underscores the importance of using Value Proposition Design to link stakeholder challenges with system capabilities and expected outcomes (Osterwalder et al., 2014).

Furthermore, access control is a technical function, while access management is a governance capability. Concerns identified in the consultations extend beyond physical barriers; they include identities, permissions, user categories, data responsibilities, and accountability within a multi-actor ecosystem. This distinction forms the basis for the three-layer framework outlined in the next section.

4.4. CLOUD-ENABLED ACCESS MANAGEMENT FRAMEWORK

This section presents a cloud-enabled access management framework for smart port ecosystems, drawing on evidence from the literature review, market benchmarking, and stakeholder consultation. The framework integrates findings into three interdependent layers: adoption drivers, technology enablers, and governance outcomes.

This structure reflects the study's design-oriented logic. It posits that cloud-enabled access management generates value not just through technology adoption, but by aligning

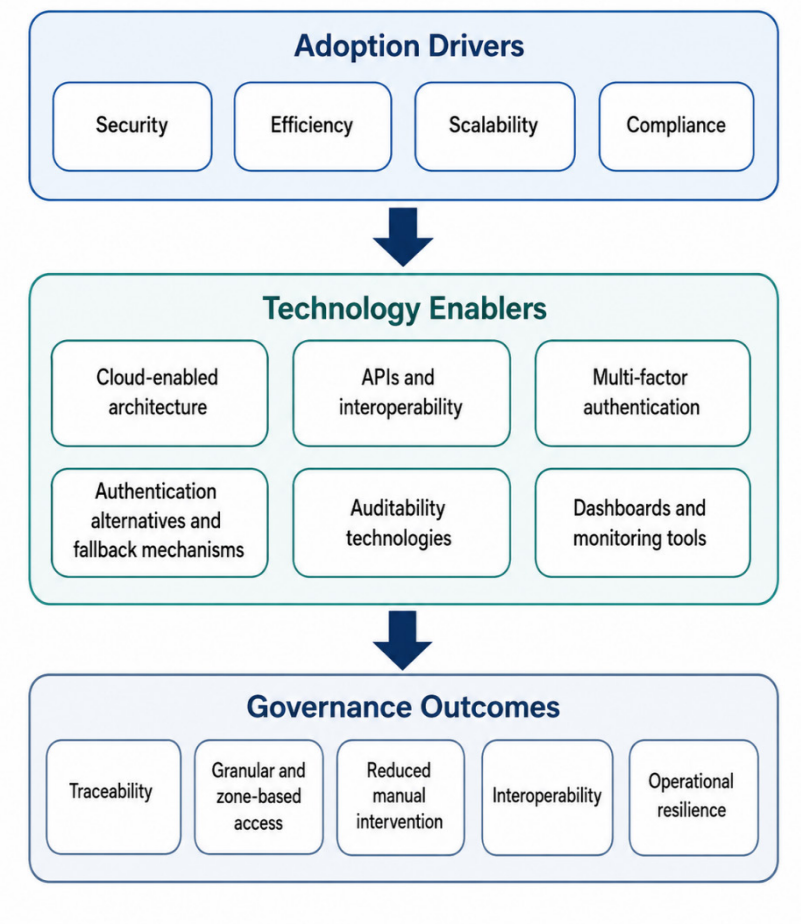
specific operational and governance needs with appropriate technological capabilities. This alignment leads to improved port coordination, security, and resilience.

The first layer concerns adoption drivers: security, efficiency, scalability and compliance. Security is the primary driver, as ports are critical infrastructures where access decisions involve people, vehicles, and restricted zones. Concerns about biometric reliability, suspicious behaviour, and limited traceability highlight the need for secure authorisation and real-time monitoring (Dimakopoulou & Rantos, 2024; Hu et al., 2020; Senarak, 2021). Efficiency is the second driver. Stakeholder feedback indicated that access delays and manual validation create administrative burdens and operational bottlenecks, affecting workforce mobility and vehicle flows. Cloud solutions can help streamline processes through pre-registration, remote permission management, and automated scheduling (Sarabia-Jacome et al., 2020; Tijan et al., 2021). Scalability matters because port environments involve heterogeneous users and variable access needs. High turnover and frequent credential updates can be challenging. Cloud-based systems offer modular deployment and configurable permissions, allowing for adaptability to evolving operational needs (Chauhan & Shiaeles, 2023; Hu et al., 2020). Compliance involves managing personal data and access records securely. It is essential to adhere to regulations such as the GDPR and ISO standards to ensure lawful data processing and auditability. Compliance is seen not just as a constraint but as a vital aspect of trust and governance (Hu et al., 2020; Mell & Grance, 2011).

The second layer comprises the technological enablers of cloud-enabled access management: cloud architecture, APIs and interoperability, multi-factor authentication, alternative and fallback authentication mechanisms, auditability technologies, and monitoring dashboards (Carlan & Vanelslander, 2021; Sarabia-Jacome et al., 2020). Authentication diversity improves operational flexibility, particularly when biometric methods raise concerns about reliability, privacy, or user acceptance. Auditability may rely on conventional logging systems or, where tamper-resistant records and distributed trust are required, blockchain-based solutions (Agyekum et al., 2022; Yang et al., 2020). Dashboards and monitoring tools convert access data into actionable information for oversight and decision-making.

The third layer focuses on governance outcomes, including traceability, zone-based access, reduced manual intervention, interoperability, and operational resilience. Traceability supports auditing, incident investigation, and accountability, while zone-based access enables context-sensitive permissions across gates, terminals, warehouses, restricted areas, and vessel-related interfaces. Reduced manual control lowers administrative burden and allows staff to focus on exceptional cases. Interoperability strengthens coordination and data-driven governance, while operational resilience is enhanced through improved visibility, remote administration, credential revocation, incident response, and continuity management (Dimakopoulou & Rantos, 2024; Senarak, 2021). The proposed framework is presented in Figure 1.

Figure 1. Cloud-enabled access management framework for smart ports



Source: Authors' elaboration

The framework should not be viewed as a linear implementation process. The three layers are interdependent and can influence each other through feedback. For example, compliance requirements may affect authentication and data architectures, while interoperability constraints can shape deployment. Experience with operational outcomes may also lead to redesigning permissions and dashboards. Thus, the framework is a dynamic analytical structure rather than a fixed technological blueprint.

This interpretation highlights the difference between access control and access management. Access control focuses on the mechanisms for granting or denying access, whereas access management encompasses the governance of identities, permissions, user categories, zones, data responsibilities, exceptions, and accountability. In smart port ecosystems, this broader view is crucial, as access decisions are linked to complex operational relationships rather than isolated technical transactions.

The framework, therefore, positions cloud-enabled access management as an integrated governance capability rather than an isolated technical subsystem. Its value lies not in replacing individual access devices, but in enabling a more configurable, traceable and interoperable approach to managing identities, permissions and access-related processes across multiple actors and systems.

The proposed framework provides the basis for the next section, which examines the business model and regulatory requirements associated with its implementation.

4.5. BUSINESS MODEL AND REGULATORY REQUIREMENTS

The development of cloud-enabled access management in smart ports requires a solid business model, clear responsibilities, and a regulatory framework for data protection, cybersecurity, and operational continuity. The framework in Section 4.4 must be integrated into the organisational and economic structures that define value creation and governance in the port ecosystem. This reflects a broader movement from product-based access control towards service-oriented digital platforms, consistent with the business model innovation literature that emphasises the value proposition, delivery mechanisms, revenue logic, and customer-oriented value creation (Osterwalder et al., 2014; Teece, 2010).

Four interrelated requirements emerge from the analysis: value proposition, service configuration, cost structure and risk allocation. The value proposition must demonstrate how the system reduces manual procedures, improves traceability, supports compliance and strengthens resilience. Service configuration must define whether the model is cloud-based, hybrid or integrated with legacy infrastructures. The cost structure must consider subscription fees, integration, hardware adaptation, maintenance, cybersecurity safeguards, and staff training. Risk allocation must clarify responsibilities for data protection, availability, incident response, vendor dependency and service-level agreements.

Regulatory compliance is a core component of the proposed business model. In European ports, the GDPR establishes the legal basis for lawful, transparent, and proportionate processing of personal data. ISO/IEC 27001 provides a framework for information security management; ISO/IEC 27017 addresses cloud-specific security controls; and ISO/IEC 27018 focuses on protecting personally identifiable information in public cloud environments. NIST SP 800-144 provides guidance on cloud security and privacy, while NIST SP 800-145 defines cloud service and deployment models (European Parliament and Council of the European Union, 2016; International Organisation for Standardisation, 2015, 2019, 2022; Mell & Grance, 2011).

These requirements highlight the importance of privacy by design and security by design. Compliance should be embedded in the system architecture from the outset rather than added after deployment. This also requires a clear allocation of responsibilities among port authorities, terminal operators, technology providers, and cloud service providers.

Interoperability must likewise be treated as both a governance and compliance requirement. Port access systems may need to connect to Port Community Systems, single windows for logistics, surveillance systems, contractor databases, human resources platforms, and security operations. Although such integration can reduce fragmentation and manual intervention, it also increases the need for robust API governance, data-sharing rules, cybersecurity controls, and contractual clarity. Without these safeguards, interoperability may amplify rather than mitigate operational and security risks (Carlan & Vanelslander, 2021; Sarabia-Jacome et al., 2020; Tijan et al., 2021).

The main business model and regulatory requirements for cloud-enabled access management in smart ports are illustrated in Table 5.

Table 5. Business model and regulatory requirements for cloud-enabled access management

Requirement area	Main requirement	Relevance for smart ports
Value proposition	Demonstrate security, efficiency, traceability and compliance benefits	Ensures that the system responds to operational pain points rather than merely adding technology
Service configuration	Define cloud, hybrid or legacy-integrated deployment models	Supports gradual transition from existing infrastructures to scalable access management
Cost structure	Consider subscription, integration, maintenance, cybersecurity and training costs	Improves financial predictability and supports informed procurement decisions
Risk allocation	Clarify responsibilities for data protection, availability, incident response and vendor dependency	Reduces ambiguity among port authorities, operators and technology providers
GDPR compliance	Ensure lawful, transparent and proportionate processing of personal data	Protects users' rights and strengthens trust in digital access systems
ISO/IEC 27001	Establish an information security management system	Supports systematic governance of information security risks
ISO/IEC 27017	Define cloud-specific security controls and shared responsibilities	Clarifies obligations between cloud providers and port organisations
ISO/IEC 27018	Protect personally identifiable information in cloud environments	Strengthens privacy safeguards in cloud-based access records
NIST cloud guidance	Support cloud risk assessment, security controls and governance principles	Provides structured guidance for secure cloud adoption and incident response
Interoperability governance	Establish API governance, data-sharing rules and integration controls	Enables coordination while limiting cybersecurity and compliance risks

Source: Authors' elaboration

This section also clarifies the transition from access control to access governance. A technically advanced system may offer authentication, dashboards and remote management, but its long-term value depends on whether it can be governed responsibly. For this reason, the proposed framework positions compliance, risk allocation and business model design as integral components of cloud-enabled access management. This provides the basis for the Discussion section, where the findings are interpreted in relation to smart port governance, business model innovation and the transition from legacy systems to integrated digital ecosystems.

5. DISCUSSION

The findings suggest that the value of cloud-enabled access management lies not in the individual components of the proposed framework, but in their alignment across operational needs, technological capabilities, and governance responsibilities. Security, efficiency, scalability, and compliance generate value only when cloud architecture, authentication mechanisms, interoperability, and monitoring tools are configured to address concrete operational challenges and support accountable coordination among port actors. Cloud-enabled access management should therefore be understood as a component of smart port governance rather than as an isolated security technology.

This perspective extends the smart port literature, which has largely focused on automation, the Internet of Things, data exchange, Port Community Systems, digital twins, and logistics optimisation (Pham, 2023; Sarabia-Jacome et al., 2020; Tijan et al., 2021). Access management deserves greater attention because access points represent operational interfaces where identities, permissions, security rules, and digital records converge. It is

therefore relevant not only to physical security, but also to coordination, accountability, and the governance of operational interdependencies.

The findings also reinforce the view that port digitalisation is a socio-technical and governance process rather than a purely technological transition. Smart port development depends on interoperability, stakeholder coordination, and the integration of digital systems into operational routines (Aksentijevic et al., 2021; Carlan & Vanelslander, 2021; Sarabia-Jacome et al., 2020; Tijan et al., 2021). The proposed framework extends this argument by showing that identities and permissions form part of the port's digital coordination architecture. Role-, zone-, time-, and context-based permissions reflect the distribution of operational rights and responsibilities across actors, rather than merely technical system settings.

This interpretation also broadens the scope of Port Community Systems. Existing research primarily emphasises cargo, document, and information flows as mechanisms to reduce fragmentation and improve coordination and competitiveness (Carlan et al., 2016; Koliousis, 2020). The findings suggest that interoperability should also include identities, permissions, and access-event data. However, such integration raises additional concerns regarding the allocation of responsibility, cybersecurity, and cross-organisational data governance. Interoperability should therefore be actively governed rather than assumed to be inherently beneficial.

From a cybersecurity perspective, the benefits of cloud-enabled access management are inseparable from the redistribution of responsibilities among port organisations, technology providers, and cloud service providers. Cloud-based and hybrid architectures may improve visibility, credential lifecycle management, and remote administration, but they also introduce dependencies that require explicit governance arrangements (Chauhan & Shiaeles, 2023; Sun, 2019). The central issue is therefore not whether cloud technologies inherently increase or reduce risk, but how risk ownership, access privileges, incident response, and continuity responsibilities are allocated across organisational boundaries.

The findings also support the relevance of context-sensitive authorisation models. Attribute-Based Access Control and other fine-grained mechanisms are well established in the access-control literature (Hu et al., 2020; Mohamed et al., 2022). Their specific relevance to this study lies in their applicability to port environments characterised by temporary users, differentiated zones and rapidly changing operational conditions. In such settings, static credentials are poorly suited to permissions that may depend on role, organisation, location, schedule, document validity or task. The contribution, therefore, lies not in proposing ABAC as a novel model, but in showing how context-sensitive authorisation supports the governance requirements of complex port ecosystems.

The stakeholder evidence similarly challenges technology-specific approaches to authentication. Rather than privileging a single mechanism, the findings support a portfolio logic in which biometric, mobile and physical credentials are selected according to operational context, risk and continuity requirements. This is particularly relevant where biometric reliability, privacy concerns, or device limitations make exclusive reliance on a single technology problematic (Bast & Yeh, 2024; Parkinson & Khan, 2023). Authentication diversity should therefore be interpreted as both an operational resilience mechanism and a security capability.

This argument leads to a broader principle of technological pragmatism. Cloud-enabled access governance need not rely exclusively on high-cost computer vision or advanced biometrics. RFID, barcode-based identifiers, and other Automatic Identification and Data Capture technologies may serve as effective components of modular architectures, particularly where legacy integration, lifecycle cost, or operational continuity constraints

require more sophisticated solutions. The implication is that technology selection should be problem-driven rather than novelty-driven. The cloud layer can provide a configurable environment for managing heterogeneous credentials and devices without requiring immediate replacement of existing infrastructure.

Auditability should be interpreted with similar caution. Existing studies have explored blockchain-based mechanisms for secure data sharing, privacy protection and tamper-resistant records (Agyekum et al., 2022; Yang et al., 2020). However, the findings do not support blockchain as a default component of cloud-enabled access management. Its relevance is limited to governance contexts that require distributed verification, cross-organisational trust, or strong resistance to record manipulation. Conventional logging mechanisms may be sufficient in many applications. This distinction helps avoid technology-driven implementation without demonstrated operational value.

The study also contributes to research on business model innovation. The key implication is that value creation depends on alignment rather than on service-based delivery alone. A subscription or cloud model does not constitute meaningful innovation if it fails to reduce operational friction, clarify responsibilities or integrate with existing infrastructures. The findings therefore support a broader interpretation of business model innovation in which value proposition, service configuration, cost structure and risk allocation are interdependent (Osterwalder et al., 2014; Teece, 2010). In this context, cloud-enabled access management creates value when technical capabilities are translated into outcomes that stakeholders recognise as operationally relevant.

The stakeholder evidence provides empirical support for this alignment perspective. Authentication failures, access delays, workforce variability, fragmented permissions and limited interoperability represent operational problems rather than abstract technological gaps. Mechanisms such as remote permission management, credential lifecycle control and API integration are valuable only insofar as they address those problems. This reinforces the usefulness of Value Proposition Design as a bridge between stakeholder requirements and system configuration (Osterwalder et al., 2014). It also supports ecosystem-based perspectives on port value creation, which argue that value emerges through coordination among actors rather than through isolated organisational decisions (De Martino, 2021; Tsvetkova & Hellström, 2022).

Operational resilience should likewise be interpreted as a contingent outcome rather than an inherent property of cloud adoption. Cloud-enabled access management may support continuity through remote administration, rapid permission changes and improved visibility, but centralised services may also create connectivity dependencies, concentration risks or vendor-related vulnerabilities. Resilience, therefore, depends on redundancy, fallback arrangements, continuity planning, and clear allocation of responsibility. This explains why hybrid architectures may remain relevant in operationally critical environments.

A central theoretical implication is the distinction between access control and access management. Access control concerns the mechanisms used to grant or deny entry, whereas access management encompasses identities, permissions, credential lifecycles, user categories, zones, exceptions, data responsibilities, and accountability. The findings show that many of the most significant challenges in port environments are organisational rather than device-specific. They arise from coordinating changing user populations, differentiated permissions, multiple systems, and cross-organisational responsibilities. Reframing access management as a governance capability is therefore a principal contribution of this study.

This distinction also clarifies the dual role of interoperability. Technically, interoperability depends on APIs, device compatibility, and integration with legacy infrastructure.

From a governance perspective, it can reduce fragmentation and improve coordination. However, integration may also expand attack surfaces and create uncertainty regarding data ownership, accountability, and incident response. Interoperability is therefore both an operational enabler and a governance challenge, extending the smart port and Port Community System literature to include identities, permissions, and access-event data (Carlan & Vanelslander, 2021; Sarabia-Jacome et al., 2020; Tijan et al., 2021).

The findings further support a gradual approach to digital transformation. Ports commonly operate historically layered systems, heterogeneous devices, and legacy infrastructure. Cloud-enabled access management should therefore not assume immediate system replacement. Hybrid deployment, modular integration, and compatibility with existing technologies may offer more feasible transition pathways, consistent with research emphasising migration planning, organisational readiness, and risk controls (Chauhan & Shiaeles, 2023; Sun, 2019).

Cloud-enabled access management can support smart port transformation under three conditions. First, implementation must address clearly defined operational and governance problems rather than pursue technology adoption for its own sake. Second, systems must be embedded in secure, interoperable, and responsibility-aware governance structures. Third, the business model must align stakeholder value, service configuration, lifecycle costs, compliance, and risk allocation.

The principal theoretical contribution is therefore to position cloud-enabled access management at the intersection of smart port governance, cybersecurity, and business model innovation. Access management is not merely an authentication issue, but a socio-technical coordination challenge involving operational needs, technological capabilities, governance responsibilities, and value creation. The practical contribution is a structured framework that port authorities, terminal operators, and technology providers can use to assess drivers of adoption, implementation requirements, business model considerations, and expected governance outcomes.

6. CONCLUSION

This study examined how cloud-enabled access management can support the transition from fragmented legacy systems to integrated smart port governance. Drawing on a literature review, market benchmarking, stakeholder consultations, and value proposition analysis, it developed a three-layer framework linking adoption drivers, technological enablers, and governance outcomes.

The findings show that cloud-enabled access management can support smart port governance when four conditions are jointly satisfied. First, implementation must respond to clearly defined operational and governance needs, particularly security, efficiency, scalability, and compliance. Second, these needs must be matched with appropriate technological enablers, including cloud architecture, APIs, interoperability, multi-factor authentication, fallback mechanisms, auditability tools, and real-time monitoring. Third, implementation should generate governance outcomes such as traceability, granular access control, reduced manual intervention, interoperability, and operational resilience. Fourth, these elements must be embedded in a coherent business model and regulatory framework that clarifies value creation, deployment, lifecycle costs, risk allocation, and data governance responsibilities.

The study makes three theoretical contributions. First, it extends the smart port literature by positioning access management as part of the digital governance infrastructure of port ecosystems. Although previous research has focused primarily on automation, the Internet of Things, data exchange, and Port Community Systems, identities, permissions, and ac-

cess-event data have received less attention (Pham, 2023; Sarabia-Jacome et al., 2020; Tijan et al., 2021). The findings show that access points are not merely physical barriers, but operational interfaces through which people, assets, rules, and digital records are coordinated.

Second, the study distinguishes access management from access control. While access control concerns the mechanisms used to grant or deny entry, access management encompasses the governance of identities, permissions, credential lifecycles, user categories, zones, exceptions, and accountability. This distinction is especially relevant in ports, where access decisions depend on changing roles, operational conditions, and cross-system interactions.

Third, the study contributes to research on business model innovation by showing that cloud-enabled access management should not be evaluated solely as a technical architecture. Its value depends on the alignment of stakeholder needs, service configuration, cost structures, regulatory compliance, and risk allocation (Osterwalder et al., 2014; Teece, 2010).

Methodologically, the study integrates academic literature, market evidence, stakeholder insights, and design-oriented artefacts within a single analytical structure. The framework is therefore presented as a design-oriented contribution rather than a universally validated model.

In practical terms, the framework can assist port authorities in assessing traceability, interoperability, differentiated permissions, and resilience; support terminal operators and logistics firms in reducing manual procedures and improving credential management; guide technology providers towards modular and interoperable solutions; and help policymakers embed privacy, cybersecurity, and responsibility allocation into system design from the outset.

The findings also support a pragmatic approach to technology selection. Cloud-enabled access management does not require exclusive reliance on advanced biometrics, computer vision or other high-complexity technologies. RFID, barcode-based identification, mobile credentials, cards and biometric methods may coexist within modular architectures. The relevant criterion is not technological novelty, but the capacity of the selected configuration to respond to risk, throughput, environmental conditions, interoperability requirements and lifecycle cost.

Several limitations should be acknowledged. First, the study is exploratory and design-oriented and does not provide a longitudinal evaluation of a fully deployed cloud-enabled access management system. Second, the literature review was conducted to support conceptual integration and framework development rather than as a fully systematic review or meta-analysis. Third, market benchmarking identified recurring capabilities and business model patterns but did not compare or rank commercial providers. Fourth, the stakeholder component involved six participants across nine consultation meetings and therefore does not statistically represent the wider population of port actors. Finally, the framework emerged from a specific port-innovation context and may require adaptation based on port scale, governance model, digital maturity, regulatory conditions, and existing infrastructure.

Future research should therefore test and refine the framework in different port environments. Comparative studies could examine whether drivers of adoption and technology enablers vary across large gateway ports, regional ports, and specialised terminals. Longitudinal studies could evaluate effects on access delays, incident response, user experience, compliance performance and operational continuity. Further research could also explore the role of artificial intelligence, anomaly detection, predictive analytics and digital twins in access management. Attention should be given to the ethical and legal implications of

biometric processing, automated access decisions, data retention and cross-organisational data sharing.

In conclusion, cloud-enabled access management can contribute to the transformation of smart ports when designed as a secure, interoperable, and value-oriented governance capability. Its strategic relevance lies not merely in digitising access control, but in improving how port ecosystems coordinate identities, permissions, data, responsibilities and operational risk across heterogeneous actors and systems. By integrating security, efficiency, scalability, compliance and resilience, cloud-enabled access management can become an important component of contemporary smart port governance.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Scite.ai and SciSpace.ai to organise and interact with documents. After using these tools/services, the author(s) reviewed and edited the content as needed and took full responsibility for the publication's content.

Conflicts of interest

The authors declare no conflicts of interest.

Funding

Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n.º 53)

Acknowledgment

NECE - Research Centre for Business Sciences funded by the Multiannual Funding Program of R&D Centers of FCT—Fundação para a Ciência e Tecnologia, Portugal, under Grant number UID/04630/2025, DOI: 10.54499/UID/04630/2025

REFERENCES

Agyekum, K. O.-B. O., Xia, Q., Sifah, E. B., Cobblah, C. N. A., Xia, H., & Gao, J. (2022). A Proxy Re-Encryption Approach to Secure Data Sharing in the Internet of Things Based on Blockchain. *IEEE Systems Journal*, *16*(1), 1685–1696. https://doi.org/10.1109/JSYST.2021.3076759

Aksentijevic, S., Tijan, E., Panjako, A., & Mrcela, G. (2021). Digitalization of Port Access Control: Case Study Port of Šibenik. *2021 44th International Convention on Information, Communication and Electronic Technology (MIPRO)*, 1294–1299. https://doi.org/10.23919/MIPRO52101.2021.9596650

Barasti, D., Troscia, M., Lattuca, D., Tardo, A., Barsanti, I., & Pagano, P. (2021). An ICT Prototyping Framework for the "Port of the Future". *Sensors*, *22*(1), 246. https://doi.org/10.3390/s22010246

Bast, C., & Yeh, K.-H. (2024). Emerging Authentication Technologies for Zero Trust on the Internet of Things. *Symmetry*, *16*(8), 993. https://doi.org/10.3390/sym16080993

Carlan, V., Sys, C., & Vanelslander, T. (2016). How port community systems can contribute to port competitiveness: Developing a cost–benefit framework. *Research in Transportation Business & Management*, *19*, 51–64. https://doi.org/10.1016/j.rtbm.2016.03.009

Carlan, V., & Vanelslander, T. (2021). Economic Aspects of Introducing Artificial Intelligence Solutions in Logistics and Port Sectors: The Data Entry Case. *Frontiers in Future Transportation*, *2*. https://doi.org/10.3389/ffutr.2021.710330

Chauhan, M., & Shiaeles, S. (2023). An Analysis of Cloud Security Frameworks, Problems and Proposed Solutions. *Network*, *3*(3), 422–450. https://doi.org/10.3390/network3030018

Chenail, R. (2016). Bringing Method to the Madness: Sandelowski and Barroso's Handbook for Synthesizing Qualitative Research. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2009.2820

Creswell, J. W. (2009). *Research Design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). SAGE Publications. Inc. https://www.ucg.ac.me/skladiste/blog_609332/objava_105202/fajlovi/Creswell.pdf, accessed on 24/05/2024.

de Langen, P. W., Sornn-Friese, H., & Hallworth, J. (2020). The Role of Port Development Companies in Transitioning the Port Business Ecosystem; The Case of Port of Amsterdam's Circular Activities. *Sustainability*, *12*(11). https://doi.org/10.3390/su12114397

De Martino, M. (2021). Value Creation for Sustainability in Port: Perspectives of Analysis and Future Research Directions. *Sustainability*, *13*(21), 12268. https://doi.org/10.3390/su132112268

Dimakopoulou, A., & Rantos, K. (2024). Comprehensive Analysis of Maritime Cybersecurity Landscape Based on the NIST CSF v2.0. *Journal of Marine Science and Engineering*, *12*(6), 919. https://doi.org/10.3390/jmse12060919

Ding, W., Yan, Z., & Deng, R. H. (2020). Privacy-Preserving Data Processing with Flexible Access Control. *IEEE Transactions on Dependable and Secure Computing*, *17*(2), 363–376. https://doi.org/10.1109/TDSC.2017.2786247

Dubey, S., & Rai, P. K. (2021). A Review of Cloud Service Security with Various Access Control Methods. *International Journal of Computer Science and Mobile Computing*, *10*(3), 39–45. https://doi.org/10.47760/ijcsmc.2021.v10i03.005

El Kafhali, S., El Mir, I., & Hanini, M. (2022). Security Threats, Defense Mechanisms, Challenges, and Future Directions in Cloud Computing. *Archives of Computational Methods in Engineering*, *29*(1), 223–246. https://doi.org/10.1007/s11831-021-09573-y

European Parliament and Council of the European Union. (2016). Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data. L 119, 1–88. *Official Journal of the European Union*, 1–88. https://eur-lex.europa.eu/eli/reg/2016/679/oj/eng, accessed on 04/05/2025.

Ferrari, E. (2010). Access Control in Data Management Systems. *Synthesis Lectures on Data Management*, *2*(1), 1–117. https://doi.org/10.2200/S00281ED1V01Y201005DTM004

Garzia, F., Sammarco, E., & Cusani, R. (2009). *Integrated access control system for ports*. 313–323. https://doi.org/10.2495/SAFE090301

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research1. *MIS Quarterly*, *28*(1), 75–106. https://doi.org/10.2307/25148625

Hu, V. C., Iorga, M., Bao, W., Li, A., Li, Q., & Gouglidis, A. (2020). *General access control guidance for cloud systems*. https://doi.org/10.6028/NIST.SP.800-210

International Organization for Standardization. (2015). *ISO/IEC 27017:2015 Information technology — Security techniques — Code of practice for information security controls based on ISO/IEC 27002 for cloud services. ISO*. https://amnafzar.net/files/1/ISO%2027000/ISO%20IEC%2027017-2015.pdf

International Organization for Standardization. (2019). *ISO/IEC 27018:2019 Information technology — Security techniques — Code of practice for protection of personally identifiable information in public clouds acting as PII processors. ISO*. https://www.glocertinternational.com/services/iso-certifications/iso-27018, accessed on 04/07/2026.

International Organization for Standardization. (2022). *ISO/IEC 27001:2022* Information security, cybersecurity and privacy protection — Information security management systems — Requirements. ISO. https://www.exactls.com/wp-content/uploads/2025/02/ISO_IEC-270012022-ed.3.pdf, accessed on 04/07/2026.

Koliousis, I. (2020). A conceptual framework that monitors port facility access through integrated Port Community Systems and improves port and terminal security performance. *International Journal of Shipping and Transport Logistics*, *12*(4), 251. https://doi.org/10.1504/IJSTL.2020.10029955

Marinov, Y. A., & Lisenyi, Y. V. (2024). The Role of Cloud Technologies in the Management of Logistics Operations. *Business Inform*, *9*(560), 94–101. https://doi.org/10.32983/2222-4459-2024-9-94-101

Marjohan, M., Satria, R., Sunanto, S., & Ishwara, P. I. (2026). The Implementation of Financial Technology in Digital Investment Applications for the Citizens of Indonesia. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 393-413. https://doi.org/10.2478/eoik-2026-0042

Mell, P. M., & Grance, T. (2011). *The NIST definition of cloud computing*. https://doi.org/10.6028/NIST.SP.800-145

Miles, M. B., Huberman, M. A., & Saldaña, J. (2013). *Qualitative-Data-Analysis* (Helen Salmon, Ed.; Third edition). SAGE Publications, Inc. https://www.metodos.work/wp-content/uploads/2024/01/Qualitative-Data-Analysis.pdf, accessed on 10/05/2026.

Mileski, J., Clott, C., & Galvao, C. B. (2018). Cyberattacks on ships: a wicked problem approach. *Maritime Business Review*, *3*(4), 414–430. https://doi.org/10.1108/MABR-08-2018-0026

Mohamed, A. K. Y. S., Auer, D., Hofer, D., & Küng, J. (2022). A systematic literature review for authorization and access control: definitions, strategies and models. *International Journal of Web Information Systems*, *18*(2–3), 156–180. https://doi.org/10.1108/IJWIS-04-2022-0077

Mussina, S., Khussainova, Z., Atabayeva, A., & Kazbekov, T. (2026). Estimating the Effects of Macroeconomic Factors on Net Migration: A 2SLS Approach in Panel Data. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 415 - 433. https://doi.org/10.2478/eoik-2026-0043

Namasudra, S. (2019). An improved attribute-based encryption technique towards the data security in cloud computing. *Concurrency and Computation: Practice and Experience*, *31*(3). https://doi.org/10.1002/cpe.4364

Nguyen, H. P., Nguyen, P. Q. P., Nguyen, D. K. P., Bui, V. D., & Nguyen, D. T. (2023). Application of IoT Technologies in Seaport Management. *JOIV : International Journal on Informatics Visualization*, *7*(1), 228. https://doi.org/10.30630/joiv.7.1.1697

Nguyen, M. H., Tran, T. M. T., & Pham, S. A. (2026). Shock, Skills, or Sales? Disentangling the Drivers of Green Action in ASEAN Enterprises. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 269-291. https://doi.org/10.2478/eoik-2026-0036

Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., & Papadakos, T. (Designed by). (2014). *Value proposition design: How to create products and services customers want* (Ed. K. R. S. Wiley, Ed.). https://content.e-bookshelf.de/media/reading/L-3223510-409f7d175c.pdf, accessed on 07/05/2026

Parkinson, S., & Khan, S. (2023). A Survey on Empirical Security Analysis of Access-control Systems: A Real-world Perspective. *ACM Computing Surveys*, *55*(6), 1–28. https://doi.org/10.1145/3533703

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Pham, T. Y. (2023). A smart port development: Systematic literature and bibliometric analysis. *The Asian Journal of Shipping and Logistics*, *39*(3), 57–62. https://doi.org/10.1016/j.ajsl.2023.06.005

Sarabia-Jacome, D., Palau, C. E., Esteve, M., & Boronat, F. (2020). Seaport Data Space for Improving Logistic Maritime Operations. *IEEE Access*, *8*, 4372–4382. https://doi.org/10.1109/ACCESS.2019.2963283

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2023). *Research Methods for Business Students* (9th ed.). Pearson Education Limited. https://www.researchgate.net/publication/240218229_Research_Methods_for_Business_Students, accessed on 16/04/2025.

Senarak, C. (2021). Port cybersecurity and threat: A structural model for prevention and policy development. *The Asian Journal of Shipping and Logistics*, *37*(1), 20–36. https://doi.org/10.1016/j.ajsl.2020.05.001

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sun, P. J. (2019). Privacy Protection and Data Security in Cloud Computing: A Survey, Challenges, and Solutions. *IEEE Access*, *7*, 147420–147452. https://doi.org/10.1109/ACCESS.2019.2946185

Teece, D. J. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning*, *43*(2–3), 172–194. https://doi.org/10.1016/j.lrp.2009.07.003

Tijan, E., Jović, M., Panjako, A., & Žgaljić, D. (2021). The Role of Port Authority in Port Governance and Port Community System Implementation. *Sustainability*, *13*(5), 2795. https://doi.org/10.3390/su13052795

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Tsvetkova, A., & Hellström, M. (2022). Creating value through autonomous shipping: an ecosystem perspective. *Maritime Economics & Logistics*, *24*(2), 255–277. https://doi.org/10.1057/s41278-022-00216-y

Yang, C., Tan, L., Shi, N., Xu, B., Cao, Y., & Yu, K. (2020). AuthPrivacyChain: A Blockchain-Based Access Control Framework With Privacy Protection in Cloud. *IEEE Access*, *8*, 70604–70615. https://doi.org/10.1109/ACCESS.2020.2985762

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

ARTIFICIAL INTELLIGENCE, IT INFRASTRUCTURE AND CYBERSECURITY IN LABOUR MARKET TRANSFORMATION: BRIDGING THE GAP IN UNDERSTANDING DIGITAL INEQUALITY IN THE EUROPEAN UNION

Mariusz Łazarski[1], Patrycja Zmysłowska-Łazarska[2]

Received 16.02.2026. | Send to review 19.03.2026. | Accepted 03.08.2026.

Original Article

CC BY NC ND

[1] WSB-NLU University in Nowy Sącz, Poland

[2] Patrycja Zmysłowska-Łazarska ATiNS in Wrocław, Poland

***Corresponding Author:**
Mariusz Łazarski

Email:
mlazarski@wsb-nlu.edu.pl

JEL Classification:
C23, J24, O33, O38

Doi: 10.61432/CPNE0401027l

UDK: 007.52:331.5.024.52(4672EU)

ABSTRACT

The rapid advancement of artificial intelligence (AI) is reshaping contemporary labour markets, generating both opportunities and challenges within the digital economy. Although existing research has widely examined the effects of AI on employment dynamics, less attention has been given to the combined role of IT infrastructure and cybersecurity in shaping digital inequality. This study addresses this gap by analysing how AI adoption, IT infrastructure quality, and cybersecurity readiness influence labour market transformation and digital disparities across European Union countries. Using panel data from Eurostat, OECD, DESI, and cybersecurity-related indicators for EU Member States, the study develops a multidimensional framework that links technological, institutional, and socioeconomic factors. The empirical findings suggest that AI adoption is positively associated with digital inequality. However, stronger IT infrastructure and higher cybersecurity readiness mitigate this effect through moderating interactions, supporting a more inclusive labour market transformation. The study contributes to the literature by integrating previously fragmented research streams and offering a broader understanding of inequality in the digital economy. The findings suggest that investments in digital infrastructure and cybersecurity should accompany AI-driven innovation to ensure a more equitable distribution of technological benefits. Effective digital transformation therefore requires coordinated strategies that combine technological advancement, digital inclusion, and cyber resilience.

Keywords: *artificial intelligence, digital inequality, labour market transformation, cybersecurity, digital infrastructure, European Union, digital transformation*

1. INTRODUCTION

The rapid advancement of digital technologies has fundamentally reshaped contemporary economies, positioning artificial intelligence (AI) as a key driver of economic and social transformation. AI-enabled automation and data-driven decision-making increasingly influence labour markets by changing skill requirements, employment structures, and productivity dynamics (Brynjolfsson, Rock, & Syverson, 2021; Acemoglu & Restrepo, 2020; Hunady et al., 2025). While these developments create new opportunities for innovation and economic growth, they also generate challenges related to labour market polarization, job displacement, and structural adjustment.

Alongside these changes, digital inequality has emerged as an important area of economic research, reflecting disparities in access to digital technologies, digital skills, and the ability to benefit from digital transformation (van Dijk, 2020; OECD, 2021). Recent studies emphasize that digital inequality extends beyond physical access to infrastructure, encompassing differences in digital competencies, effective technology use, and participation in the digital economy, thereby reinforcing broader socioeconomic disparities (van Dijk, 2020; OECD, 2021). Although the European Union has made considerable progress in digital integration, substantial differences remain across Member States in digital infrastructure, human capital, and technology adoption, as reflected in the Digital Economy and Society Index (European Commission, 2024).

Although a growing body of research examines AI-driven labour market transformation, most studies focus primarily on the direct effects of automation while paying limited attention to the broader technological and institutional environment. In particular, IT infrastructure, which enables digital participation and technology adoption, remains insufficiently incorporated into analyses of labour market outcomes (Aumeboonsuke & Caplanova, 2026). Similarly, cybersecurity has become an increasingly important, yet underexplored, determinant of digital transformation, influencing trust in digital systems and the resilience of economic structures (ENISA, 2023). The rapid diffusion of generative AI has introduced additional cybersecurity challenges related to data integrity, model manipulation, and trust in automated decision-making, with potential implications for organizational performance and labour market dynamics (Łazarski, 2026). Consequently, inadequate cybersecurity readiness may deepen digital exclusion by limiting secure access to digital services and increasing vulnerability to cyber threats.

These observations reveal an important research gap concerning the combined effects of AI adoption, IT infrastructure, and cybersecurity on labour market transformation and digital inequality. Existing studies typically analyse these dimensions separately, overlooking their interaction effects and the systemic mechanisms through which they shape digital disparities. This fragmentation limits understanding of the multidimensional nature of inequality across European Union countries.

Accordingly, this study develops an integrated analytical framework to examine how AI adoption, IT infrastructure, and cybersecurity jointly influence labour market transformation and digital inequality in the European Union. The study addresses the following research question:

How do technological and institutional factors jointly influence labour market outcomes and digital inequality in the digital economy?

The novelty of this research lies in integrating artificial intelligence, IT infrastructure, and cybersecurity within a single analytical framework explaining digital inequality. Unlike previous studies that examine these factors independently, this paper analyses both their direct and interaction effects using panel data from European Union Member States. By incorporating cybersecurity as both a technological and institutional determinant, the study extends existing research on labour market transformation and provides a more comprehensive explanation of the mechanisms underlying inclusive digital development.

Based on the theoretical framework and identified research gap, the following hypotheses are proposed:

H_1: *Artificial intelligence adoption is positively associated with digital inequality in European Union countries.*

H_2: *Higher levels of IT infrastructure development are associated with lower levels of digital inequality.*

H_3: *Higher levels of cybersecurity readiness are associated with lower levels of digital inequality.*

H*$_4$*: IT infrastructure moderates the relationship between artificial intelligence adoption and digital inequality by reducing the inequality-enhancing effects of AI.

H*$_5$*: Cybersecurity readiness moderates the relationship between artificial intelligence adoption and digital inequality by reducing the inequality-enhancing effects of AI.

These hypotheses assume that the effects of AI on labour market transformation and digital inequality depend on the technological and institutional environment in which digital technologies are implemented. Accordingly, IT infrastructure and cybersecurity are expected to exert both direct effects on digital inequality and moderating effects on the relationship between AI adoption and inequality.

This study makes four main contributions. First, it incorporates cybersecurity as a key dimension in the analysis of digital inequality. Second, it develops an integrated framework linking artificial intelligence, digital infrastructure, and cybersecurity within the context of labour market transformation. Third, it provides empirical evidence from panel data covering European Union Member States, contributing to the literature on the socioeconomic consequences of digital transformation. Finally, it offers policy implications for designing inclusive and resilient digital development strategies that reduce digital disparities while supporting technological innovation.

The remainder of the paper is organized as follows. Section 2 reviews the literature, Section 3 describes the methodology and data, Section 4 presents the empirical results, Section 5 discusses the findings, and Section 6 concludes.

2. LITERATURE REVIEW

Table 1. Summary of Key Literature

Author	Main focus	Key findings	Research gap
Acemoglu & Restrepo (2020)	Automation	Labour displacement	No cybersecurity
Brynjolfsson et al. (2021)	Productivity	Complementary investments	No digital inequality
van Dijk (2020)	Digital divide	Multidimensional inequality	No AI
ENISA (2023)	Cybersecurity	Digital resilience	No labour market analysis
OECD (2023)	AI and employment	Skills adaptation	No integrated model

Source: Own elaboration based on the reviewed literature

Table 1 summarizes the most influential studies on artificial intelligence, digital inequality, and cybersecurity, highlighting the fragmentation of existing research and the need for an integrated analytical framework.

The literature on artificial intelligence (AI), labour market transformation, and digital inequality has expanded rapidly, reflecting the growing role of digital technologies in economic development. Existing research shows that AI does not affect labour markets uniformly; rather, its effects depend on technological adoption, workforce skills, institutional capacity, and digital infrastructure. AI-driven automation is increasingly associated with changes in task composition rather than the direct replacement of human labour. Acemoglu and Restrepo (2020) argue that automation reduces demand for routine tasks while increasing the value of complementary human skills. Similarly, Autor (2022) emphasizes that technological change generates both displacement and augmentation effects, depending on the adaptability of workers, firms, and institutions. Consequently, AI reshapes labour markets by increasing demand for analytical, digital, and problem-solving competencies.

The productivity gains associated with AI are also contingent upon complementary investments. Brynjolfsson, Rock, and Syverson (2021) argue that general-purpose technologies require organizational change, human capital development, and digital capabilities to generate substantial economic benefits. Likewise, Bessen (2018) highlights that AI adoption may create new employment opportunities through demand-side effects that offset automation-related job displacement. Agrawal, Gans, and Goldfarb (2022) further argue that AI should be viewed not only as an automation technology but also as a prediction-enhancing mechanism that transforms organizational decision-making. However, inadequate digital infrastructure may limit the ability of workers and firms to realize these benefits.

Digital inequality represents another important strand of the literature. Rather than focusing solely on access to digital technologies, van Dijk (2020) conceptualizes the digital divide as a multidimensional phenomenon encompassing access, digital skills, usage, and socioeconomic outcomes. This perspective is particularly relevant in the context of AI, where disparities increasingly reflect differences in the ability to use advanced technologies effectively. Consequently, digital inequality should be understood not only as a technological issue but also as a labour market and social policy challenge.

Institutional evidence supports these findings. The European Commission (2024) reports persistent disparities across European Union Member States in digital infrastructure, human capital, and business digitalization, while Eurostat (2025) documents significant differences in ICT use across households, individuals, and regions. These disparities influence the capacity of workers and firms to adapt to AI-driven labour market changes, making digital inequality both a cause and a consequence of technological transformation (Seisenbekov et al., 2026).

Compared with AI and digital infrastructure, cybersecurity remains relatively underexplored in the socioeconomic literature. ENISA (2023) identifies cyber threats as a major challenge to trust, resilience, and the security of digital systems. As labour markets increasingly rely on online platforms, cloud computing, data exchange, and AI-based decision-making, cybersecurity readiness becomes an essential prerequisite for digital participation. Łazarski (2026) argues that generative AI introduces additional risks related to data integrity, model manipulation, and organizational risk management, potentially affecting both firms and workers. Weak cyber resilience may therefore reduce trust in digital services, discourage technology adoption, and deepen digital exclusion.

Labour market institutions and skills policies further shape the impact of AI. OECD (2023) emphasizes that productivity gains depend on workers' ability to adapt to evolving skill requirements. Similarly, the World Economic Forum (2023) and Cedefop (2023) highlight the growing importance of digital and transversal skills, while the International Labour Organization (2021) notes that digital labour platforms create new employment opportunities but also raise concerns regarding job quality, security, and inclusion. Together, these findings suggest that AI-driven labour market transformation should be analysed alongside education, reskilling, and institutional support.

Despite growing interest in cybersecurity, empirical evidence linking cybersecurity readiness directly to digital inequality remains limited, particularly in comparative studies of European Union Member States. Most existing research focuses on technical or organizational aspects of cybersecurity, with limited attention to its broader socioeconomic implications.

The literature also offers contrasting views regarding the distributional consequences of AI adoption. Some studies emphasize productivity growth and employment creation through technological complementarity (Brynjolfsson et al., 2021; Bessen, 2018), whereas others highlight labour market polarization and unequal access to technological oppor-

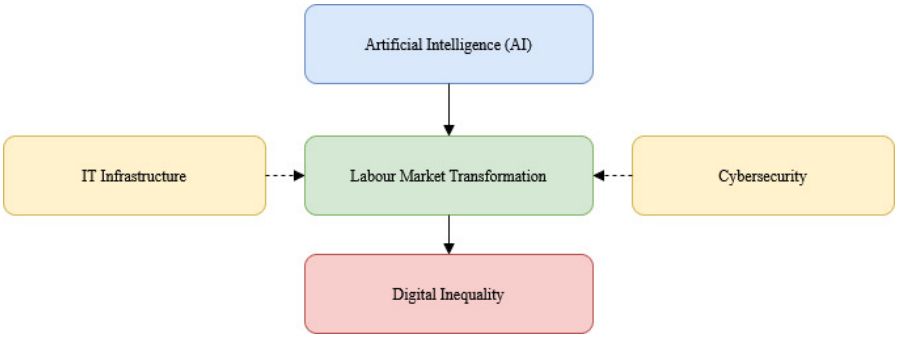
tunities (Acemoglu & Restrepo, 2020; Autor, 2022). These differing perspectives suggest that the effects of AI depend on contextual factors, particularly digital infrastructure and institutional readiness.

Overall, the literature demonstrates that AI, digital infrastructure, cybersecurity, and digital inequality are closely interconnected. However, these dimensions are typically analysed independently. Studies on AI primarily focus on automation and skills, research on digital inequality emphasizes access and competencies, and cybersecurity is generally examined from technical or organizational perspectives. This fragmentation limits understanding of how these factors jointly shape labour market transformation and digital inequality within the European Union.

The reviewed studies indicate that AI may widen digital disparities when technological benefits are concentrated among digitally advantaged groups, whereas digital infrastructure and cybersecurity function as enabling conditions that promote broader participation in the digital economy. These findings provide the theoretical basis for the hypotheses concerning the direct and moderating effects of IT infrastructure and cybersecurity readiness. To the best of the author's knowledge, no previous study has simultaneously examined these relationships using panel data covering all European Union Member States.

Accordingly, this study adopts an integrated perspective, assuming that the labour market effects of AI are conditioned by the quality of IT infrastructure and the level of cybersecurity readiness. Digital inequality is therefore conceptualized as a multidimensional outcome shaped by technological, institutional, and socioeconomic factors. The conceptual framework is presented in Figure 1 and illustrates how IT infrastructure and cybersecurity readiness condition the relationship between AI adoption and digital inequality.

Figure 1. Conceptual framework linking artificial intelligence, IT infrastructure, cybersecurity, labour market transformation, and digital inequality



Source: own elaboration based on Acemoglu and Restrepo (2020), Brynjolfsson et al. (2021), OECD (2023), and ENISA (2023)

The framework assumes that artificial intelligence directly affects digital inequality through its influence on labour market transformation. Simultaneously, IT infrastructure and cybersecurity readiness exert both direct effects on digital inequality and indirect moderating effects by shaping the conditions under which AI-related technologies are adopted and utilized.

3. METHODOLOGY

3.1. RESEARCH DESIGN

This study employs a quantitative research design to examine the relationships among artificial intelligence (AI), IT infrastructure, cybersecurity, labour market transformation, and digital inequality in the European Union. A panel data approach is applied, enabling the analysis of cross-country heterogeneity and temporal dynamics. This methodological

choice is consistent with prior empirical studies on technological change and labour market outcomes (Acemoglu & Restrepo, 2020; Brynjolfsson et al., 2021).

The analysis is grounded in the conceptual framework presented in Figure 1, which assumes that AI affects labour market transformation, while IT infrastructure and cybersecurity operate as enabling and moderating factors. Digital inequality is treated as the dependent outcome, reflecting disparities in access to digital technologies, digital skills, and participation in the digital economy.

The empirical analysis relies on secondary data obtained from several international databases, including Eurostat for labour market indicators, ICT usage, and digital skills; the European Commission's DESI database for digital infrastructure, human capital, and digitalisation indicators; OECD sources for AI adoption, employment structure, and skills; and ENISA indicators for cybersecurity readiness and the cyber-risk environment.

The dataset comprises annual observations for the 27 Member States of the European Union over the period 2016-2023, resulting in a maximum of 216 country-year observations. The panel is treated as balanced where data availability permits. This period captures both the gradual diffusion of AI technologies and the more recent acceleration associated with advances in machine learning and generative AI.

Prior to estimation, missing observations were systematically assessed to ensure data consistency. Where missing values were limited and occurred within continuous time series, linear interpolation was applied. Variables with substantial missingness were excluded from the final specification to reduce the risk of estimation bias.

The use of panel data enables the study to account for both cross-country differences and changes over time in digital transformation processes. It also allows for the control of unobserved country-specific heterogeneity that may influence labour market outcomes and digital inequality. The selected period provides sufficient temporal variation for panel estimation, while the use of harmonised international data sources enhances the reliability, comparability, and consistency of the empirical analysis.

Table 2 presents the structure of the dataset and the main characteristics of the sample.

Table 2. Structure of the Panel Dataset

Item	Value
Geographical coverage	EU-27 Member States
Period	2016-2023
Number of countries	27
Number of years	8
Observations	216
Panel structure	Balanced panel
Data sources	Eurostat, OECD, DESI, ENISA
Missing data treatment	Linear interpolation and listwise exclusion

Source: Own elaboration

3.2. VARIABLES AND MEASUREMENT

Digital inequality (DI) is operationalised as a composite index that captures disparities in digital access, digital skills, and participation in the digital economy. Following the multidimensional approach proposed by van Dijk (2020) and recent OECD recommendations, the index incorporates indicators across three core dimensions of digital inclusion.

The access dimension includes the percentage of households with internet access and broadband coverage. The skills dimension comprises the share of individuals with at least

basic digital skills and the share of ICT specialists in total employment. The usage dimension captures the percentage of individuals regularly using online public services and the percentage engaged in online transactions.

All indicators were normalised using min-max transformation:

$$X_{norm} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (1)$$

The Digital Inequality Index was subsequently calculated as the arithmetic mean of the normalized indicators:

$$DI^* = \frac{1}{n}\sum_{j=1}^{n} x_j \quad (2)$$

To facilitate interpretation, the Digital Inequality Index (DI) was subsequently defined as:

$$DI = 1 - DI^* \quad (3)$$

Consequently, higher values of DI indicate higher levels of digital inequality, whereas lower values indicate higher levels of digital inclusion.

All indicators included in the Digital Inequality Index received equal weights. Following normalization, the composite index was calculated using arithmetic averaging, consistent with previous studies on multidimensional measures of digital inclusion.

Table 3. Variables and Operationalization

Variable	Description	Source
DI	Composite Digital Inequality Index	Eurostat, DESI
AI	Share of enterprises using AI technologies	OECD, Eurostat
ITI	Composite IT Infrastructure Index	DESI
CYB	Cybersecurity Readiness Index	ENISA
GDPpc	GDP per capita (PPP)	Eurostat
EDU	Tertiary education attainment	Eurostat
EMP	Employment rate	Eurostat

Source: Own elaboration based on Eurostat, OECD, DESI and ENISA

Table 4. Construction of Composite Indices

Index	Components	Source
DI	Internet access, broadband coverage, digital skills, ICT specialists, e-government use, online transactions	Eurostat, DESI
ITI	Broadband coverage, VHCN coverage, internet quality, connectivity	DESI
CYB	Cybersecurity strategy, preparedness, resilience, incident response	ENISA

Source: Own elaboration based on Eurostat, DESI and ENISA

The IT Infrastructure Index (ITI) is constructed using indicators related to fixed broadband coverage, very high-capacity network availability, internet speed, and household connectivity. Following the methodology applied in the Digital Economy and Society Index (DESI), all indicators are normalised using min-max transformation and aggregated into a composite index ranging from 0 to 1. Higher values indicate more advanced digital infrastructure development.

AI adoption (AI) is measured as the percentage of enterprises using at least one artificial intelligence technology, including machine learning, natural language processing, com-

puter vision, and intelligent automation systems. The indicator is derived from OECD and Eurostat databases and reflects the diffusion of AI technologies across national economies. It is intended to capture the extent to which AI-based solutions contribute to structural changes in labour markets and economic activity.

Cybersecurity readiness (CYB) is operationalised as a composite index based on publicly available ENISA indicators covering national cybersecurity strategies, incident response capabilities, cyber resilience mechanisms and institutional preparedness. To ensure cross-country comparability, the indicators are harmonised, normalised using min-max transformation, and aggregated into a single index ranging from 0 to 1. Higher values represent stronger cybersecurity readiness.

The model incorporates IT infrastructure and cybersecurity as key moderating variables, reflecting the enabling conditions of digital transformation. IT infrastructure captures the availability and quality of digital connectivity, while cybersecurity reflects institutional capacity to manage digital risks and ensure trust in digital systems. These dimensions are particularly relevant given the increasing reliance on digital technologies in economic and labour market activities.

A set of control variables is also included to account for broader socioeconomic factors that may influence digital inequality. These controls capture differences in economic development, educational attainment, labour market conditions, and structural characteristics of national economies. Their inclusion allows the model to better isolate the effects of AI adoption, IT infrastructure, and cybersecurity readiness on digital inequality.

3.3. MODEL SPECIFICATION

The empirical analysis employs a panel data regression framework to examine the relationships between artificial intelligence, IT infrastructure, cybersecurity readiness, and digital inequality across European Union countries. The model assumes that digital inequality is shaped not only by technological adoption but also by the institutional and infrastructural conditions under which digital technologies are implemented. In this context, AI is expected to influence labour market structures and access to digital opportunities, while IT infrastructure and cybersecurity readiness may condition the magnitude and direction of these effects.

To capture these mechanisms, the model includes both direct effects and interaction terms. The interaction terms assess whether the relationship between AI adoption and digital inequality varies according to the level of IT infrastructure development and cybersecurity readiness. This specification reflects the assumption that the socioeconomic effects of technology are context-dependent rather than uniform across countries. Control variables capturing macroeconomic and structural characteristics, including income levels, education, and labour market conditions, are incorporated to reduce omitted variable bias and improve the robustness of the estimates.

A panel data approach is applied to account for unobserved heterogeneity across countries and over time. Country-specific effects capture time-invariant structural differences among Member States, while time effects control for common shocks affecting all countries in a given year. The model is estimated using both fixed-effects and random-effects specifications, with the preferred specification selected on the basis of standard diagnostic tests.

To determine the most appropriate estimation approach, both fixed-effects (FE) and random-effects (RE) models were estimated. Both fixed-effects and random-effects specifications were considered. Given the objective of controlling for unobserved country-specific heterogeneity, the fixed-effects model was adopted as the primary estimation approach.

Robust standard errors clustered at the country level were used to address potential heteroskedasticity and serial correlation.

Description of variables used in the model:

- level of digital inequality in country i at time t,
- level of artificial intelligence adoption,
- quality of IT infrastructure,
- cybersecurity readiness,
- interaction terms capturing moderating effects,
- vector of control variables (macroeconomic and structural factors),
- unobserved country-specific effects,
- time-fixed effects,
- stochastic error term.

3.4. DIAGNOSTIC AND ROBUSTNESS PROCEDURES

Potential multicollinearity was assessed using the correlation matrix. All pairwise correlation coefficients remained below the commonly accepted threshold of 0.80, suggesting that multicollinearity was unlikely to affect the estimation results. Furthermore, the consistency of coefficient signs and significance levels across model specifications indicates that the main findings are robust.

4. RESULTS

4.1. DESCRIPTIVE STATISTICS

Table 5. Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
DI	0.54	0.18	0.21	0.89
AI	0.37	0.15	0.1	0.72
ITI	0.68	0.14	0.35	0.92
CYB	0.61	0.16	0.28	0.88
GDP per capita	32.4	12.6	8.5	78.3
Education	0.42	0.09	0.21	0.65
Employment rate	0.69	0.08	0.52	0.82

Source: own elaboration based on Eurostat, OECD, and DESI data

Table 5 reports the descriptive statistics for the main variables included in the analysis. The results reveal substantial variation across European Union countries in digital inequality, AI adoption, IT infrastructure, and cybersecurity readiness. The relatively high standard deviation of digital inequality indicates persistent cross-country disparities in digital access, skills, and participation. AI adoption also displays considerable variation, reflecting differences in technological diffusion, firm-level digitalisation and economic development across Member States.

The IT infrastructure indicators suggest that, although some countries have achieved advanced levels of connectivity and digital readiness, others continue to lag behind. Cybersecurity readiness likewise varies notably across the sample, indicating differences in institutional capacity, cyber resilience, and exposure to digital risks.

4.2. CORRELATION ANALYSIS

Table 6. Correlation matrix

Variable	DI	AI	ITI	CYB
DI	1	-	-	-
AI	0.214	1	-	-
ITI	-0.482	0.356	1	-
CYB	-0.401	0.298	0.522	1

Source: own elaboration

Table 6 presents the pairwise correlation coefficients among the variables. The results indicate a negative correlation between IT infrastructure and digital inequality, suggesting that higher levels of connectivity are associated with lower disparities in digital access, skills, and participation. A similar negative association is observed between cybersecurity readiness and digital inequality. Moreover, all correlation coefficients remain below the commonly accepted threshold of 0.80, indicating no evidence of severe multicollinearity among the explanatory variables.

The relationship between AI adoption and digital inequality appears more complex. Although AI adoption is positively correlated with economic development, its direct association with digital inequality is less clear, suggesting that its effects may be conditional on moderating factors such as IT infrastructure and cybersecurity readiness.

4.3. REGRESSION RESULTS

Table 7. Panel regression results (Fixed Effects)

Variable	Coefficient	Std. Error	p-value
AI	0.215	0.082	0.011
ITI	-0.342	0.095	0.002
CYB	-0.198	0.073	0.008
AI x ITI	-0.156	0.067	0.019
AI x CYB	-0.121	0.059	0.041
Observations	216	-	-
R-squared	0.62	-	-

Source: own elaboration

Table 7 presents the results of the panel regression analysis.

The fixed-effects specification was retained as the primary model, as it controls for unobserved country-specific characteristics that may influence digital inequality. The model explains approximately 62% of the variation in digital inequality across countries and over time ($R^2 = 0.62$).

The results indicate that artificial intelligence has a positive and statistically significant effect on digital inequality. This suggests that, in the absence of adequate supporting conditions, greater AI adoption may intensify digital disparities. IT infrastructure shows a negative and statistically significant coefficient, indicating that improvements in digital connectivity and infrastructure contribute to reducing digital inequality. This finding confirms the importance of technological accessibility for inclusive digital transformation.

Cybersecurity readiness also has a negative and statistically significant effect on digital inequality, suggesting that stronger cybersecurity frameworks enhance trust in digital systems and facilitate broader participation in the digital economy.

The interaction terms provide further evidence of conditional effects. The interaction between AI and IT infrastructure is negative and statistically significant, indicating that the inequality-enhancing effect of AI is weaker in countries with more developed digital infrastructure. Similarly, the interaction between AI and cybersecurity readiness is negative, suggesting that stronger cybersecurity capacity mitigates the adverse distributional effects of AI adoption.

Overall, the findings confirm that the impact of artificial intelligence on labour market outcomes and digital inequality depends on the quality of IT infrastructure and the level of cybersecurity readiness. The empirical results support all five research hypotheses. AI adoption is positively associated with digital inequality (H_1), whereas IT infrastructure (H_2) and cybersecurity readiness (H_3) reduce digital inequality. In addition, the negative and statistically significant interaction effects support the moderating roles of IT infrastructure (H_4) and cybersecurity readiness (H_5).

Table 8. Hypotheses verification

Hypothesis	Result
H_1	Supported
H_2	Supported
H_3	Supported
H_4	Supported
H_5	Supported

Source: own elaboration

As reported in Table 8, all proposed hypotheses are empirically supported. The findings confirm the direct effects of artificial intelligence, IT infrastructure, and cybersecurity readiness on digital inequality, as well as the moderating roles of IT infrastructure and cybersecurity in the relationship between AI adoption and digital inequality.

Overall, the results are consistent with the proposed theoretical framework. AI adoption is positively associated with digital inequality, whereas IT infrastructure and cybersecurity readiness significantly reduce digital disparities. Moreover, the negative and statistically significant interaction effects indicate that both factors mitigate the inequality-enhancing impact of AI adoption. These findings suggest that the socioeconomic consequences of artificial intelligence are contingent upon the broader technological and institutional environment.

4.4. ROBUSTNESS CHECKS

To assess the robustness of the results, alternative model specifications were estimated, including models excluding selected control variables and models without interaction terms. The results remained qualitatively consistent across specifications. The stability of coefficient signs and significance levels indicates that the main findings are robust to alternative model formulations.

5. DISCUSSION

The findings provide empirical support for all five hypotheses and offer important insights into the relationship between artificial intelligence, IT infrastructure, cybersecurity, and digital inequality in the European Union. They confirm that the effects of AI on labour

market transformation are not uniform, but depend on the technological and institutional environment in which AI is adopted.

The positive and statistically significant effect of AI on digital inequality suggests that, without adequate supporting conditions, technological advancement may intensify existing disparities. This result is consistent with studies showing that the benefits of technological change are unevenly distributed across individuals, regions, and sectors (Acemoglu & Restrepo, 2020; Autor, 2022). Workers with stronger digital skills and better access to advanced technologies are more likely to benefit from AI-driven change, while others may face greater risks of exclusion. This supports the view that digital inequality concerns not only access, but also capabilities, effective use, and adaptability (van Dijk, 2020; OECD, 2021).

The negative coefficients for IT infrastructure and cybersecurity readiness highlight their role in reducing digital inequality. Improved infrastructure expands access to high-quality connectivity and digital services, enabling wider participation in the digital economy. This finding is consistent with the view that infrastructure is a prerequisite for inclusive digital transformation (OECD, 2021; European Commission, 2024; Ha et al., 2026). Similarly, cybersecurity readiness appears to reduce inequality by strengthening trust in digital systems and protecting users from digital risks. This supports the argument that cybersecurity is not merely a technical issue, but also a socioeconomic factor shaping participation in digital environments (ENISA, 2023; Łazarski, 2026).

The interaction effects further confirm the conditional nature of AI-related outcomes. The negative interaction between AI and IT infrastructure indicates that the inequality-enhancing effect of AI is weaker in countries with more developed digital infrastructure. In such contexts, individuals and firms are better positioned to adopt and use advanced technologies, supporting more inclusive labour market outcomes. Similarly, the moderating effect of cybersecurity suggests that stronger cyber resilience mitigates the risks associated with AI adoption and facilitates more equitable participation in the digital economy.

These findings contribute to the literature by integrating previously fragmented research streams. While earlier studies have examined AI-driven labour market change or digital inequality separately, this study demonstrates that these phenomena are closely interconnected. It highlights the importance of analysing both technological and institutional conditions when assessing the distributional effects of digital transformation.

From a policy perspective, the results suggest that AI-driven economic growth should be accompanied by sustained investment in digital infrastructure and cybersecurity. Without such support, AI adoption may reinforce existing inequalities and limit the inclusive potential of technological innovation. Policymakers should therefore adopt a comprehensive approach that combines technological development with digital skills policies, broader access to digital resources, and stronger cyber resilience. Such an approach is essential for ensuring that labour market digitalisation contributes to inclusive and sustainable economic development.

Despite its contributions, the study has several limitations. The analysis relies on aggregate country-level data, which may not fully capture within-country disparities or sector-specific dynamics. In addition, the measurement of AI adoption and cybersecurity readiness is constrained by data availability and the use of proxy indicators. Future research could address these limitations by using micro-level data, examining sectoral differences, and incorporating more refined measures of technological adoption and cyber risk.

6. CONCLUSION

This study examined the relationship between artificial intelligence, IT infrastructure, cybersecurity, and digital inequality in the context of labour market transformation in the European Union. Using an integrated analytical framework and panel data analysis, it addressed a gap in the literature, where these dimensions have often been studied separately.The findings indicate that artificial intelligence is positively associated with digital inequality, suggesting that AI adoption may intensify existing disparities when adequate support systems are lacking. However, IT infrastructure and cybersecurity appear to mitigate these effects. Strong digital infrastructure improves access to digital resources and participation in the digital economy, while robust cybersecurity enhances trust and reduces exposure to cyber risks. The results also show that the effect of artificial intelligence on digital inequality depends on levels of infrastructure and cybersecurity readiness. This highlights the importance of considering the broader institutional and structural context of digital transformation. The study contributes by integrating technological, infrastructural, and institutional factors into a single framework, emphasizing cybersecurity as a key dimension of digital inequality, and providing empirical evidence from the European Union. From a policy perspective, the findings suggest that AI-driven growth should be supported by investments in connectivity, digital skills, and cyber resilience. Coordinated policies are needed to promote innovation while advancing digital inclusion and institutional capacity. The study is limited by its reliance on aggregated country-level data and proxy indicators for artificial intelligence and cybersecurity. Future research could use more granular data, examine sector-specific dynamics, and assess long-term labour market effects. Overall, the study shows that the relationship between artificial intelligence and digital inequality is complex and context-dependent. Inclusive digital transformation requires technological advancement alongside strong infrastructure, cybersecurity, and effective public policy.

REFERENCES

Acemoglu, D., & Restrepo, P. (2020). Robots and jobs: Evidence from US labor markets. *Journal of Political Economy*, 128(6), 2188-2244. https://doi.org/10.1086/705716

Agrawal, A., Gans, J., & Goldfarb, A. (2022). *Prediction Machines, Updated and Expanded: The Simple Economics of Artificial Intelligence*. Harvard Business Review Press. [Online]. Available at: https://www.scirp.org/reference/referencespapers?referenceid=3683521 [Accessed 07 May 2026].

Aumeboonsuke, V., & Caplanova, A. (2026). Determinants of the Digital Gap: A Comparative Analysis of Central Europe and Southeast Asia, 2002–2024. *ECONOMICS - Innovative and Economic Research Journal*, 14(2), 309 - 332. https://doi.org/10.2478/eoik-2026-0038

Autor, D. H. (2022). *The Labor Market Impacts of Technological Change: From Unbridled Enthusiasm to Qualified Optimism to Vast Uncertainty*. NBER Working Paper No. 30074. National Bureau of Economic Research. [Online]. Available at: https://www.nber.org/papers/w30074 [Accessed 07 May 2026].

Bessen, J. (2018). *AI and Jobs: The Role of Demand*. NBER Working Paper No. 24235. National Bureau of Economic Research. [Online]. Available at: https://www.nber.org/papers/w24235 [Accessed 07 May 2026].

Brynjolfsson, E., Rock, D., & Syverson, C. (2021). The productivity J-curve: How intangibles complement general purpose technologies. *American Economic Journal: Macroeconomics*, 13(1), 333–372. https://doi.org/10.1257/mac.20180386

Cedefop. (2023). Skills in transition: The way to 2035. [Online]. Available at: https://www.cedefop.europa.eu/en/publications/9183 [Accessed 07 May 2026].

ENISA. (2023). ENISA Threat Landscape 2023. [Online]. Available at: https://www.enisa.europa.eu/publications/enisa-threat-landscape-2023 [Accessed 07 May 2026].

European Commission. (2024). Report on the State of the Digital Decade 2024. [Online]. Available at: https://digital-strategy.ec.europa.eu/en/library/report-state-digital-decade-2024 [Accessed 07 May 2026].

Eurostat. (2025). Digital economy and society statistics - households and individuals. [Online]. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=624172&title=Digital_economy_and_society_statistics_-_households_and_individuals [Accessed 07 May 2026].

Ha, T. M. (2026). How Digital Capabilities Drive Innovation in Banking: Extending the Resource-Based View in The Era of Digital Transformation. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 353-373. https://doi.org/10.2478/eoik-2026-0040

Hunady, J., Demeova, E., & Chylakova, V. (2025). The role of digital skills and digitalisation in enhancing labour productivity in the EU. *Collection of Papers New Economy*, 3(1), 33–45. https://doi.org/10.61432/CPNE0301033h

International Labour Organization. (2021). World Employment and Social Outlook 2021: The role of digital labour platforms in transforming the world of work. [Online]. Available at: https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@dgreports/@dcomm/@publ/documents/publication/wcms_771749.pdf [Accessed 07 May 2026].

International Telecommunication Union. (2022). Measuring digital development: Facts and figures 2022. [Online]. Available at: https://www.itu.int/itu-d/reports/statistics/facts-figures-2022 [Accessed 07 May 2026].

Łazarski, M. (2026). From detection to trust: Managing cybersecurity risks of generative AI systems in organizations. *Journal of Information Assurance & Cybersecurity*, 2026, Article ID 274939. https://doi.org/10.5171/2026.274939

OECD. (2021). *The digital transformation of SMEs*. OECD Publishing. https://doi.org/10.1787/bdb9256a-en

OECD. (2023). *OECD Employment Outlook 2023: Artificial Intelligence and the Labour Market*. OECD Publishing. https://doi.org/10.1787/08785bba-en

Seisenbekov, A., Beisenova, M., Koshetayev, D., Akhmetova, Z., & Suyunbayev, S. (2026). The Impact of Digitalization and Innovation on Postal and Courier Services in the Context of Sustainable Economic Development: Evidence From Kazakhstan. *ECONOMICS - Innovative and Economic Research Journal*, 14(2), 249-268. https://doi.org/10.2478/eoik-2026-0035

van Dijk, J. (2020). *The Digital Divide*. Polity Press. [Online]. Available at: https://www.researchgate.net/publication/339751402_Jan_Dijk_2020_The_digital_divide_Cambridge_UK_Polity_208_pp_1799_paperback_ISBN_9781509534456 [Accessed 07 May 2026].

World Bank. (2021). *World Development Report 2021: Data for Better Lives*. World Bank. https://doi.org/10.1596/978-1-4648-1600-0

World Economic Forum. (2023). The Future of Jobs Report 2023. [Online]. Available at: https://www3.weforum.org/docs/WEF_Future_of_Jobs_2023.pdf [Accessed 07 May 2026].

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

THE STRUCTURE OF SOCIAL TRUST: THE ISSUE OF INSTITUTIONAL HETEROGENEITY ACROSS COUNTRIES

Viktor Koziuk[1], Yuriy Hayda[2], Oleksandr Dluhopolskyi[3], Oksana Liashenko[4], Oksana Shymanska[1]

Received 06.03.2026. | Send to review 22.03.2026. | Accepted 02.08.2026.

Original Article

CC BY NC ND

[1] West Ukrainian National University, Ukraine

[2] West Ukrainian National University, Chernihiv Polytechnic National University, Ukraine

[3] West Ukrainian National University, Ukraine; Lubelska Academia WSEI, Republic of Poland

[4] Loughborough University, United Kingdom; Lesya Ukrainka Volyn National University, Ukraine

***Corresponding Author:**
Oleksandr Dluhopolskyi

Email:
dlugopolsky77@gmail.com

JEL Classification:
A13, H11, O15, O17

Doi: 10.61432/CPNE0401041k

UDK: 316.62(4):004.738.1

ABSTRACT

This study investigates the heterogeneity of social trust structures across countries, focusing on the relationships among interpersonal trust, institutional trust, and confidence in the armed forces. Using data from the World Values Survey Wave 7 covering 88 countries, the study applies correlation analysis, analytical grouping, hierarchical and k-means clustering, ANOVA, and distance-based regression to identify patterns in trust configurations. The findings reveal that institutional trust is highly interdependent, particularly among political, legal, and administrative institutions, whereas interpersonal trust exhibits weaker associations with these structures. Cluster analysis demonstrates substantial cross-country variation in the interaction between interpersonal and institutional trust, challenging the assumption of a universal trust configuration. Confidence in the armed forces consistently exceeds both interpersonal trust and confidence in most other public institutions across all clusters. After controlling for interpersonal trust, an indirect relationship emerges between confidence in the armed forces and institutional trust, suggesting that these dimensions may originate from different social and political mechanisms. The results support the hypothesis that social trust is structurally heterogeneous and shaped by cultural, historical, and political contexts. Confidence in the armed forces appears to function as a stabilizing mechanism supporting societal needs for order, security, and national identity, particularly in countries characterized by weak political institutions or limited policy effectiveness. This study contributes to a more nuanced understanding of cross-national trust configurations and institutional legitimacy.

Keywords: *social trust, confidence, economy, institution, income, distribution*

1. INTRODUCTION

Social trust is considered an important dimension of a country's institutional characteristics. The nature of social trust determines the effectiveness of decentralized interactions. The burden of transaction costs directly shapes the flexibility of the economy and its capacity to adapt rapidly to shocks. Social trust is a crucial ingredient in the relationship between society and political institutions. A lack of social trust often signifies a loss of legitimacy in the implementation of public policies or serves as a precondition for electoral change (Levi et al., 2009; Hetherington, 1998; Hetherington, 2005).

Russia's war against Ukraine has demonstrated how crucial social trust is in matters of volunteering and charitable support for the army. In essence, the lack of efficiency in the centralized approach to supplying the defense forces has been partially offset by citizens' self-organization, which formed decentralized networks through which the material foundation of armed resistance against criminal aggression was significantly strengthened. It is difficult to ignore the fact that this serves as a clear example of how social trust operates in practice. On the other hand, Ukraine, like many other countries with comparable income levels and institutional quality, does not exemplify high standards of institutional trust.

At the same time, interpersonal trust within decentralized networks is not an unconditional substitute for the lack of institutional trust. In many societies, both types of social trust remain at low levels. Likewise, in some societies they are positively correlated at high levels. Conversely, certain countries may demonstrate a dominance of trust in central authorities despite the absence of strong interpersonal relationships. In light of Ukraine's experience with volunteering and charitable support, trust in the army, together with a sufficient level of interpersonal trust to sustain resilient decentralized networks, coexists with low trust in public institutions. This raises the question of whether the structure of social trust is homogeneous across countries. Different combinations of social trust components may reflect distinct institutional development trajectories and generate specific patterns that are difficult to detect through general indicators of trust in others. As Newton, Zmerli (2011) and Boda et al. (2018) argue, social trust is complex, differentiated, and dynamic; therefore, a focus on trust in individual institutions may fail to capture more intricate forms of social organization and informal regulators of interaction.

This article continues the discussion on the relationship between interpersonal and institutional trust in the context of cross-country heterogeneity and the distinctive role of confidence in the armed forces. Given the growing vulnerability to military threats worldwide, confidence in the armed forces is considered an important criterion of heterogeneity. Correlation analysis confirms that confidence in the armed forces is less strongly associated with trust in other public institutions, while cluster analysis highlights patterns of similarity among countries based on different combinations of social trust components. At the same time, an analytical grouping approach based on the level of trust in others and a clustering approach that incorporates all elements of social trust produce different results.

The findings demonstrate that when the variable of trust in others is controlled for, a latent relationship emerges between trust in the military and institutional trust. This suggests that interpersonal and institutional trust may originate from different sources, whereas trust in the military represents a specific expression of the willingness to accept the anchoring of order and protection, even when political institutions are not trusted due to their weakness or the characteristics of the political regime. In this formulation, the hypothesis of social trust heterogeneity receives empirical support, adding further nuance to our understanding of how the elements of social trust may be combined across countries.

In this study, social trust heterogeneity refers to the existence of different structural configurations of interpersonal and institutional trust across countries, implying that trust dimensions do not necessarily evolve jointly and may reflect different historical, cultural, and political trajectories.

2. LITERATURE REVIEW

Research on social trust emphasizes that it is grounded in expectations of positive outcomes from social interactions (Levi, Stoker, 2000; Hosking, 2017). There is a well-estab-

lished consensus regarding the relationship between social trust and economic performance (Beugelsdijk et al., 2004; Dincer, Uslaner, 2010; Aghion et al., 2010; Bjørnskov, 2012; Bjørnskov, 2022). Such trust constitutes a foundation of well-being; moreover, it is an important source of optimization for decentralized interactions through the channel of transaction costs, the burden of which is a powerful driver in the formation of institutions designed to support and regulate social exchanges (Coase, 1960; Gorodnichenko, Roland, 2011).

Beyond the transaction cost channel, social trust plays a crucial role in creating rational incentives for political decision-making (Peiró-Palomino et al., 2024). In turn, political decisions are made in the public interest, generating a positive feedback loop (Hetherington, 1998; Hetherington, 2005; Kahan, 2001; Hawdon, 2008).

However, social trust remains a subject of ongoing debate.

First, the sources of social trust are highly diverse. It may originate at the individual level, reflect cultural characteristics, or develop through feedback loops between well-being, environment, experience, and beliefs (Kirby, 2025). Empirical studies often confirm the validity of the particular source of social trust they emphasize, which may indicate certain theoretical biases, or alternatively, the complexity, multidimensionality, and dynamic nature of social trust (Boda et al., 2018; Kwon, 2019).

At the same time, the persistence of certain aspects of social trust suggests that it functions as an exogenous factor linking culture and the economy. Social trust, especially its institutional dimension, is shaped through historical processes and reflects the long-term interaction of political and economic institutions (Fukuyama, 1995; Campbell, 2004; Eurofound, 2018).

In turn, Keele (2007) notes that while there is a cross-national correlation between interpersonal and institutional trust, interpersonal trust is considerably less volatile over time than trust in institutions. Nannestad et al. (2014) likewise argue that culture plays a more significant role than institutions in shaping social trust. This may indicate that different dimensions of social trust can have distinct origins.

Second, the problem of variability in the relationship between interpersonal and institutional trust over time and across countries may stem from neglecting the issue of context. The context in which economic agents demonstrate trust can play an important role in explaining why different configurations of interpersonal and institutional trust are observed. Boda, Medve-Bálint (2015) attribute this phenomenon to the dominance of cross-sectional empirical research. By contrast, accounting for changes in trust over time allows for a better understanding of the specific circumstances under which it was formed or fluctuated.

Another dimension of the context problem concerns how personal experience interacts with the cultural environment when extrapolated to institutional interactions. An example of the importance of context is found in studies examining the relationship between well-being and institutional trust. Kaasa, Parts (2009) point to the absence of a relationship between household well-being and trust in public institutions across 31 European countries. In other words, cultural determinants of institutional trust appear more convincing (Kaasa, Andriani, 2022).

Meanwhile, Catterberg, Moreno (2006) demonstrate that income levels generally have a positive effect on institutional trust, albeit with important caveats. In mature, affluent democracies, an inverse relationship is observed between income levels and institutional trust, whereas in poorer countries, rising incomes tend to strengthen such trust.

Third, trust in particular political institutions may not reflect the full range of issues encompassed by social trust in its structural integrity. Boda et al. (2018) highlight the prob-

lem of the politicization of trust in public institutions. Personal experience, perceptions of the outcomes of specific policies, crises, and related factors can all influence fluctuations in trust. Likewise, trust in a specific public institution may not necessarily reflect cultural attitudes but may instead relate more closely to questions of legitimacy (Jackson et al., 2011; Jackson et al., 2013).

Grosskopf (2008), in turn, emphasizes the importance of context: trust in government contains a clear component of political self-identification, whereas trust in judges relies more heavily on perceptions of fairness. A notable example is research on trust in central banks. The global financial crisis and the inflationary surge of 2021–2023 significantly undermined trust in monetary institutions across many countries (Ehrmann, 2024). Cultural factors were unlikely to play a major role in circumstances where trust was shaped primarily by individuals' perceptions of an institution's functional effectiveness based on their own experience.

Similarly, political identification (political partisanship) strongly shapes trust in independent regulators, and societal political fragmentation amplifies this effect (Binder et al., 2025; Kuang et al., 2025). On the other hand, political polarization may influence the intensity of engagement in political activity without necessarily eroding institutional trust, as demonstrated by Kuhn, Marquis (2025) in the case of Switzerland.

Confidence in the armed forces differs from confidence in political institutions because military organizations are frequently perceived as providers of security, continuity, and national identity rather than as actors competing within partisan politics.

This article empirically confirms the heterogeneity of countries in terms of the structure of social trust. Grouping countries based on levels of trust in others revealed a number of differences in the correlations among various elements of social trust. It was also found that confidence in the armed forces somewhat falls outside the correlational pattern typically observed for trust in public institutions.

Applying a cluster approach that incorporates all elements of social trust produced results different from those obtained through analytical grouping based solely on levels of trust in others. The composition of the clusters and the distribution of the corresponding variable values point to hidden relationships among the elements of social trust that may carry contextual or functional significance.

At the same time, controlling for the variable of trust in others demonstrates that an indirect relationship exists between confidence in the armed forces and trust in political institutions, one that is not readily visible in cluster analysis. This suggests that interpersonal and institutional trust may have distinct origins, while confidence in the armed forces may embody an anchoring of the need for order and protection that cannot be fulfilled under conditions of weak political institutions, a vulnerable democratic regime, or ineffective public policy.

Research hypotheses:

H_1: The structure of social trust is heterogeneous across countries rather than homogeneous.

H_2: Interpersonal trust and institutional trust exhibit different patterns of interaction across country groups.

H_3: Confidence in the armed forces constitutes a distinct dimension of institutional trust and displays weaker integration with other political institutions.

H_4: Country clusters based on the full set of trust indicators differ from classifications based solely on interpersonal trust.

3. METHODOLOGY

The study is based on data from the World Values Survey Wave 7 and covers 88 countries. The empirical component consists of several stages.

At the first stage, a correlation analysis was conducted to examine the relationships among the elements of social trust (Trust in Others (TIO), Confidence in the Justice System (CJS), Confidence in the Police (CPo), Confidence in the Civil Service (CCS), Confidence in the Armed Forces (CAF), Confidence in Political Parties (CPP), Confidence in Government (CG), and Confidence in Parliament (CPa)) for the entire sample.

The correlation analysis was grounded in the construction of a correlation matrix using Cheddock's gradations, defined as follows: 0.0–0.1 – very weak (light gray); 0.1–0.3 – weak (light blue); 0.3–0.5 – moderate (blue); 0.5–0.7 – considerable (blue-cyan); 0.7–0.9 – strong (blue); 0.9–1.0 – very strong (dark blue).

Subsequently, the sample of 88 countries was divided into three groups based on the variation in trust in others as the foundational dimension of social trust (Kirby, 2025). Countries were categorized into low-, medium-, and high-trust groups according to a formal criterion:

1. the first group – N (mean value) – 0.5σ (standard deviation);
2. the second group – > N – 0.5σ but < N + 0.5σ;
3. the third group – > N + 0.5σ.

For each group, a correlation analysis among the elements of social trust was also conducted and compared with the results of the correlation matrix across the groups and with the overall sample. Differences in the patterns of relationships would indicate whether the criterion of variation in trust in others is substantively significant.

At the third stage, a cluster analysis was conducted to refine the analytical picture of country groupings obtained from their classification based on the N ± 0.5σ criterion. An ANOVA test was also applied to assess the similarity of variances in the values of social trust elements across the identified clusters and to determine the statistical significance of the clustering. The cluster analysis revealed differences between the groups formed through clustering and those derived from the grouping based on the N ± 0.5σ criterion. The use of the mean ±0.5 standard deviation criterion follows exploratory classification approaches frequently applied in comparative social research to distinguish low-, medium-, and high-trust societies while preserving balanced group sizes. Alternative thresholds (±1σ and tercile classification) produced qualitatively similar results.

At the fourth stage, an approach was applied to measure the distance between confidence in the armed forces (CAF) and trust in others (TIO), as well as the distance between confidence in political institutions (the average of CPP, CG, and CPa) and trust in others. The relationship between these distances was tested using graphical regression across the full sample of countries.

The choice of this approach was driven by several theoretical considerations. Trust in others may not reflect confidence in political institutions in some countries (Kirby, 2025; Boda et al., 2018; Kaasa, Parts, 2008), while in others it may correlate depending on cultural characteristics (Fukuyama, 1995; Campbell, 2004; Keele, 2007; Nannestad et al., 2014). Confidence in the armed forces may represent a way of relying on authority and an institution of order and protection, whereas other law-enforcement institutions may be perceived through the lens of political partisanship and reflect the broader problem of the reverse relationship between social trust and institutional quality (Martinangeli et al., 2020; Acemoglu, Robinson, 2012; Ostrom, 2005).

Confidence in the armed forces is also an important factor of national self-identification, particularly when other political institutions are perceived by citizens as distorted due to political attitudes toward them, their functional inefficiency, or cultural distrust of hierarchies (Abouzzohour, Yousef, 2024). It may also reflect the need for protection in light of existing threats. Accordingly, the distance between CAF and TIO indicates the extent to which confidence in the armed forces prevails over interpersonal trust. Similarly, the distance between trust in political institutions or the legal system and TIO reflects the degree to which trust in formal authority exists in society given the prevailing level of interpersonal trust.

Thus, analyzing the relationship between these distances suggests that the context of national defense or identification with an authority of order may carry significant weight in situations where the correlation between institutional and interpersonal trust may be subject to cultural or individual distortions.

4. RESULTS

The elements of social trust (Trust in Others (TIO), Confidence in the Justice System (CJS), Confidence in the Police (CPo), Confidence in the Civil Service (CCS), Confidence in the Armed Forces (CAF), Confidence in Political Parties (CPP), Confidence in Government (CG), and Confidence in Parliament (CPa)) can exhibit different forms of relationships depending on the theoretical perspective adopted. To determine the basic nature of these relationships, a correlation matrix (Figure 1) was constructed using data from the World Values Survey Wave 7 covering 88 countries. The results indicate that, in the overall sample, certain stable patterns emerge in the linkage between interpersonal and institutional trust.

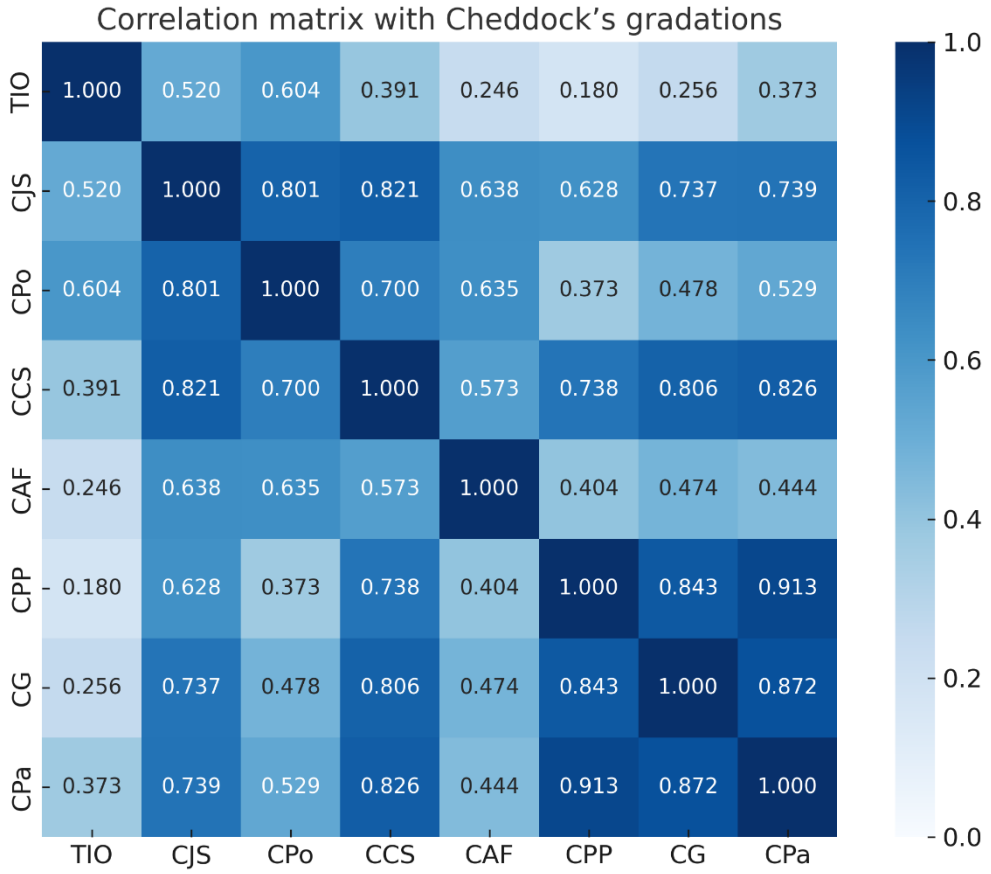
The correlation matrix reveals generally strong positive relationships among the levels of trust in different state institutions. Confidence in the judiciary system (CJS) shows particularly high correlations with confidence in the police (CPo, r = 0.801) and civil service (CCS, r = 0.821), indicating that perceptions of law enforcement and administrative fairness are closely interlinked. Similarly, confidence in political parties (CPP) is strongly associated with confidence in the government (CG, r = 0.843) and parliament (CPa, r = 0.913), suggesting that political institutions tend to be evaluated together by respondents. Moderate to strong correlations are also found between confidence in the army (CAF) and other institutions, though these coefficients are slightly weaker compared to those among the core political institutions. The lowest correlations involve trust in others (TIO), which remains only weakly to moderately related to institutional trust, indicating a certain independence between generalized social trust and institutional trust.

So, the preliminary results of empirical tests can be formulated next. Institutional trust is highly interdependent, particularly within clusters of law enforcement/justice and political institutions. Confidence in the army demonstrates a distinct, though somewhat weaker, relationship with other institutions. Generally, trust in others is only partially connected with institutional trust, highlighting a potential differentiation between social and institutional dimensions of trust.

In clustering sample countries, we applied three approaches. The first approach consisted in dividing the countries into groups according to the first variable, using the standard deviation as the criterion for differentiation. The second approach was based on hierarchical agglomerative clustering, which made it possible to trace the gradual merging of countries into larger groups depending on their similar profiles. The third approach is applied to the k-means method, which partitions the sample into a predetermined number

of clusters by minimizing within-cluster variance. The combination of these approaches ensured both the robustness of the results and the comparability of cluster structures.

Figure 1. Correlation matrix for social trust elements on entire group



Source: authors calculations based on WVS data

The results of grouping in accordance with N +/- 0,5σ method are in Table 1.

Table 1. Country grouping by the level of trust in others

Group (interval, number of countries, mean trust)	Countries
Group 1: Trust > 33.08 (n=20, mean=51.25)	Australia, Austria, Belarus, Canada, China, Denmark, Estonia, Finland, Germany, Iceland, Japan, Netherlands, New Zealand, Norway, Singapore, Spain, Sweden, Switzerland, United Kingdom, United States
Group 2: 15.68 ≤ Trust ≤ 33.08 (n=34, mean=23.23)	Andorra, Argentina, Armenia, Av, Azerbaijan, Bulgaria, Czechia, France, Guatemala, Hungary, Italy, Jordan, Kazakhstan, Latvia, Lithuania, Malaysia, Maldives, Mongolia, Montenegro, Morocco, Pakistan, Poland, Portugal, Puerto Rico, Russia, Serbia, Slovakia, Slovenia, South Korea, Taiwan, Tajikistan, Thailand, Ukraine, Vietnam
Group 3: Trust < 15.68 (n=34, mean=9.72)	Albania, Bangladesh, Bolivia, Bosnia and Herzegovina, Brazil, Chile, Colombia, Croatia, Cyprus, Ecuador, Egypt, Ethiopia, Georgia, Greece, Indonesia, Iran, Iraq, Kenya, Kyrgyzstan, Lebanon, Libya, Mexico, Myanmar, Nicaragua, Nigeria, North Macedonia, Peru, Philippines, Romania, Tunisia, Turkey, Uruguay, Venezuela, Zimbabwe

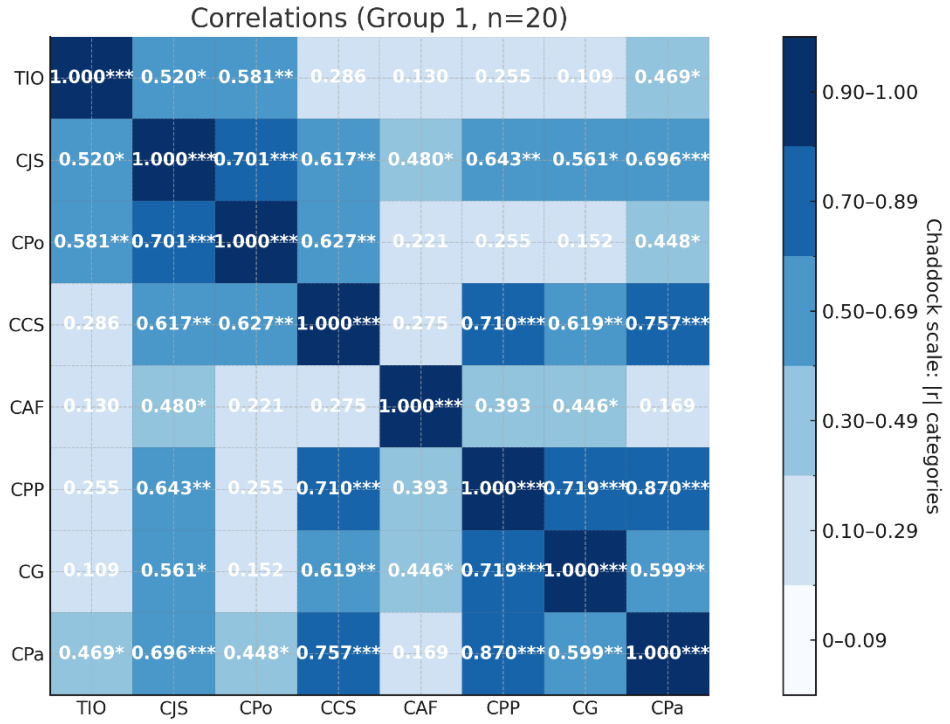
Source: authors calculations based on WVS data

The results of country grouping generally reflect research discussion on sources of trust. Generally, higher trust in others co-exist with high level of incomes. However, such pattern of relations is not absolute and deviations from it are not rare. In the same vein it is

clear that in the case of middle and low level of trust more contradictory forces may shape the picture of trust across the countries.

The next step is correlation analysis between elements of social trust across three countries groups represented in Table 1. The results are shown in Figures 2-4. Generally, the patterns of relations between elements of trust across the country's groups are close to the one that is on Figure 1. However, some noticeable moments take place.

Figure 2. Correlation matrix for social trust elements: the group of high trust

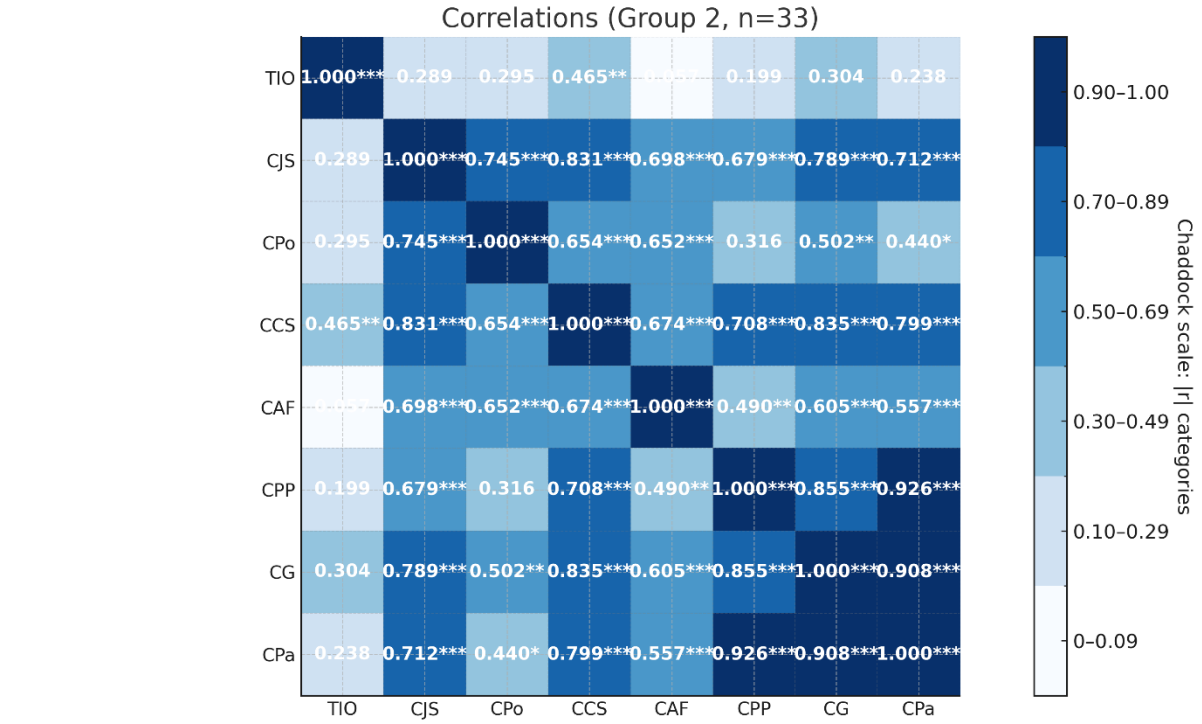


Significance: * p<0.05, ** p<0.01, *** p<0.001

Source: authors calculations based on WVS data.

The results suggest that for countries with high level of trust confidence in political institutions and personal trust are in the weakest relations compared to groups with middle and low level of trust. The correlations get higher levels between mentioned elements of social trust in second and third countries groups. This reflects the idea that level of income is not pre-defining force of institutional trust. Rather the higher level of personal trust in the high level of trust group, the weaker the correlation of TIO with confidence in political and justice institutions and vice versa. Also, it is clear that the strongest correlation between TIO and confidence in army forces takes place in the third group of countries, while in the second its weakest. In first group, confidence in army forces is in the weakest relations with other elements of social trust compere to other groups. Bearing in mind the composition of groups (Table 1), it is likely that level of income may be associated with the observed pattern between trust in others and confidence in army forces. The higher the income, the weaker the correlation. And the opposite is true for less wealthy countries with low level of trust. In such countries personal and institutional trust correlates more.

Figure 3. Correlation matrix for social trust elements: the group of middle level of trust



Significance: * p<0.05, ** p<0.01, *** p<0.001

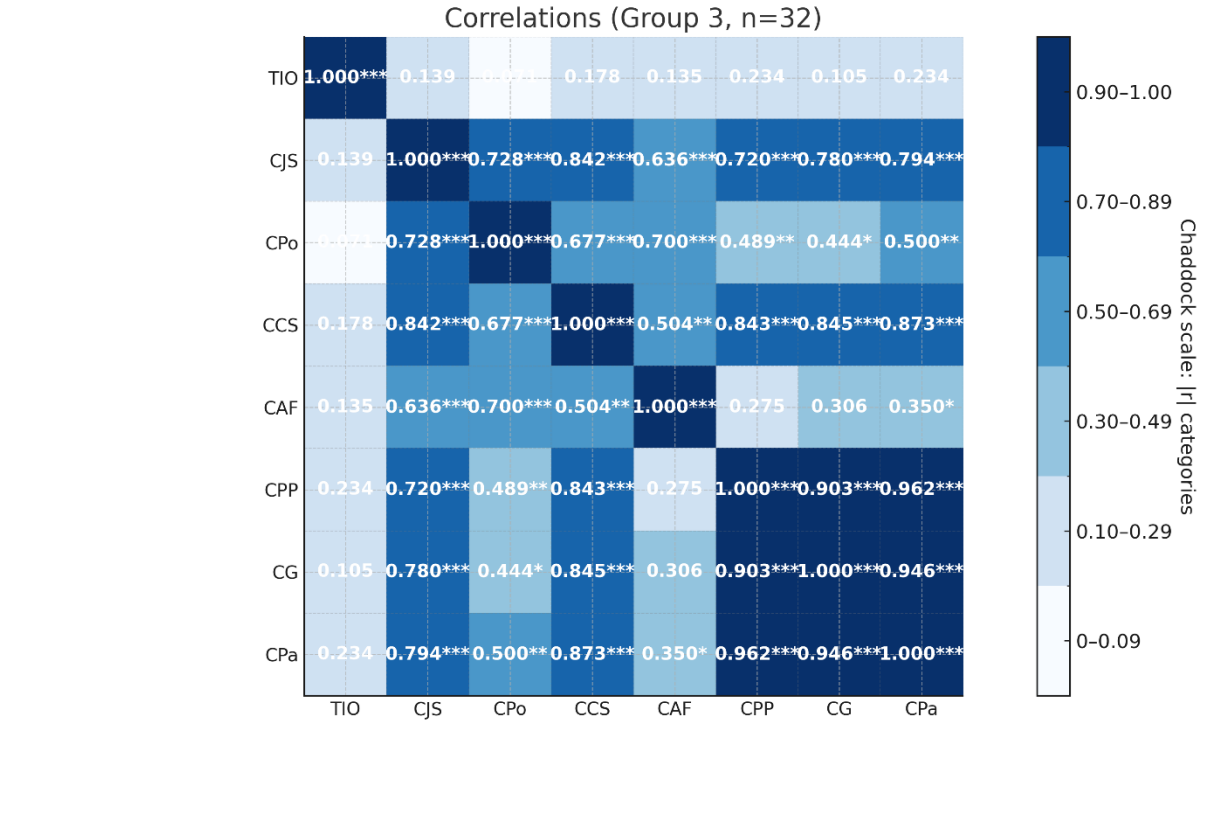
Source: authors calculations based on WVS data

The next step is the more formal cluster analysis of countries that is expected to reflect more comprehensive relations between elements of social trust. The results are in Figure 5.

The analysis of the dendrogram shows that at the distance level of 600 the sample splits into three clusters (Figure 5). This indicates the existence of three groups of objects, within which relative similarity is higher than between groups. This corresponds with intuition to split the countries by the level of trust (Table 1).

According to the results of hierarchical clustering (Ward's method, Euclidean distance), at the threshold distance level of 600 the sample divides into three clusters (Figure 5). Ukraine belongs to the first cluster together with the countries of the Balkans, the Caucasus, and parts of Latin America (Italy, Slovakia, North Macedonia, Georgia, Armenia, Lebanon, Tunisia, Romania, Serbia, Slovenia, Croatia, Poland, etc.). The other two clusters unite, respectively, a group of developed democracies (the United States, Canada, the countries of Northern and Western Europe, Japan, South Korea, Hong Kong, Singapore) and a group consisting mainly of South and Southeast Asian countries along with several post-Soviet Asian states. This suggests that the similarity of institutional trust profiles may prevail over geographical proximity.

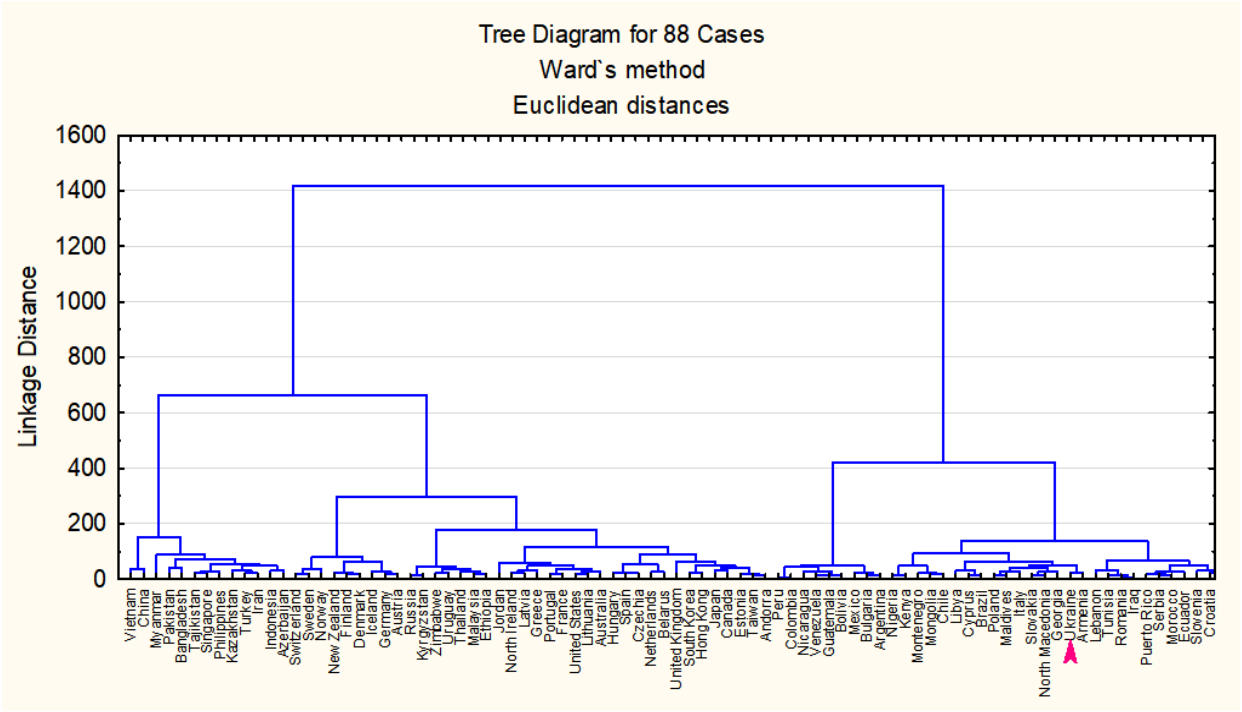
Figure 4. Correlation matrix for social trust elements: the group of low trust



Significance: * p<0.05, ** p<0.01, *** p<0.001

Source: authors calculations based on WVS data

Figure 5. The results of countries clustering by combination of elements of social trust



Source: authors calculations based on WVS data

We conducted a k-means cluster analysis based on the results of a hierarchical agglomerative cluster analysis and therefore specified the number of clusters as three. The results are shown in Table 2.

Table 2. The group's composition according to cluster analysis results

Cluster	Country (ISO Alpha-3)	Means of cluster							
		TIO	CJS	CPo	CCS	CAF	CPP	CG	CPa
1 (n=14)	AZE, BGD, CHN, IDN, IRN, KAZ, MMR, NOR, PAK, PHL, SGP, TJK, TUR, VNM	25.53	74.31	74.08	71.91	83.19	55.17	77.11	69.54
2 (n=38)	AND, AUS, AUT, BLR, CAN, DNK, EST, ETH, FIN, FRA, GEO, DEU, GRC, HKG, HUN, ISL, ITA, JPN, JOR, KGZ, LVA, LTU, MYS, NLD, NZL, GBR, PRT, RUS, KOR, ESP, SWE, CHE, TWN, THA, GBR, USA, URY, ZWE	33.95	60.23	72.15	52.10	68.80	20.86	42.72	34.52
3 (n=36)	ALB, ARG, ARM, BOL, BIH, BRA, BGR, CHL, COL, HRV, CYP, CZE, ECU, GTM, IRQ, KEN, LBN, LBY, MDV, MEX, MNG, MNE, MAR, NIC, NGA, MKD, PER, POL, PRI, ROU, SRB, SVK, SVN, TUN, UKR, VEN	14.31	31.24	43.13	28.81	54.13	13.01	23.39	17.70

Source: authors calculations based on WVS data

Table 3 demonstrates that the identified trust configurations are embedded in broader socioeconomic and institutional contexts. Cluster 2, dominated by advanced democracies, combines the highest levels of economic development, democratic quality, and institutional integrity with the lowest degree of state fragility. By contrast, Cluster 1 is characterized by moderate income levels and institutional quality but relatively low democratic performance, while simultaneously exhibiting the highest confidence in the armed forces. The additional evidence presented in Table 3 indicates that Cluster 1 countries are characterized by lower democratic quality and higher levels of state fragility than advanced democracies. This institutional environment may contribute to stronger reliance on hierarchical institutions and explain the relatively high confidence in the armed forces despite lower interpersonal trust. Cluster 3 displays lower levels of economic development and institutional quality together with higher state fragility. These findings suggest that the structure of social trust cannot be fully understood without considering broader characteristics of political and economic development.

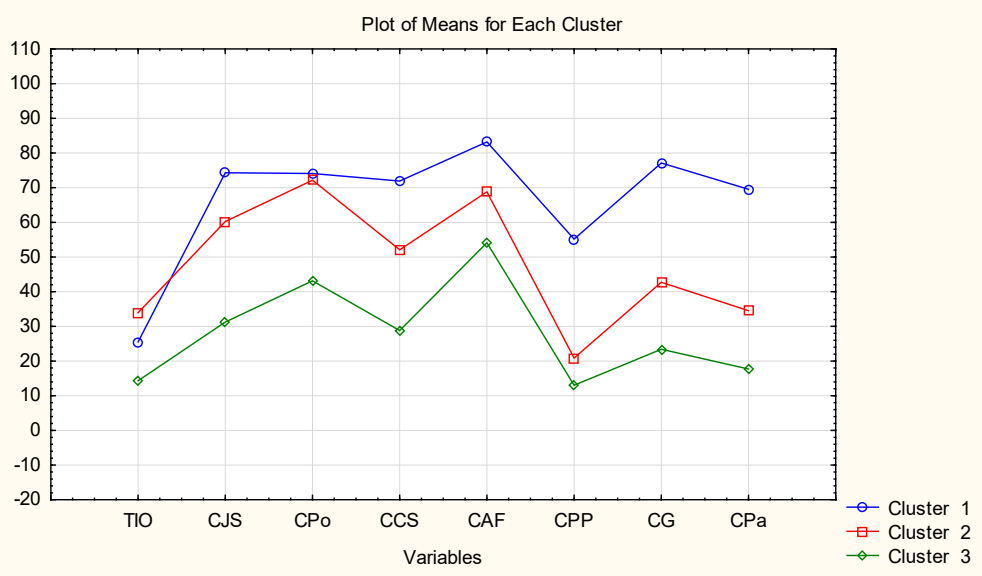
Table 3. Socioeconomic and institutional characteristics of identified trust clusters

Indicator	Cluster 1	Cluster 2	Cluster 3
GDP per capita, PPP (current international USD)	28,500	54,800	18,700
Democracy Index (0–10)	4.8	8.1	5.6
Corruption Perceptions Index (0–100)	39.2	71.8	42.5
Fragile States Index (0–120)	74.6	42.3	68.9

Source: authors' calculations based on World Values Survey Wave 7, IMF, Economist Intelligence Unit, Transparency International and Fund for Peace databases

Figure 6 demonstrates distribution of each variable's means across the obtained clusters. Table 3 demonstrates results of ANOVA analysis that confirms statistical significance of clustering. The ANOVA results indicate that all variables significantly differentiate between the three clusters ($p < 0.001$). High F-values for CG, CPa, CCS, and CPP suggest that these variables contribute most strongly to the separation of clusters, while TIO and CAF show relatively weaker, though still significant, discriminatory power. Overall, the analysis confirms that the identified clusters are statistically distinct in terms of the included variables.

Figure 6. Distribution of clusters' means



Source: authors calculations based on WVS data

As the data shows, country grouping by the criteria of TIO level (Table 1) and clustering by the criteria of k-means cluster analysis based on the results of a hierarchical agglomerate methods (Table 3) provide different results. In the first approximation this means that grouping criteria play a role and this opens the door for possible variation in analysis results. More formal cluster tests are based on all elements of social trust. Thus, it provides clustering on hidden relations between variables that are not visible using one criterion for grouping. As we may see from division of countries across clusters, relations between personal and institutional trust become more nuanced and more striking from theory viewpoint.

First of all, there is no strict co-existence between level of trust and level of income, as we can see from country composition of groups in Tables 1 & 4. Second, distribution of variables across the clusters shows more complicated picture of how personal and institutional trust interrelated. Cluster 1 (Table 4, Figure 6) agglomerates countries with lowest level of trust in others with high level of institutional trust and with highest level of confidence in the armed forces. This is a specific group of countries with less democratic political regime and very likely high attitude toward hierarchies and power distance. It also means that low levels of TIO may reflect cultural adaptation mechanisms associated with specific political environments. Cluster 2 is group of countries with moderate levels of trust in others as well as institutional trust. And it is a group of mostly developed democracies. Surprised, relatively low level of confidence in public policy institutions strongly corresponds with Catterberg, Moreno (2006) findings. Confidence in the armed forces here is on a similar level to confidence in policy that's meat that in perception of citizens the authorities with rights to bear arms are trusted in a similar way. And this is not the case

for Cluster 1 and Cluster 3. Cluster 3 is a group of mostly emerging market countries with lowest level of trust in others, lowest level of institutional trust, and level of confidence in the armed forces that outperform other public authorities.

Table 4. Results of ANOVA test of clusters' means

Variable	Analysis of variance					
	Between SS	df	Within SS	df	F	signif. p
TIO	7147.28	2	18881.23	85	16.0879	0.000001
CJS	24889.41	2	11424.28	85	92.5923	0.000000
CPo	18597.12	2	16197.31	85	48.7968	0.000000
CCS	21439.14	2	9448.01	85	96.4397	0.000000
CAF	9432.22	2	17727.23	85	22.6132	0.000000
CPP	18248.69	2	8279.39	85	93.6746	0.000000
CG	29484.92	2	12123.06	85	103.3657	0.000000
CPa	27201.40	2	10004.65	85	115.5523	0.000000

Source: authors calculations based on WVS data

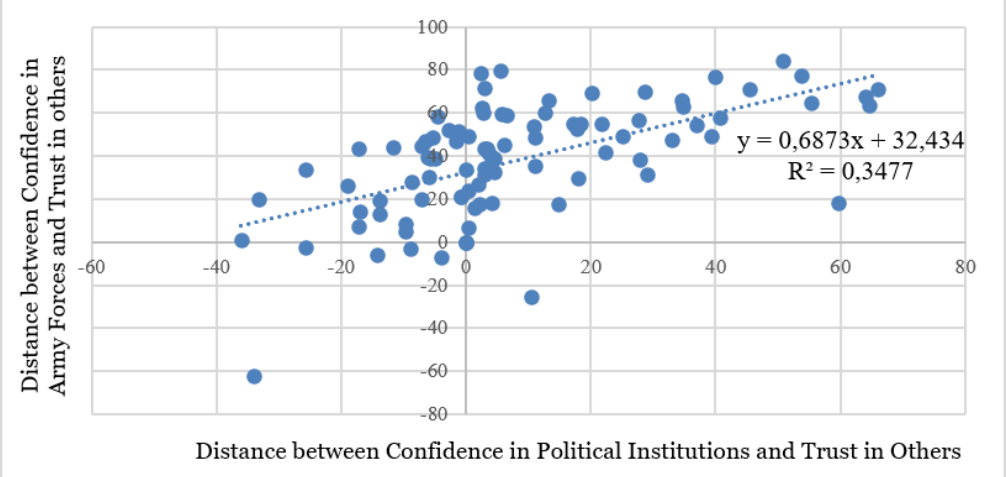
Cluster validity was additionally assessed using the silhouette coefficient and the Calinski-Harabasz criterion, both supporting the three-cluster solution.

The most interesting thing is that confidence in army forces outperform confidence in public institutions in all three clusters and substantially exceeds level of personal trust. However, it is very likely that in Cluster 1 & 3 these are the signs of perception of army forces as a national self-identification, or functional efficiency compere to other public institutions. While the confidence in the armed forces in Cluster 2 is closer to general perception of enforcement system, yet the lack of confidence in public policy institutions.

Having in mind this specific position of CAF across other elements of social trust the distance between it and TIO and distance between confidence in political intuitions / justice system and TIO shows the hidden relations between personal and institutional trust.

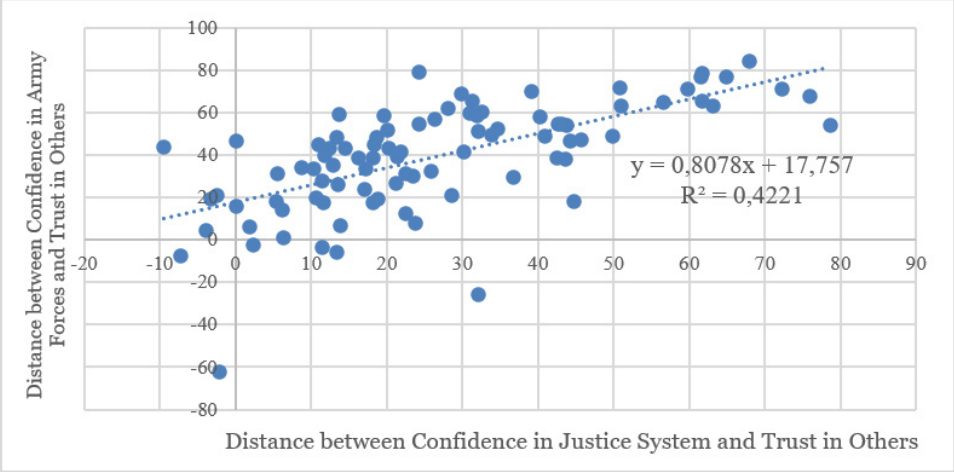
Figures 7-8 demonstrate that such distances are in opposite relations.

Figure 7. Distance between confidence in the armed forces and trust in others vs distance between confidence in political institutions and trust in others



Source: authors calculations based on WVS data

Figure 8. Distance between confidence in the armed forces and trust in others vs distance between confidence in justice system and trust in others



Source: authors calculations based on WVS data

Since both distance measures include TIO as a common component, the possibility of mathematical coupling cannot be entirely excluded. Therefore, the regression results should be interpreted as exploratory evidence of structural association rather than causal dependence.

How should the results presented in Figures 7–8 be interpreted?

First, they partly reflect the data shown in Figure 6. For the most part, the analyzed distances lie in the positive range, indicating that the sources of interpersonal and institutional trust may differ. To some extent, this corresponds with the previously identified phenomenon whereby trust in political institutions reflects both the political context and the cultural dimension (Boda et al., 2018).

In other words, trust in others may serve as a criterion for differentiating countries, as suggested in some studies (Keele, 2007), and may depend on cultural factors or levels of well-being. However, it is insufficient for explaining the more complex phenomenon of social trust and for conducting a comprehensive differentiation of countries (Kirby, 2025).

Second, after normalizing institutional trust measures relative to interpersonal trust, trust in the armed forces and in political institutions or the legal system appear much closer than suggested by the cluster analysis (Figure 6). This leads to a broader conclusion that trust in others is more strongly an embodiment of cultural and historical factors combined with elements of adaptation to the political regime.

Institutional trust, by contrast, reflects a complex combination of satisfaction with authorities, their legitimacy, and their effectiveness. This interpretation is broadly consistent with Catterberg, Moreno (2006), as well as with the view of institutional trust as a source of legitimacy (Jackson et al., 2011; Jackson et al., 2013).

Third, confidencein the armed forces plays a unique role, as it embodies an aspect of institutional trust that cannot be realized under conditions of weak institutions and, consequently, ineffective public policy. At the same time, it preserves elements of national self-identification and anchors the need for order and protection, particularly in contexts where the everyday functioning of democracy may be perceived as chaotic.

5. CONCLUSION

The relationship between interpersonal and institutional trust remains a subject of ongoing debate. This is largely due to the fact that cultural drivers of trust, embodied in trust in others, may become distorted within political processes and in manifestations

of legitimacy when institutional trust is concerned. The growing prevalence of military threats worldwide also raises the question of the role of trust in the armed forces within the broader structure of social trust.

This article employs analytical grouping, correlation, cluster, and regression methods, allowing several conclusions to be drawn. Social trust is a complex phenomenon, and hidden relationships often exist among its elements that are not always readily identifiable. Confidence in the armed forces correlates strongly with other elements of social trust across groups of countries classified by levels of trust in others. In groups dominated by lower-income countries, a more concentrated pattern of high correlation among elements of institutional trust is observed.

However, the cluster approach reveals a different grouping of countries in which the pattern of relationships between interpersonal and institutional trust takes distinct forms. When controlling for the variable of trust in others, trust in the armed forces and institutional trust begin to demonstrate an indirect relationship that was not detected in the cluster analysis. This leads to the conclusion that interpersonal and institutional trust may originate from different sources. **C**onfidence in armed forces may coexist with lower levels of institutional trust and potentially serve as an alternative source of legitimacy of institutional trust in the context of national self-identification and anchor the need for order and protection that cannot be fulfilled under conditions of weak political institutions.

The inclusion of macro-institutional indicators suggests that social trust heterogeneity is closely associated with broader development trajectories. Economic prosperity, democratic quality, corruption control, and state capacity appear to shape not only the level of trust but also its internal structure and distribution across institutional domains.

The study has several limitations. First, the analysis relies on cross-sectional data from a single WVS wave and therefore cannot capture temporal dynamics of trust. Second, explanatory variables such as GDP per capita, democratic quality, corruption perceptions, conflict exposure, or state capacity were not incorporated directly into the clustering procedure. Third, the results should be interpreted as exploratory rather than causal.

Acknowledgement

The authors acknowledge that this research was conducted within the framework of the Erasmus+ KA2 project SUSTED “Education for Sustainable Development: Synergy of Competences for the Recovery of Ukraine” (101178414-SUSTED). The project aims to strengthen institutional capacity, human capital development, and evidence-based policymaking in support of Ukraine’s post-war recovery and long-term sustainable development.

REFERENCES

Abouzzohour, Y., & Yousef, T. M. (2024). *The paradox of trust in the military in the Middle East and North Africa*. Middle East Council on Global Affairs. https://mecouncil.org/publication/the-paradox-of-trust-in-the-military-in-the-middle-east-and-north-africa/

Acemoglu, D., & Robinson, J. A. (2012), *Why nations fail: The origins of power, prosperity and poverty*. Crown Business, New York. https://coleurope.on.worldcat.org/oclc/813861619

Aghion, P., Algan, Y., Cahuc, P., & Shleifer, A. (2010). Regulations and distrust. *Quarterly Journal of Economics, 25,* 1015–1049. https://www.jstor.org/stable/27867505

Beugelsdijk, S. H., de Groot, L. F., & van Schaik, A.B. T.M. (2004). Trust and economic growth: a robustness analysis. *Oxford Economic Papers, 56,* 118–134. https://www.jstor.org/stable/3488916

Binder C., Couture C., & Smit A. (2025). Partisan Trust in the Federal Reserve. *NBER Working Papers, 33684,* 1-43. https://www.nber.org/papers/w33684

Bjornskov, Ch. (2012). How Does Social Trust Affect Economic Growth? *Southern Economic Journal, 78(4),* 1346-1368. https://www.jstor.org/stable/41638856

Bjornskov, Ch. (2022). Social trust and patterns of growth. *Southern Economic Journal, 89,* 216–237. https://www.jstor.org/stable/27190315

Boda, Z., Medgyesi, M., Fondeville, N., & Özdemir, E. (2018). *Societal change and trust in institutions*. Erufound. Publications Office of the European Union, Luxembourg. 66 p. Available at: https://assets.eurofound.europa.eu/f/279033/44a922f19b/ef18036en.pdf [Accessed 9 February 2026].

Boda, Z., & Medve-Bálint, G. (2015). How perceptions and personal contact matter: The individual-level determinants of trust in police in Hungary. *Policing and Society, 27(7),* 732–749. http://dx.doi.org/10.1080/10439463.2015.1053479

Campbell, W. R. (2004). The sources of institutional trust in East and West Germany: civic culture or economic performance? *German Politics, 13(3),* 401–418. https://doi.org/10.1080/0964400042000287437

Catterberg, G., & Moreno, A. (2006). The individual bases of political trust: Trends in new and established democracies. *International Journal of Public Opinion Research, 18(1),* 31–48. https://doi.org/10.1093/ijpor/edh081

Coase, R. H. (1960) The problem of social cost. *Journal of Law and Economics, 3,* 1–44. https://doi.org/10.1086/674872

Dincer, O., & Uslaner, E. M. (2010). Trust and growth. *Public Choice, 142,* 59–67. https://www.jstor.org/stable/2667866

Ehrmann M. (2024). Trust in Central Banks. *European Central Bank Working Paper, 3006*. https://doi.org/10.1111/joes.12703

Eurofound (2018). *Societal change and trust in institutions*. Publications Office of the European Union. https://assets.eurofound.europa.eu/f/279033/44a922f19b/ef18036en.pdf [Accessed 9 February 2026].

Fukuyama, F. (1995). *Trust: The social virtues and the creation of prosperity*. Free Press Paperbacks, New York. https://www.jstor.org/stable/20752121

Gorodnichenko, Y., & Roland, G. (2011) Which dimensions of culture matter for long-run growth? *American Economic Review, 101,* 492–498. https://www.jstor.org/stable/29783795

Grosskopf, A. (2008). Explaining the democratic trust conundrum: The sources of institutional trust in the reunited Germany. *International Social Science Review, 83(1/2),* 3–26. https://www.jstor.org/stable/41889924

Hawdon, J. (2008). Legitimacy, trust, social capital, and policing styles: A theoretical statement. *Police Quarterly, 11(2)*. https://doi.org/10.1177/1098611107311852

Hetherington, M. J. (1998). The political relevance of political trust. *American Political Science Review, 92(4),* 791. https://doi.org/10.2307/2586304

Hetherington, M. J. (2005). *Why trust matters: Declining political trust and the demise of American liberalism*. Princeton University Press, Princeton, NJ. https://doi.org/10.2307/j.ctv301fkq

Hosking, G. (2017). *Trust in the trustworthy: a key to social cohesion?* H. Prange-Gstöhl (Ed.), Trust at risk? Implications for EU policies and institutions, 8–16. http://dx.doi.org/10.18235/0003911

Jackson, J., Kuha, J., Hough, M. Bradford, B., Hohl, K., & Gerber, M. (2013). *Trust and legitimacy across Europe: A FIDUCIA report on comparative public attitudes towards legal authority*. FIDUCIA Project. https://researchonline.lse.ac.uk/id/eprint/50650/1/Jackson_Trust_legitimacy_Europe_2013.pdf

Jackson, J., Pooler, T., Hohl, K., Kuha, J., Bradford, B., & Hough, M. (2011). *Trust in justice: Topline results from round 5 of the European Social Survey*. ESS Topline Results Series. European Commission. https://researchonline.lse.ac.uk/id/eprint/41680/1/Trust%20in%20justice%28lsero%29.pdf

Kaasa, A., & Andriani, L. (2022). Determinants of institutional trust: The role of cultural context. *Journal of Institutional Economics, 18(1),* 45–65. https://doi.org/10.1017/S1744137421000199

Kaasa, A., & Parts, E. (2008). Individual-level determinants of social capital in Europe: Differences between country groups. *Acta Sociologica, 51(2),* 145–168. https://www.jstor.org/stable/20460044

Kahan, D. M. (2003). The logic of reciprocity: Trust, collective action, and law. *Michigan Law Review, 102(1),* 71–103. https://doi.org/10.2307/3595400

Keele, L. (2007). Social capital and the dynamics of trust in government. *American Journal of Political Science, 51(2),* 241–254.

Kirby, N. (2025). What is social trust? *Critical Review of International Social and Political Philosophy,* 1–19. https://doi.org/10.1080/13698230.2025.2528380

Kuang, P., Weber, M., & Xie, S. (2025). Central bank communication with the polarized public. *Working Paper, 33524,* 1–43. https://www.nber.org/papers/w33524

Kuhn U., & Marquis L. (2025). Does ideological polarization promote political engagement and trust? Evidence from Swiss panel data, 1999–2023. *European Journal of Political Research,* 1–25. https://doi.org/10.1017/S1475676525100248

Kwon, O. Y. (2019). Social trust: Its concepts, determinants, roles, and raising ways. *Business,* 19–49. https://doi.org/10.4337/9781784719609.00008

Levi, M., Sacks, A., & Tyler, T. (2009). Conceptualizing legitimacy, measuring legitimating beliefs. *American Behavioral Scientist, 53(3),* 354–375. https://doi.org/10.1177/0002764209338797

Levi, M., & Stoker, L. (2000). Political trust and trustworthiness. *Annual Review of Political Science, 3(1),* 475–507. https://doi.org/10.1146/annurev.polisci.3.1.475

Martinangeli, A., Povitkina, M., Jagers, S., & Rothstei, B. (2020). Institutional Quality Causes Social Trust: Evidence from Survey and Experimental Data on Trusting Under the Shadow of Doubt. *CeCAR Working Paper Series, 10,* 1-42. The Centre for Collective Action Research. https://ideas.repec.org/p/mpi/wpaper/tax-mpg-rps-2020-04.html

Nannestad, P., Svendsen, G. T., Dinesen, P. T., & Sønderskov, K. M. (2014). Do institutions or culture determine the level of social trust? the natural experiment of migration from non-western to western countries. *Journal of Ethnic and Migration Studies, 40(4),* 544–565. https://doi.org/10.1080/1369183X.2013.830499

Newton, K., & Zmerli, S. (2011). Three forms of trust and their association. *European Political Science Review, 3(2),* 169–200. https://doi.org/10.1017/S1755773910000330

Ostrom, E. (2005). *Understanding institutional diversity*. Prinston University Press, Prinston, New Jersey. https://doi.org/10.2307/j.ctt7s7wm

Peiró-Palomino, J., Gianmoena, L., Picazo-Tadeo, A. J., & Rios, V. (2024). Social trust and the advanced aspects of social progress: Evidence for the European regions. *European Journal of Political Economy, 83*, 102547. https://doi.org/10.1016/j.ejpoleco.2024.102547

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

LABOR MARKET CHALLENGES IN BUSINESS TRANSFORMATION BY AI: EMPIRICAL EXPERIENCE OF SELECTED EUROPEAN COUNTRIES

Snežana Radukić[1*], Zorana Stanković[2], Žarko Popović[1]

Received 11.03.2026. | Send to review 16.03.2026. | Accepted 25.08.2026.

Original Article

CC BY NC ND

[1] Faculty of Economics University of Nis, Serbia

[2] Faculty of Mechanical Engineering University of Nis, Serbia

***Corresponding Author:**
Snežana Radukić

Email:
snezana.radukic@eknfak.ni.ac.rs

JEL Classification:
E24, J44, O33

Doi: 10.61432/CPNE0401061r

UDK: 331.5.024.52(4-672EU):658.6

ABSTRACT

Technological transformation, changes in the structure of workplaces, economic and environmental pressures shape business models and the behavior of participants in the labor market in all European countries. This paper explores the impact of artificial intelligence (AI) on the labor market in Europe, which can still be assessed as uncertain. Focusing on the transformation of business models, the paper identifies key challenges: job polarization, the growing digital skills gap and the need for urgent reskilling initiatives. Analyzing empirical data, it explores how AI is redefining labor demand by pushing certain workers out of the market and creating a need for workers with specific technological competencies. The results reveal considerable disparities in AI adoption across European countries, with Scandinavian economies demonstrating significantly higher levels of enterprise AI usage than Southeastern and Eastern European countries. The findings further indicate that skills shortages, demographic pressures, and limited technological readiness represent major barriers to successful business transformation. Scenario analysis suggests that the future resilience and competitiveness of European labor markets will depend on technological sovereignty, continuous workforce adaptation, and effective public policies supporting innovation and social inclusion. Sectoral evidence confirms that the effects of AI differ substantially across industries, requiring tailored approaches to workforce development and digital transformation. The results indicate the necessity of synergy between business strategies and public policies in order to mitigate structural disruptions in the labor market and preserve the well-being, safety and protection of those who suffer the negative effects of artificial intelligence on wages and employment.

Keywords: *artificial intelligence adoption, labor market structure, technological sovereignty, circularity, adaptability and reskilling*

1. INTRODUCTION

According to the World Economic Forum (2025), technological progress, led by the spread of digital access, artificial intelligence and automation, is the most powerful driver of change in the global labor market until 2030. These trends will lead to the opening of about 170 million new technology jobs such as experts in artificial intelligence, big data analysis and software, but also to the closing of about 92 million stable administrative and clerical positions. Rapid change also brings high volatility of skills, with analytical

thinking, technological literacy and security becoming the fastest growing and most in-demand competencies. In addition to technology, economic and environmental pressures such as rising costs of living and environmental protection are shaping modern business models and polarizing the labor market by forcing companies to develop resilience and agility, while valuing flexibility and creative thinking. Demographic differences, the aging of the population in developed countries and the growth of the working population in developing countries are further transforming the labor market (Nguyen et al., 2026). Since there is a gap between required and offered skills, mass additional training and reskilling of employees has become the norm. In this regard, companies are increasingly focusing on preserving the welfare of workers and setting wages in line with productivity growth.

Radukic et al. (2019) determine that countries with higher efficiency in the goods market achieve more favorable indicators in the labor market, indicating that competitiveness is key to technological transformation. The findings highlight significant regional differences and the problem of brain drain, which is a primary challenge for adapting the workforce in the context of the introduction of artificial intelligence.

The impact of the business transformation caused by the development of artificial intelligence on changes in labor markets in Europe is huge and covers areas from education to competition and innovation and even inequality (Agrawal et al., 2026). European public policies must promote the adaptation of the educational system to artificial intelligence, to manage the costs arising from the possible disappearance of jobs through active employment policies, to provide infrastructure that supports the development of artificial intelligence, to develop a regulatory framework that provides legal certainty and protects those workers who suffer the negative effects of artificial intelligence on wages and employment.

While the literature review synthesizes existing evidence on the relationship between artificial intelligence and labor market transformation, the original contribution of this study lies in its comparative empirical analysis of selected European countries, identifying regional disparities in AI adoption, sector-specific patterns of business transformation, and policy implications for workforce adaptation and digital skills development. The cumulative impact of artificial intelligence on the labor market will depend on a number of factors, among which can be distinguished: the relationship between the jobs that artificial intelligence complements and those that are replaced, productivity increases, income levels, increased demand for goods and services that will require workers and new occupations that arise as a result of artificial intelligence, either directly or due to the emergence of new products, services or business models (Hunady et al., 2025). Therefore, the paper will examine the hypotheses:

- In countries with higher levels of economic development and employment, there are greater possibilities of adopting AI technology.
- AI will significantly affect the transformation of business and the labor market.

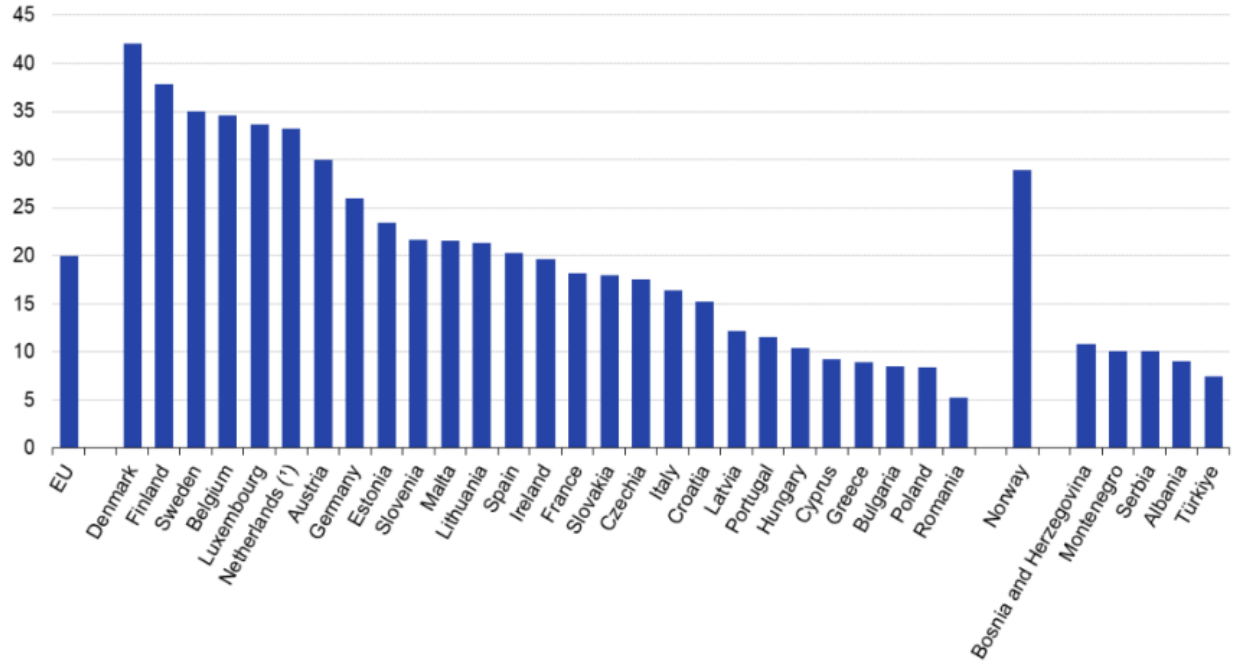
The paper is organized as follows. Section 1 presents theoretical background in favor of labor market structure and generative artificial intelligence. Section 2 explains labor market scenarios for the next decade. Section 3 deals with the research results and discussion. Last Section concludes the paper with implications derived from the findings.

2. LABOR MARKET STRUCTURE AND GENERATIVE ARTIFICIAL INTELLIGENCE

The current state of the OECD labor market provides a key empirical basis for understanding the conditions under which business transformation takes place. Record high rates of employment (72.1% in the first quarter of 2025) and labor force participation

(76.6%), with historically low unemployment at 4.9%, show that businesses in Europe and the rest of the OECD are driving the AI transformation in an extremely tight labor market. However, early signs of a slowdown and a decline in employment growth (from 0.20 to 0.12 percentage points) indicate that macroeconomic pressures, geopolitical uncertainties and announced tariffs may limit the resources companies have available to invest in advanced technologies and retraining. Structural changes in worker preferences and wage dynamics further shape the space for implementing AI solutions in European countries. AI can serve as a tool to optimize processes where specific personnel are still lacking. At the same time, the stability of real wage growth (an average of 2.5% in 33 out of 37 countries) and the growth of unit labor costs in relation to profits create a strong economic incentive for companies to raise productivity through automation and AI transformation. The flexibility workers demand, reflected in the rise of voluntary part-time work, also coincides with the need for digitally transformed workplaces that support new work models (OECD, 2025).

Figure 1. Percentage of enterprises in Europe using AI technologies in 2025



Source: Eurostat

Based on the Figure 1, the enterprises in Scandinavian countries are leading in the use of AI technologies (Denmark 42.03%, Finland 37.82%, Sweden 35.04%, Norway 28.89%). However, in countries such as Cyprus, Greece, Bulgaria, Poland and Romania, less than 10% of enterprises use AI technologies. In non-EU countries, such as Bosnia and Herzegovina, Montenegro, Serbia, Albania and Turkey, at most about 10% of enterprises use these technologies.

The latest studies confirm that changes in the labor market are conditioned by the adoption of artificial intelligence technologies in large companies in Europe. Based on panel data econometrics and supervised machine learning techniques, it was determined how public health expenditures, credit access, export activity, inflation, capital formation, openness to trade, and labor market structure affect the intensity with which companies adopt at least one artificial intelligence technology. The adoption of AI tools has been shown to be associated with higher GDP per capita, health care spending, inflation and openness to trade, but lower levels of credit, exports and capital formation. Labor markets with high unemployment are characterized by reduced adoption of AI. Cluster analysis identified

groups of European Union member states with a similar level of AI adoption that are most often accompanied by higher economic and institutional development. Namely, the spread of artificial intelligence is shaped by technological readiness and opportunities for investment, but also by macroeconomic conditions and fair labor institutions. Targeted public policies can accelerate the equitable adoption of AI technologies within the European labor market (Drago et al., 2025).

Research by Borissov & Hristozov (2024) indicates that the application of artificial intelligence, primarily through software solutions for automation, will lead to a transformation of the structure of jobs in Europe and an increase in productivity between 11% and 37% by 2035. Although focused on the public sector, the paper highlights key challenges for the labor market in the context of business transformation, which include the necessity of process optimization and rapid adaptation of the workforce to new technological demands.

However, the impact of artificial intelligence on the labor market can still be assessed as uncertain. On the one hand, the overall effect on existing occupations must be considered, which will depend, among other things, on the degree of overlap between the possibilities of artificial intelligence applications and the tasks performed by the worker, as well as the degree of workplace protection due to technical, legal or ethical reasons. In this regard, three types of occupations can be distinguished (CaixaBank Research, 2024):

a) High exposure to AI and high workplace protection. The technical potential of artificial intelligence is high, but the degree of workplace protection is also high. In these professions, artificial intelligence can improve the skills of workers (doctors, lawyers).
b) High exposure to AI and low workplace protection. The technical potential of artificial intelligence is high and the level of workplace protection is low. In these jobs, artificial intelligence could improve the skills of workers and replace them (call center operators).
c) Low exposure to AI and low technical potential of artificial intelligence. These occupations would not be greatly affected by the development of artificial intelligence (artists).

Generative artificial intelligence is one of the most revolutionary technologies of the modern age. It creates, imitates, and enhances content of all kinds, making it a general-purpose technology with the potential for business, economic, and ultimately social transformation. Generative AI impacts productivity as it accumulates business value and shapes the workforce (McKinsey & Company, 2023).

Empirical studies, which mostly have a microeconomic character and refer to certain occupations, show that artificial intelligence has a very high potential to increase the productivity of workers. For example, in a controlled experiment, it was found that the time spent on a task involving writing text was reduced by about 40% for workers who used ChatGPT (Noy & Zhang, 2023). It was also estimated that contact center productivity, as measured by the number of issues resolved per hour, increased by 14% due to the impact of artificial intelligence on less experienced workers, although the impact was not significant for more experienced workers. One conclusion that emerges from these studies is that AI improves the productivity of workers who start out with lower productivity levels because it accelerates their skills and allows them to overcome the learning curve more quickly (Brynjolfsson & Raymond, 2025).

A big challenge for European countries is to exploit the full potential of AI. The transformative capacity of generative artificial intelligence stems from its multi-purpose nature and impact on different sectors and activities. It represents the basis for continuous growth

and development of other technologies and processes. Moreover, its specificity is reflected in its great accessibility and adaptability because its use does not require much knowledge, and the infrastructure it needs already exists. So, while in Europe before ChatGPT only 10% of companies used artificial intelligence, this percentage is expected to increase dramatically in the coming years (the goal is to reach 75% by 2030, according to the European Commission, n.d.). This implies that the impact of artificial intelligence on productivity could materialize in a much shorter time frame, that is, within a few years, not decades.

It is difficult to predict precisely what the effect of artificial intelligence on employment in a particular occupation might be. It is estimated that in occupations with high exposure to artificial intelligence and high protection, an increase in worker productivity would reduce the number of employees needed for a certain level of production. However, if demand for the goods or services produced by these types of workers increases sufficiently, then the number of employees in these categories may increase (the costs of these goods and services would decrease due to increased productivity).

Digitization and new technologies are expected to bring only a slight acceleration of productivity, while explosive growth is unlikely. The net effect of digitization on employment is likely to be negative, but it is uncertain how much this will be offset by greater availability and the creation of new types of goods and services. Employment itself will depend on the speed of adaptation of the educational system to technological changes and the needs of the labor market, as well as opportunities for professional education and retraining, while the additional reduction of working hours represents an important reserve for mitigating the decline in employment and increasing the well-being of citizens. In the long run, the slowdown and transition to negative world population growth will lead to a reduction in the labor force, so full employment will be achieved even with a reduction in the number of jobs (Arsić, 2020).

3. LABOUR MARKET SCENARIOS FOR THE NEXT DECADE

Figure 2 shows that digitalization is expected to reshape the structure of employment across European Union member states over the next decade. According to Teigland & Wiberg (2025), there are four scenarios for the labor market in EU in 2035:

- Scenario 1: *Race to the Bottom: China in EU's Driver's Seat*,
- Scenario 2: *The Wild West: EU in Total Disarray,*
- Scenario 3. *Circularity: The EU as a Sustainable, Resilient Island*,
- Scenario 4. *A Transformed World: The Sky Is the Limit*.

In the context of analyzing the impact of artificial intelligence on business transformation, the presented scenario matrix clearly illustrates that labor market challenges in Europe directly depend on the intersection of political integration and the direction of technological development. The most favorable conditions for workforce adaptation are achieved in Scenario 4 ("A Transformed World"), where high political will and a focus on technology for exploration enable a synergy between innovation and worker retraining. Conversely, Scenario 1 ("Race to the Bottom") and Scenario 2 ("The Wild West"), which rely on technology solely for exploitation, pose the greatest risks to the workforce. Within these frameworks, a lack of coordinated policy or a loss of technological sovereignty to global competitors, such as China, could lead to mass technological unemployment, a widening digital divide, and structural disarray in the European labor market.

Figure 2. Four alterative futures for the EU in 2035

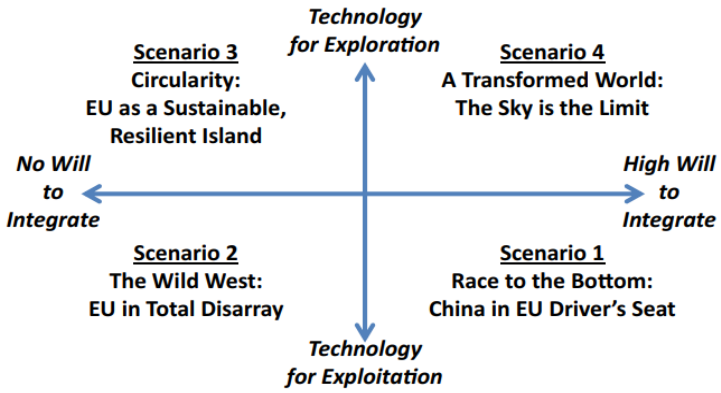


Fig. 10.1 The year 2035: Four alternative futures for the EU

Source: Teigland & Wiberg, 2025

Within the scenario "Race to the bottom: China in EU Driver's Seat", projected for the labor market of the European Union until 2035, global efficiency becomes primarily dictated by the synergy of digital technologies and quantum computers, whereby Chinese and American technology corporations assume an absolute leadership position and external coordination of European labor flows. This asymmetric influence of external technology giants results in a deep polarization of jobs and the generation of dramatically different work profiles. Namely, while highly skilled technological and AI jobs are concentrated in the north of Europe in the sectors of mining, advanced manufacturing and autonomous vehicles, the geographical areas of central and southern Europe are reserved for high-tech, but primarily precision agriculture; at the same time, the entire continent is being flooded with low-skilled service jobs in the local, labor-intensive health and care sectors. This profound structural divergence devalues internal cohesion, reducing its labor market to a fragmented platform subordinated to the profit optimization of extraterrestrial technological monopolists.

While the scenario "Race to the bottom: China in the EU Driver's Seat" foresees the complete technological and economic dominance of China, which becomes the global leader in AI standards and protection. This scenario is characterized by a decline in EU competitiveness, dependence on Chinese supply chains and the deployment of mass surveillance technology. Europe is losing technological sovereignty, but retains a semblance of economic functionality under the dictates of multinational corporations. The scenario "The Wild West: EU in Total Disarray" takes a step further into the future. While the first scenario is characterized by rigidly coordinated polarization under the control of foreign capital, the second scenario foresees the economic regression of the European Union due to protectionism, trade wars and the collapse of the WTO, leading to deep stagflation, mass bankruptcies and extreme poverty. In the face of cybercrime and destruction of infrastructure, the EU abandons digitization and green projects, redirecting resources to the defense industry

In the conditions of globalization and general instability, digital technology in "The Wild West" scenario loses its primary role as a generator of economic growth and becomes exclusively an instrument of physical and online security. The labor market in such an environment is experiencing a complete collapse, fueled by a drastic economic decline and the dominant expansion of the gray economy, which completely replaces legal flows. The employment structure is losing its middle layer and polarizing into extreme categories: high-tech jobs are becoming rare, located exclusively within the dedicated industry and national defense sectors in small and medium-sized enterprises. On the other hand, the vast majority of the working-age population is permanently relegated to the zone of tem-

porary unstable jobs, dependent on low-skilled daily jobs on the black market, without any legal and social protection.

Against visions of technological dependence, the third scenario of "Circularity: EU as a Sustainable, Resilient Island" projects a radically different transformation in which the European Union successfully establishes technological sovereignty and ecological sustainability. Digital technology is no longer an instrument of external exploitation or a tool for crisis management, but becomes the primary driver of economic development and closed cycles of production (circularity). Through a significantly strengthened common industrial policy, the EU manages to generate stable, high-tech jobs evenly distributed across all economic sectors. The key pillar of this transformation is an innovative ecosystem driven by advanced artificial intelligence, which radically changes the dynamics of the labor market. Instead of polarization, the workforce is characterized by high adaptability, given that individuals, with the systemic support of generative artificial intelligence, go through continuous processes of additional training and reskilling and reskilling. In this way, economic growth in Europe is based on internal innovation, social security and human-centered technological development.

The fourth scenario "A transformed world: the sky is the limit" projects a radically redefined global reality because the synergy of digital technology and comprehensive quantization optimizes the existing system and creates a completely new structure of the labor market. Here, the European Union occupies an absolute leadership position at the global level, positioning itself as a leader whose focus is on long-term sustainability. An extreme technological leap and automation lead to a transformation of the concept of work and working time. Namely, the labor market in high-tech sectors is moving to a three-day work week, while, along with the dramatic freeing of citizens' free time, a massive and highly developed leisure industry is being generated. Work loses its traditional role as a mere means of survival and is transformed into a sphere of personal development and innovation, which successfully realizes a post-scarcity welfare society under the auspices of European technological sovereignty.

The comparative analysis of the four presented scenarios of the development of the European labor market until 2035, from the loss of sovereignty to the sustainable closure of the economy, up to the radical utopian transformation, gives clear and urgent signals to the creators of public policies. These scenarios indicate that the future of the labor market will not be a passive result of technological development, but will directly depend on the strategic decisions made today. In this regard, the key implications for the creators of economic and regulatory policies can be systematized through three fundamental pillars:

- The imperative of technological sovereignty suggests that continuous investment in quantum computing and artificial intelligence infrastructure is necessary because this is the only way to reduce dependence on American and Chinese technological monopolies.
- The reform of educational systems and the concept of lifelong learning require the creation of an institutional framework for mass retraining of workers, where generative AI must not be treated as a threat that replaces people, but as an inclusive tool that improves human cognitive abilities and facilitates learning.
- Proactive regulation of the labor market and social protection in order to prevent the breakdown of social cohesion and the transition of the working-age population to the gray economy. Conceptualizing more flexible working hours and a simplified social security system must accompany the automation of traditional occupations.

Ultimately, the above scenarios suggest that passivity leads to fragmentation, while only proactive, environmentally aware and technologically sovereign policies can create stable, fair and high-tech labor markets.

4. METHODOLOGY AND DATA

This study adopts a quantitative descriptive-comparative research design based on the analysis of secondary data to examine the impact of artificial intelligence and digital transformation on business processes and labor market dynamics in Europe. The empirical analysis relies on data published in the World Economic Forum's Future of Jobs Report 2025, which provides harmonized survey-based information collected from organizations across Europe and other world regions. This source was selected because it offers comprehensive, internationally comparable, and standardized indicators on technological adoption, labor market trends, skills development, organizational transformation, and sectoral dynamics, ensuring methodological consistency and a high level of reliability in data interpretation.

The secondary data were systematically selected according to their relevance to the research objectives. The analysis focuses on four key dimensions: (a) macroeconomic and technological trends driving business transformation, (b) the projected evolution of workforce skills by 2030, (d) organizational barriers to business transformation, and (c) sectoral differences across 22 European industries. The analytical procedure was conducted in several stages. First, a comparative analysis of European and global indicators was performed to identify regional specificities in labor market restructuring, AI adoption, technological transformation, and demographic pressures. Second, a temporal comparison of core workforce skills between 2025 and the projected requirements for 2030 was carried out to examine the transition from predominantly cognitive and interpersonal competencies toward hybrid profiles combining advanced digital and technological capabilities. Finally, a sector-level comparative analysis was undertaken to identify differences in AI exposure, labor-market churn, skill disruption, and organizational priorities across European industries, highlighting sector-specific patterns and notable anomalies.

The empirical findings were interpreted using descriptive statistical analysis supported by the existing theoretical and empirical literature on artificial intelligence, digitalization, and labor market transformation. This approach enabled a comprehensive assessment of the relationships between technological progress, workforce restructuring, and future skill requirements while providing a robust basis for discussing the implications of AI-driven business transformation for the European economy.

The study is subject to several methodological limitations inherent to the use of secondary data. The analyzed indicators are based on organizational survey responses and therefore reflect managerial perceptions and strategic expectations rather than direct measurements of actual labor market outcomes. In addition, the projected skill requirements for 2030 represent forecast-based estimates that may be influenced by unforeseen macroeconomic developments, regulatory changes, or disruptive technological breakthroughs. Nevertheless, the standardized and internationally comparable nature of the dataset provides a solid empirical foundation for analyzing current trends and assessing the future direction of business and labor market transformation in Europe.

5. RESEARCH RESULTS AND DISCUSSION

Table 1 shows comparative data for Europe and the global level on the transformation of business and the labor market, where it is clear that digitization and artificial intelligence are the primary drivers of change. As many as 90% of European and 88% of global organizations are already implementing AI programs, while the vast majority recognize technologies for data processing and automation through robots as key factors for future development. This mass technological integration directly causes great dynamics in the labor market, so in the next five years structural change is expected in about a fifth of jobs

(21% in Europe, 22% globally), with disruption and change of more than a third of the basic work skills of employees.

Table 1. Labour market trend outlook, macrotrends and technological trends in business transformation

Trend outlook	Europe	Global
Labour-market churn (Five-year structural labour-market churn)	21%	22%
Skill disruption (Shares of core skills which will change)	36%	39%
Organizations with DEI priorities (Share of organizations with Diversity, Equity, and Inclusion priorities)	84%	83%
AI exposure (Share of organizations running AI programmes)	90%	88%
Macrotrends driving business transformation (Share of organizations surveyed that identified this trend as likely to drive transformation in their organization)		
Broadening digital access	57%	60%
Rising cost of living, higher prices or inflation	51%	50%
Ageing and declining working-age populations	49%	40%
Increased focus on labour and social issues	47%	46%
Slower economic growth	37%	42%
Growing working-age populations	27%	24%
Stricter anti-trust and competition regulations	19%	17%
Increased government subsidies and industrial policy	16%	21%
Technology trends driving business transformation (Share of organizations surveyed that identified the technology as likely to drive transformation in their organization)		
AI and information processing technologies (big data, Virtual Reality…)	87%	86%
Robots and autonomous systems	62%	58%
New materials and composites	30%	30%
Semiconductors and computing technologies	17%	20%
Sensing, laser and optical technologies	15%	18%
Quantum and encryption	9%	12%
Biotechnology and gene technologies	9%	11%
Satellites and space technologies	5%	9%

Source: World Economic Forum. (2024). *The future of jobs report 2025*. World Economic Forum, pp. 226

On the macroeconomic side, the data points to serious pressures facing companies, with the spread of digital access and the rising cost of living due to inflation standing out. However, the key difference between Europe and the rest of the world lies in demographics, with an aging and shrinking working age population affecting as many as 49% of European businesses compared to 40% globally. Due to this labor shortage, European companies rely significantly more on automation and robots (62%) compared to the global average (58%) to maintain productivity in the face of slower economic growth.

Table 2. The most increased skills in Europe by 2030

Core skills of 2025		Core skills of 2030	
Analytical thinking	71%	AI and big data	91%
Resilience, flexibility and agility	71%	Networks and cybersecurity	75%
Leadership and social influence	63%	Technological literacy	73%
Motivation and self-awareness	59%	Curiosity and lifelong learning	72%
Curiosity and lifelong learning	58%	Resilience, flexibility and agility	71%

Source: World Economic Forum. (2024). *The future of jobs report 2025*. World Economic Forum, pp. 226

Data from Table 2 illustrate that in 2025, cognitive and interpersonal abilities such as analytical thinking and leadership dominated, while the projection for 2030 emphasizes a hybrid model of workers that includes technical expertise, as a primary requirement for employment, and skills. This trend confirms the conclusion that automation does not eliminate the need for human capital, but forces it to constantly improve and adopt advanced digital skills in order to respond to the demands of the labor market.

Table 3. Key barriers for business transformation

Barriers for business transformation	Europe	Global
Skills gaps in the labour maket	66%	63%
Organization culture and resistance to change	46%	46%
Inability to attact talent to the industry	41%	37%
Outdated or irflexible regulatory framework	39%	39%
Lack of adequate data and technical infrastructure	32%	32%

Source: World Economic Forum. (2024). *The future of jobs report 2025*. World Economic Forum, pp. 227

Table 3 shows the share of organizations expecting the barriers to hinder their organizational transformation. The data unequivocally confirm that the biggest challenge in the digital transformation of companies does not lie in technology itself, but in human capital, given that the lack of adequate skills on the labor market is the primary barrier for as many as 66% of companies in Europe and 63% globally. This deficit corresponds directly to the previously analyzed explosive growth in the need for specialized AI and cybersecurity competencies, creating a deep gap between current labor supply and evolving technological demands. While internal cultural resistance to change (46%) and rigid regulatory frameworks (39%) are equally represented at both observed levels, Europe faces a significantly more pronounced problem of attracting new talents to the industry (41% compared to 37% globally), which, in combination with an unfavorable demographic structure and an aging population, further slows down the implementation of advanced technological solutions and threatens the competitiveness of the European economy on the global stage (Gmyrek et al., 2025; OECD, 2025).

The conducted analysis of empirical data indicates that the global labor market is on the threshold of the most intense structural transformation in modern history. Technological progress, led by generative artificial intelligence, automation and big data analysis, has ceased to be merely an instrument of operational efficiency and has become the primary macroeconomic driver of change.

Table 4. European industry insights by sectors

European Industry Profile				
	Labor-market churn	Skill disruption	Organizations with DEI priorities	AI exposure
Accommodation, Food, and Leisure	24%	42%	80%	77%
Advanced Manufactoring	50%	37%	78%	86%
Agriculture Forestry and Fishing	24%	41%	67%	83%
Automotive and Aerospace	17%	38%	87%	83%
Chemical and Advanced materials	19%	42%	91%	83%
Education and Training	22%	44%	91%	93%
Electronics	17%	33%	87%	95%
Energy Technology and Utilities	19%	40%	81%	72%
Financial services and Capital markets	30%	41%	88%	97%
Government and Public sector	23%	38%	75%	76%
Information and Technology services	34%	32%	89%	93%
Infrastructure	14%	35%	81%	78%
Insurance and Pensions management	19%	47%	97%	0%
Medical and Healthcare services	19%	39%	91%	94%
Mining and metals	14%	35%	89%	79%
Oil and Gas	22%	28%	75%	82%
Production of Consumer goods	18%	40%	82%	90%
Professional services	19%	41%	90%	95%
Real Estate	23%	40%	95%	90%
Retail and wholesale of consumer goods	28%	38%	78%	87%
Supply chain and transportation	35%	37%	84%	88%
Telecommunications	20%	40%	85%	89%

Source: World Economic Forum. (2024). *The future of jobs report 2025*. World Economic Forum

Empirical data for Europe (Table 4) indicate that the transformation of business through artificial intelligence (AI) is affecting sectors unevenly. While advanced manufacturing sees the highest labor turnover (50%), the insurance sector shows an anomaly with zero current exposure but a high need to change skills, hinting at the coming transformation. Alongside technological pressures, sectors with extreme skills disruption, such as education and healthcare, show an exceptionally high commitment to strategies that reduce social risks. In contrast, in primary industries, the transition will primarily take place through automation, while service sectors will have to radically redefine the skills profile and inclusiveness of jobs.

6.CONCLUSION

The findings of this study confirm that artificial intelligence has become one of the most influential drivers of business transformation and labor market restructuring across Europe. The diffusion of AI technologies, automation, and advanced data-processing systems is accelerating changes in organizational models, employment structures, and skill requirements, creating both significant opportunities and substantial challenges for European economies. The analysis reveals significant disparities in the adoption of AI technologies across Europe, with Scandinavian countries leading in enterprise AI usage, while most Southeastern European and several Eastern European countries continue to exhibit rel-

atively low levels of AI integration, which confirms the first hypothesis that was set at the beginning of the research. Furthermore, previous empirical evidence discussed in the paper indicates that AI adoption is positively associated with higher GDP per capita, stronger institutional development, and lower unemployment. The OECD labor market data also suggest that historically high employment levels create favorable conditions for investments in AI technologies, supporting the conclusion that economically developed countries with stronger labor markets provide a more conducive environment for AI implementation. These findings corroborate the conclusions of Drago et al. (2025) and Radukic et al. (2019), suggesting that countries with stronger competitiveness, technological readiness, and more efficient labor market institutions are better positioned to adopt AI technologies and successfully manage the structural changes associated with digital transformation.

Also, the paper confirmed the second hypothesis that AI will significantly affect the transformation of business and the labor market. It was found that 90% of European and 88% of global organizations use AI technologies, and in the next five years it is expected that the basic working skills of employees will change by 21% in Europe and 22% globally, so digitalization and AI will affect the transformation of business (especially large companies) and the labor market. The analysis further reveals that AI is expected to accelerate labor-market restructuring, increase skill disruption, reshape workforce requirements toward advanced digital competencies, and stimulate organizational changes across all major sectors of the European economy. The identified sectoral differences, projected changes in workforce skills by 2030, and the growing importance of AI-related competencies provide robust evidence that artificial intelligence is fundamentally transforming both business operations and labor market dynamics.

The analysis demonstrates that AI adoption is no longer limited to improving operational efficiency but increasingly shapes the demand for labor, the nature of work, and the competitiveness of firms. While AI contributes to productivity growth and the creation of new technology-oriented occupations, it simultaneously increases the risk of job polarization, skill mismatches, and labor market inequalities. The results indicate that the most critical obstacle to successful business transformation is not the availability of technology itself but the growing shortage of adequately skilled workers. The widening gap between existing competencies and future labor market requirements highlights the urgent need for large-scale reskilling and upskilling initiatives.

The scenario analysis further suggests that the future of the European labor market will largely depend on policy choices regarding technological sovereignty, innovation capacity, and social inclusion. Scenarios characterized by strong political coordination, investment in domestic technological capabilities, and continuous workforce adaptation offer the most favorable outcomes in terms of employment stability, productivity growth, and social cohesion. In contrast, fragmented governance, technological dependence, and insufficient investment in human capital may intensify labor market disruptions and weaken Europe's long-term competitiveness.

Sectoral evidence reveals that the impact of AI is highly heterogeneous across industries. While advanced manufacturing, information technology, finance, healthcare, and education are expected to experience substantial changes in skill requirements and work organization, traditional sectors will face increasing pressure to automate routine tasks and improve productivity. Consequently, labor market policies must be tailored to sector-specific challenges while ensuring inclusive access to digital skills development.

The findings of this study highlight the need for coordinated action among policymakers, educational institutions, and businesses to ensure a successful transition toward an AI-driven economy. Policymakers should prioritize investments in digital infrastructure,

research and development, lifelong learning systems, and active labor market policies that support workforce reskilling and upskilling while establishing regulatory frameworks that foster responsible AI adoption and social inclusion. Educational institutions should modernize curricula by integrating artificial intelligence, digital literacy, data analytics, and cybersecurity while strengthening collaboration with industry to equip graduates with both technical and transversal competencies required in the future labor market. At the same time, businesses should complement AI investments with continuous employee training, internal reskilling programs, and human-centered implementation strategies that enhance productivity without compromising workforce adaptability. Such a coordinated approach would reduce skill shortages, strengthen labor market resilience, and ensure that artificial intelligence contributes to sustainable economic growth, competitiveness, and inclusive social development across Europe.

Ultimately, artificial intelligence should not be viewed solely as a source of labor market disruption but as a transformative technology whose long-term benefits will depend on Europe's ability to combine innovation, adaptability, and social responsibility. The successful management of this transition will determine whether AI becomes a driver of shared prosperity or a source of growing economic and social fragmentation in the coming decade.

This study has several limitations. First, the analysis is primarily based on secondary data and scenario projections, which may not fully capture the speed and complexity of future AI-driven labor market transformations. Second, the research focuses on selected European countries and aggregated sectoral trends, limiting the ability to identify country-specific and firm-level effects of AI adoption. Third, the rapidly evolving nature of artificial intelligence may alter current assumptions regarding employment, productivity, and skills demand.

Future studies could exploit longitudinal and firm-level data to examine the causal effects of AI adoption on employment, wages, and workforce composition across industries. Further research may also investigate sector-specific adaptation strategies, the effectiveness of reskilling policies, and the role of technological sovereignty in enhancing labor market resilience and competitiveness in Europe.

REFERENCES

Agrawal, P. K., Dwivedi, Y., Singh, G., Mishra, P., Bajpai, M., Kumar, N., & Kumar, M. (2026). Dynamic Interaction between Bitcoin and Developed Stock Markets: Evidence from the DCC-GARCH Model with Wavelet Coherence Approach. *Economics - Innovative and Economic Research Journal, 14*(2), 111-128. https://doi.org/10.2478/eoik-2026-0028

Arsić, M. (2020). Impact of digitalisation on economic growth, productivity and employment. *Economic Themes*, *58*(4), 431-457. https://doi.org/10.2478/ethemes-2020-0025

Borissov, B., & Hristozov, Y. (2024). Potential for using artifical intelligence in public administration. *ECONOMICS - Innovative and Economic Research Journal*, *12*(3), 409-423. https://doi.org/10.2478/eoik-2024-0034

Brynjolfsson, E., Li, D., & Raymond, L. R. (2025). Generative AI at work. *The Quarterly Journal of Economics*, *140*(2), 889–942. https://doi.org/10.48550/arXiv.2304.11771

CaixaBank Research. (2024). *Artificial intelligence: challenges and opportunities for Europe*. https://www.caixabankresearch.com/en/economics-markets/labour-market-demographics/artificial-intelligence-challenges-and-opportunities

Drago, C., Costantiello, A., Savorgnan, M., & Leogrande, A. (2025). Macroeconomic and Labor Market Drivers of AI Adoption in Europe: A Machine Learning and Panel Data Approach. *Economies*, *13*(8), 226. https://doi.org/10.3390/economies13080226Resultsand discussion

European Commission. (n.d.). *Europe's Digital Decade: Digital targets for 2030. Shaping Europe's digital future*. https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade

Eurostat. (n.d.). *Digital economy and society statistics – enterprises*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Digital_economy_and_society_statistics_-_enterprises

Gmyrek, P., Berg, J., Kamiński, K., Konopczyński, F., Ładna, A., Nafradi, B., Rosłaniec, K., & Troszyński, M. (2025). *Generative AI and jobs: A 2025 update*. International Labour Organization. https://doi.org/10.54394/QFBQ1907

Hunady, J., Demeova, E., & Chylakova, V. (2025). The role of digital skills and digitalisation in enhancing labour productivity in the EU. *Collection of Papers New Economy, 3*(1), 33–45. https://doi.org/10.61432/CPNE0301033h

McKinsey & Company. (2023). *The economic potential of generative AI: The next productivity frontier*. https://www.mckinsey.com/capabilities/tech-and-ai/our-insights/the-economic-potential-of-generative-ai-the-next-productivity-frontier

Nguyen, M.-L. T. (2026). Does the Global Crisis Affect the Relationship Between External Debt and Economic Growth? A Linear and Nonlinear Analysis. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 87-110. https://doi.org/10.2478/eoik-2026-0027

Noy, S., & Zhang, W. (2023). Experimental evidence on the productivity effects of generative artificial intelligence. *Science*, *381*(6654), 187–192. https://doi.org/10.1126/science.adh2586

OECD. (2025). *OECD Employment Outlook 2025: Can we get through the demographic crunch?* OECD Publishing. https://doi.org/10.1787/194a947b-en

Radukic, S., Mastilo, Z., Kostic, Z., & Vladusic, L. (2019). Measuring of the goods and labor markets efficiency: comparative study of Western Balkan countries. *Montenegrin Journal of Economics*, *15*(2), 95-109. https://doi.org/10.14254/1800-5845/2019.15-2.8

Teigland, R., & Wiberg, M. (2025). AI and Digitalisation's Impact on EU's Future Labour Market: Scenarios and Implications. In *The Depth and Size of the European Union in a Time of War: Interdisciplinary European Studies* (pp. 223-249). Cham: Springer Nature Switzerland. https://research.chalmers.se/en/publication/549694

World Economic Forum. (2025). *The Future of Jobs Report 2025: Structural Transformations and Labor Market Shifts*. Geneva: World Economic Forum. https://www.weforum.org/publications/the-future-of-jobs-report-2025/

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

BEYOND TECHNICAL COMPLIANCE: NXTPORT AND THE GOVERNANCE OF NEUTRAL DATA INTERMEDIATION IN THE PORT OF ANTWERP-BRUGES

Lucas Freitas[1*]

Received 16.03.2026. | Send to review 03.04.2026. | Accepted 18.08.2026.

Original Article

[1] Instituto Politécnico de Setúbal, Escola Superior de Ciências Empresariais, Setúbal, Portugal

***Corresponding Author:**
Lucas Freitas

Email:
lucas.freitas@esce.ips.p

JEL Classification:
L92, R40, O33

Doi: 10.61432/CPNE0401075f

UDK: 535.338.3:351.817(100)

ABSTRACT
The European Twin Transition is increasing pressure on seaports to develop into data driven logistics hubs. However, stakeholder reluctance to share commercially sensitive information remains a major barrier to digital integration. Although the EU Data Governance Act, Regulation 2022/868, provides a legal framework for neutral data intermediation services, evidence on their practical implementation in specific sectors remains limited. This study examines NxtPort, the digital utility platform of the Port of Antwerp Bruges, as a case of data intermediary governance. Using qualitative document analysis of publicly available governance artefacts, including the NxtPort Status Page, OpenAPI specifications hosted on GitHub, and the Service Desk portal, the study evaluates the platform's alignment with the DGA principles of neutrality, transparency, and accountability. The findings show that operational status monitoring, standardised API documentation, and formalised user support jointly strengthen stakeholder trust by making governance processes visible. The study contributes by introducing governance visibility as an analytical lens for assessing data intermediation platforms through publicly observable artefacts. This framework may also inform other ports and sectors seeking to balance data driven efficiency with regulatory compliance.

Keywords: *Data Governance Act, EU Data Strategy, Smart Ports, Data Intermediaries, NxtPort*

1. INTRODUCTION

The European Commission's Sustainable and Smart Mobility Strategy identifies digitalisation as a central driver of transport modernisation and links this transition to the objective of reducing transport emissions by 90 per cent by 2050 (European Commission, 2020). In seaports, however, the development of data driven logistics hubs remains constrained by a persistent trust gap. Digital integration requires the exchange of real time operational data, yet stakeholders are often reluctant to share commercially sensitive information with competitors or intermediaries (Richter, 2023). This tension is particularly significant in maritime ecosystems, where data have substantial economic value and the risks associated with disclosure are difficult to eliminate (Carlan, Sys, & Vanelslander, 2016).

The EU Data Governance Act addresses this challenge by establishing a Union wide framework for Data Intermediation Services as neutral facilitators of data sharing (European

Union, 2022). Such services are expected to operate according to principles of structural separation, non-discrimination, and transparency, ensuring that intermediaries do not acquire an independent commercial interest in the data they manage (European Union, 2022; Richter, 2023; Kolydas et al., 2026). Although the legal foundations of this framework are increasingly developed, limited evidence exists on how these requirements are implemented in specific sectoral contexts (von Ditfurth & Lienemann, 2022; Bouzaidi et al., 2026). Insufficient attention has been given to the publicly visible governance arrangements through which intermediaries demonstrate neutrality, transparency, and accountability (European Commission, Joint Research Centre, 2023; Mussina et al., 2026).

This article examines NxtPort, the digital utility platform of the Port of Antwerp Bruges, as a case of neutral data intermediation governance. The case is relevant because data sharing is already integrated into the port's operational processes, allowing governance practices to be examined in a mature digital environment. The article argues that NxtPort translates principles associated with the DGA into practice through visible operational information, standardised documentation, and formalised user support. It therefore introduces governance visibility as an analytical lens for assessing the alignment between platform practices and regulatory principles through publicly observable artefacts.

The study asks how NxtPort's publicly available governance arrangements reflect the DGA principles of neutrality, transparency, and accountability. In addressing this question, it seeks to clarify how data intermediation can support digital port integration while protecting commercial confidentiality and institutional trust.

2. METHODOLOGY

This study employs qualitative document analysis to examine how a digital port platform operationalises governance features associated with neutral data intermediation. Document analysis is suitable because it enables the systematic interpretation of publicly available organisational materials as evidence of institutional practice rather than as neutral representations of organisational reality (Bowen, 2009). Documents are therefore treated as socially situated artefacts that reflect and shape governance commitments, organisational arrangements, and user expectations.

The research design also follows Yin's single case study approach (Yin, 2018). The Port of Antwerp Bruges was selected according to four criteria. First, it represents a mature digital port ecosystem in which data sharing services are embedded in logistics operations. Second, it operates within the regulatory environment of the European Union and is therefore directly relevant to the DGA. Third, it provides extensive public documentation, including contractual terms, operational status information, technical specifications, and user support infrastructure. Fourth, these materials enable the study to assess how regulatory principles are translated into visible operational arrangements.

The documentary corpus consists of four publicly accessible NxtPort sources: the General Terms and Conditions, the NxtPort Status Page, OpenAPI specifications and developer materials hosted on GitHub, and the Service Desk portal (NxtPort, 2025a, 2025b, 2025c, 2025d). These sources were selected because they perform distinct governance functions and provide evidence on contractual rules, operational transparency, technical accessibility, and accountability mechanisms.

The analysis is deliberately limited to publicly accessible artefacts. This boundary is consistent with the objective of examining externally visible governance rather than internal organisational processes. It also improves transparency and replicability. Governance visibility is treated as a distinct analytical object because stakeholder confidence may de-

pend not only on internal governance arrangements, but also on whether those arrangements are visible, understandable, and accessible to users (Micheli et al., 2020).

This approach does not capture how governance is experienced by users or implemented within internal organisational processes. Public documents reveal how NxtPort communicates rules, service performance, and accountability procedures, but they do not provide evidence on informal practices, internal compliance culture, or power relations among stakeholders. The study therefore does not assess perceived trustworthiness, which would require interviews, surveys, or other participatory methods.

The analysis is organised around three dimensions derived from the DGA: neutrality, transparency, and accountability (European Union, 2022). These dimensions served as predetermined thematic categories for the systematic examination of the documentary evidence. Relevant provisions, statements, and structural features were identified within each source and compared across the documentary corpus to improve analytical consistency.

Neutrality and structural separation were assessed through the General Terms and Conditions, particularly the provisions concerning data use and the absence of an independent commercial interest in shared data (European Union, 2022; NxtPort, 2025a). Transparency was assessed through the NxtPort Status Page and the OpenAPI documentation, which provide evidence of operational visibility and technical accessibility. These features were interpreted in relation to the findability and interoperability principles of the FAIR framework (Wilkinson et al., 2016; NxtPort, 2025b, 2025c).

Accountability was examined through the Service Desk portal, with attention to the formalisation of user support, issue reporting, and service specific escalation procedures (European Union, 2022; Micheli et al., 2020; NxtPort, 2025d). Table 1 summarises the relationship between the documentary sources, the governance dimensions, and the main observations derived from each source.

The methodology combines legal, methodological, and scholarly references. The DGA provides the normative benchmark for assessing the governance arrangements (European Union, 2022). Bowen (2009) and Yin (2018) support the use of qualitative document analysis and single case study design. Additional scholarly sources situate the case within wider debates on data intermediation, institutional trust, and technical interoperability. This combination connects regulatory requirements, empirical evidence, and theoretical interpretation within a coherent analytical framework.

Table 1. Analytical mapping of documentary sources and observations

Governance artefact	Governance dimension	Analytical focus	Observation
General Terms and Conditions (NxtPort, 2025a)	Neutrality	Data-use restrictions, licensing structure, permitted platform role	Contractual provisions position NxtPort as a functionally limited intermediary rather than an independent commercial exploiter of shared data
Status Page (NxtPort, 2025b)	Transparency	Public visibility of service health and operational incidents	Platform continuity and service performance are made externally visible in real time
OpenAPI specifications and developer portal (NxtPort, 2025c)	Transparency / interoperability	Accessibility and standardisation of technical documentation	API documentation supports technical clarity and lowers barriers to integration
Service Desk portal (NxtPort, 2025d)	Accountability	Support channels, issue categories, escalation pathways	User support is formalised through structured and service-specific accountability mechanisms

Source: Author's own elaboration based on NxtPort (2025a, 2025b, 2025c, 2025d), European Union (2022), and Bowen (2009)

3.MAIN RESULTS

The analysis indicates that NxtPort applies the governance logic of neutral data intermediation through three observable mechanisms: contractual restrictions on data use, public visibility of system operations, and formalised user support. These mechanisms correspond to the analytical dimensions of neutrality, transparency, and accountability. Together, they demonstrate how governance commitments are communicated to users rather than remaining confined to internal technical arrangements.

3.1. NEUTRALITY

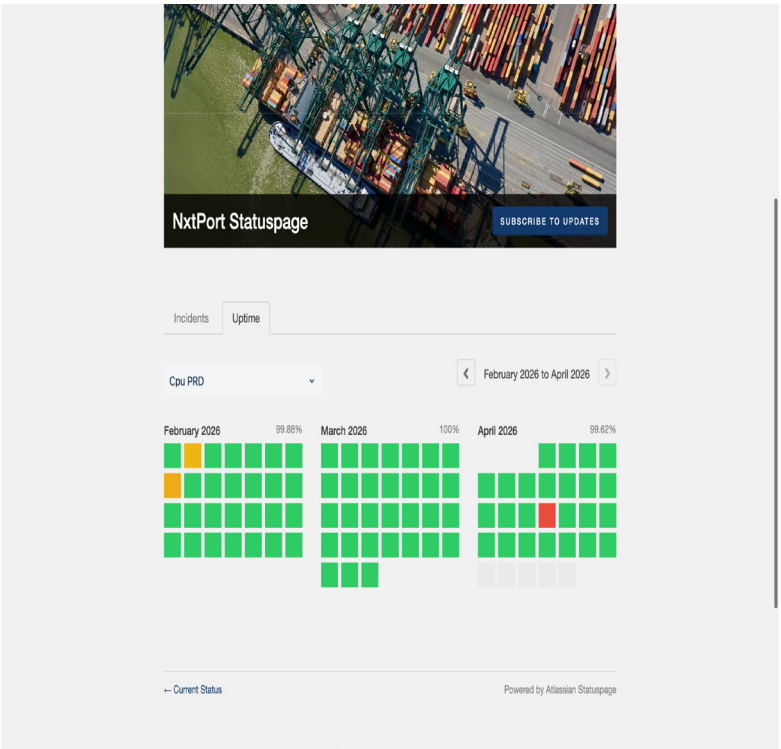
NxtPort's contractual framework shows functional alignment with several principles derived from the DGA, without establishing formal compliance with Article 12. Although the General Terms and Conditions do not use the terminology of the regulation, the licence granted by data providers is narrowly defined. It is nonexclusive, nontransferable, and limited to making data available to authorised users according to Data Sharing Rules established by subscribers (NxtPort, 2025a).

NxtPort is not granted a general right to use the data for its own independent commercial purposes. This arrangement is consistent with the intermediary function envisaged by the DGA (European Union, 2022; NxtPort, 2025a). The contractual structure therefore supports the interpretation of NxtPort as a platform that facilitates controlled data exchange rather than appropriating the economic value of the data it manages (Schweihoff et al., 2024).

3.2. TRANSPARENCY

Operational transparency is provided through the NxtPort Status Page, which publicly reports the condition of eight principal services and their associated components, including APIs, interfaces, login systems, and notification channels (NxtPort, 2025b). Although the monitored components differ across services, the platform makes service availability and disruptions publicly observable in real time.

Figure 1. Screenshot of the NxtPort Status Uptime Page

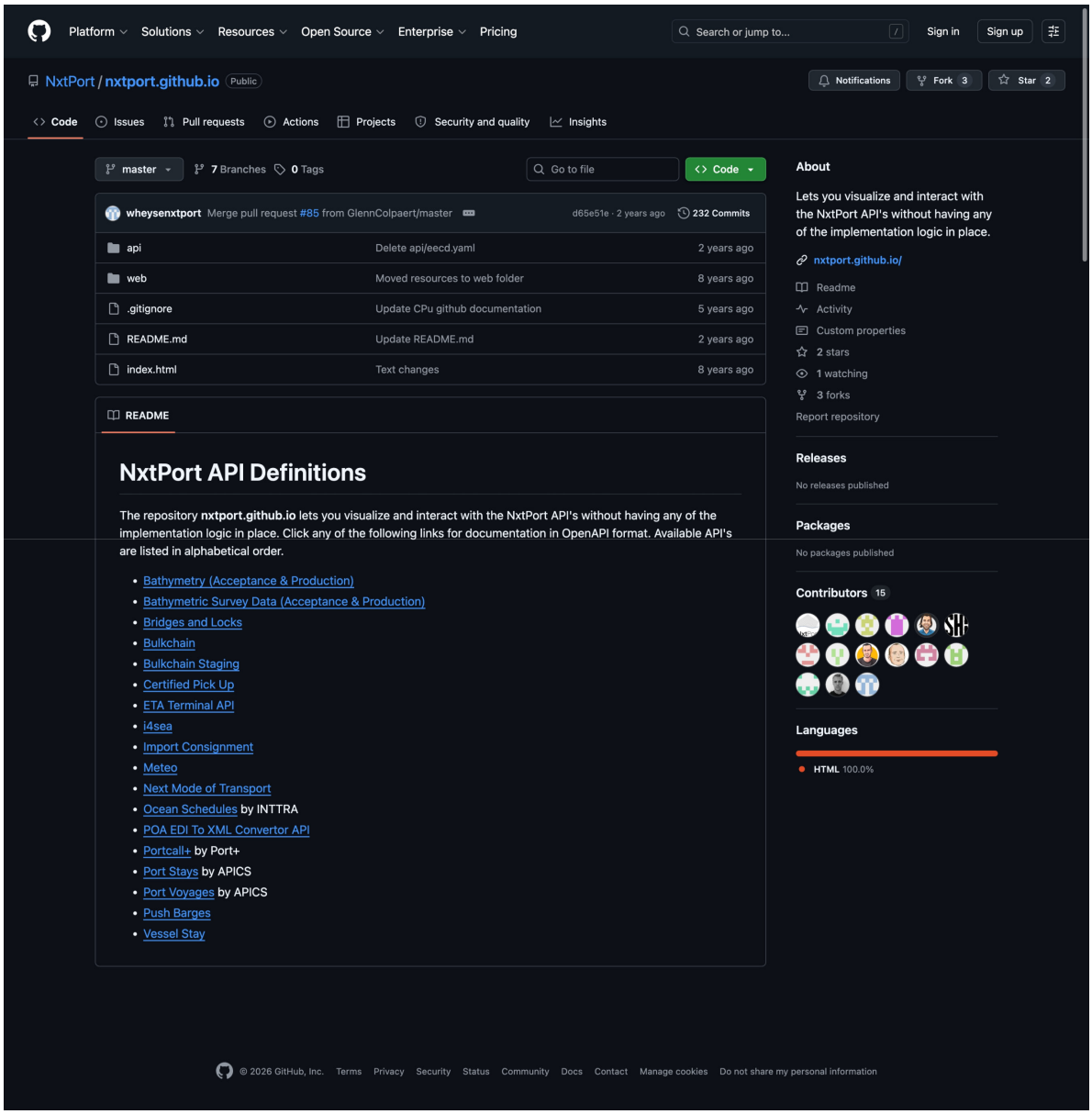


Source: https://status.nxtport.com/uptime

This visibility reduces informational asymmetry between the platform operator and its users by making operational performance publicly observable rather than confining it to internal monitoring.

Technical transparency is further supported by NxtPort's publicly accessible GitHub repositories, which contain machine readable OpenAPI specifications and an interactive developer portal for examining the available APIs (NxtPort, 2025c). These resources provide structured technical documentation that users and developers can review before implementation. By clarifying system interfaces and access requirements, they support practical interoperability and more informed participation in the platform.

Figure 2. Screenshot of NxtPort's GitHub repository



Source: https://github.com/NxtPort/nxtport.github.io

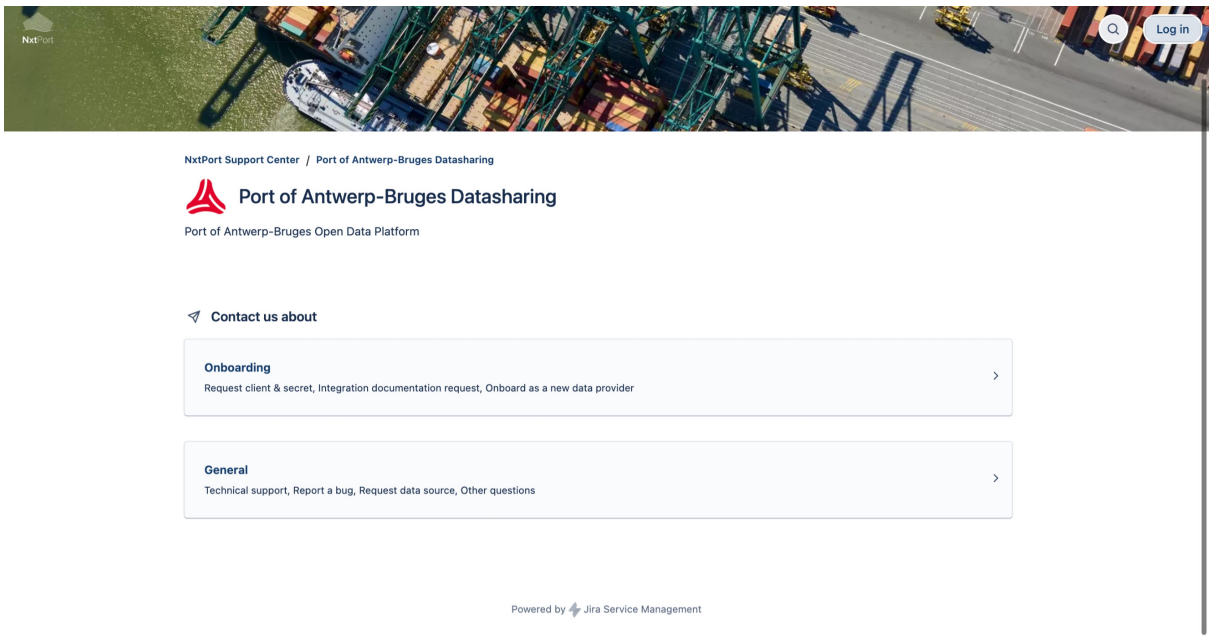
These features can be interpreted through the Findability and Interoperability dimensions of the FAIR Guiding Principles (Wilkinson et al., 2016). In this study, however, the FAIR principles serve as an analytical lens rather than as a formal compliance standard (NxtPort, 2025c).

3.3. ACCOUNTABILITY

Administrative accountability is visible in the structure of the NxtPort Service Desk portal, which provides dedicated support channels for specific platform services (NxtPort, 2025d). The portal includes categorised forms for technical assistance and issue reporting, thereby formalising interaction between users and the platform's support functions.

Rather than leaving complaint and resolution procedures informal or unclear, NxtPort provides identifiable channels through which operational problems can be reported, processed, and addressed.

Figure 3. Screenshot of NxtPort's Support Center for the Port of Antwerp-Bruges Open Data Platform



Source: https://nxtport.atlassian.net/servicedesk/customer/portal/5/group/-1

This support structure is significant because accountability in data intermediation depends not only on legal compliance, but also on accessible procedures for addressing user concerns (Micheli et al., 2020). The Service Desk therefore complements the contractual and technical elements of the platform by establishing an administrative basis for trust (European Union, 2022; Micheli et al., 2020; NxtPort, 2025d).

Overall, the evidence suggests that NxtPort promotes trust through a layered governance model rather than through a single compliance mechanism. Contractual restrictions, operational transparency, technical documentation, and formal support procedures collectively make neutrality, transparency, and accountability visible and understandable to stakeholders.

Table 2 summarises the findings by governance dimension and explains their interpretive significance.

Table 2. Summary of empirical findings by governance dimension

Governance dimension	Empirical source	Key finding	Interpretive significance
Neutrality	General Terms and Conditions	NxtPort's contractual role is limited to authorised data-sharing functions	Functional alignment with the DGA's structural-separation logic
Transparency	Status Page; OpenAPI repositories; developer portal	Platform operations and technical interfaces are publicly visible	Supports transparency of operations and facilitates interoperability
Accountability	Service Desk portal	Support and issue-resolution pathways are formalised and service-specific	Strengthens administrative trustworthiness and user recourse

Source: Author's own elaboration based on NxtPort (2025a, 2025b, 2025c, 2025d), European Union (2022), Micheli et al. (2020), Schweihoff et al. (2024), and Wilkinson et al. (2016)

4. CONCLUSION

This study examined NxtPort as a case of neutral data intermediation governance within a European port ecosystem. The findings indicate that NxtPort reflects principles associated with the Data Governance Act through a layered governance model based on contractual limits on data use, public operational and technical documentation, and structured user support (European Commission, 2020; European Union, 2022). These mechanisms suggest that trust in data intermediation depends not only on technical architecture, but also on the visibility of governance commitments and the accessibility of accountability procedures.

The findings support Micheli et al. (2020), who emphasise the organisational foundations of data governance, and extend this perspective to a regulated maritime context. They also provide an empirical illustration of the conceptual role of data intermediaries discussed by Schweihoff et al. (2024) and show how principles associated with the DGA may be translated into operational arrangements rather than remaining confined to legal doctrine (von Ditfurth & Lienemann, 2022). The NxtPort case therefore contributes to research on port digitalisation by demonstrating how regulatory expectations can become embedded in the governance of an active logistics platform.

Governance visibility should not, however, be treated as proof of neutrality or an absence of risk. Publicly accessible documentation can make platform practices more understandable without resolving all tensions within data sharing ecosystems. In the NxtPort case, its relationship with the Port of Antwerp Bruges raises questions concerning the practical independence of the intermediary from the interests of a major port authority. Public artefacts also provide limited insight into internal decision making, enforcement procedures, conflict resolution, and organisational culture. In addition, differences in bargaining power between large logistics operators and smaller participants may influence how principles of neutrality and non-discrimination are experienced in practice.

The case has broader relevance to the European Data Strategy and the Sustainable and Smart Mobility Strategy. It shows that digital transformation in ports requires more than technological modernisation. It also depends on governance arrangements that make data sharing understandable, reliable, and institutionally credible. Governance design can therefore be considered an important dimension of digital maturity because it shapes the conditions under which stakeholders are willing to participate in shared data environments.

NxtPort provides a context specific illustration of how a port platform may align its practices with emerging European data governance principles before obtaining formal

recognition under the DGA. However, the analysis does not establish legal compliance with Article 12. The platform's alignment is inferred from public governance artefacts and contractual arrangements rather than from formal notification as a Data Intermediation Services provider. The findings should therefore be understood as evidence of functional alignment with selected DGA principles rather than confirmation of full regulatory compliance.

The study makes three principal contributions. First, it provides empirical evidence of how principles associated with the DGA are expressed through publicly observable arrangements in an operational port platform. Second, it demonstrates the value of combining legal standards, qualitative document analysis, and data governance theory when examining digital intermediation in regulated sectors. Third, it introduces governance visibility as an analytical lens for assessing the relationship between platform practices and regulatory principles without requiring access to internal documents or stakeholder testimony.

The study is subject to several limitations. The analysis is restricted to publicly available materials and therefore excludes internal governance practices. The single case design supports analytical rather than statistical generalisation. In addition, the study provides a static assessment and does not capture how NxtPort's governance arrangements may evolve in response to the formal implementation of the DGA.

Future research should compare formally notified and voluntarily aligned data intermediaries, examine changes in platform governance over time, and incorporate stakeholder perspectives through interviews and surveys. Such research could determine whether publicly visible governance arrangements increase perceived trust and whether formal recognition under the DGA produces measurable organisational changes.

Despite these limitations, the NxtPort case demonstrates that visible and layered governance can provide a credible foundation for balancing commercial confidentiality with the data sharing requirements of an increasingly digital maritime economy.

Funding

This project was produced within the scope of the Agenda "NEXUS — Pacto de Inovação: Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), under project no. C645112083-00000059 (investment project no. 53).

Conflicts of Interest

The author declares no conflict of interest.

REFERENCES

Bouzaidi, T. D., Daoui, F., Solhi, S., & Tounsi, S. (2026). Economic Convergence in Africa Put to the Test of Productive Complexity: An Empirical Analysis Using System GMM Panel Data and Markov Chains. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 145-163. https://doi.org/10.2478/eoik-2026-0030

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, 9(2), 27–40. https://doi.org/10.3316/QRJ0902027

Carlan, V., Sys, C., & Vanelslander, T. (2016). How port community systems can contribute to port competitiveness: Developing a cost–benefit framework. *Research in Transportation Business & Management*, 19, 51–64. https://doi.org/10.1016/j.rtbm.2016.05.006

European Commission. (2020). *Sustainable and Smart Mobility Strategy — putting European transport on track for the future* (COM(2020) 789 final). Brussels: European Commission. Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0789 (accessed 24 April 2026).

European Commission – Joint Research Centre. (2023). *Mapping the landscape of data intermediaries*. Luxembourg: Publications Office of the European Union. Available at https://publications.jrc.ec.europa.eu/repository/handle/JRC133988 (accessed 24 April 2026).

European Union. (2022). Regulation (EU) 2022/868 of the European Parliament and of the Council of 30 May 2022 on European data governance and amending Regulation (EU) 2018/1724 (Data Governance Act). *Official Journal of the European Union*, L 152, 1–44. Available at https://eur-lex.europa.eu/eli/reg/2022/868/oj (accessed 24 April 2026).

Kolydas, A., Kontsas, S., Kalogiannidis, S., & Kalfas, D. (2026). The Effect of Cryptocurrency Taxation Policies on Individual Investment Decisions in Greece. *ECONOMICS - Innovative and Economic Research Journal*, 14(2), 1-23. https://doi.org/10.2478/eoik-2026-0045

Micheli, M., Ponti, M., Craglia, M., & Berti Suman, A. (2020). Emerging models of data governance in the age of datafication. *Big Data & Society*, 7(2), 1–15. https://doi.org/10.1177/2053951720948087

Mussina, S., Khussainova, Z., Atabayeva, A., & Kazbekov, T. (2026). Estimating the Effects of Macroeconomic Factors on Net Migration: A 2SLS Approach in Panel Data. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 415-433. https://doi.org/10.2478/eoik-2026-0043

NxtPort. (2025a). *General Terms and Conditions*. Antwerp: NxtPort International NV. Available at https://nxtport.com/ (accessed 24 April 2026).

NxtPort. (2025b). *NxtPort Status Page*. Available at https://status.nxtport.com/ (accessed 24 April 2026).

NxtPort. (2025c). *NxtPort Developer Portal and OpenAPI specifications*. GitHub repository. Available at https://github.com/nxtport (accessed 24 April 2026).

NxtPort. (2025d). *NxtPort Service Desk*. Available at https://nxtport.atlassian.net/servicedesk/customer/portals (accessed 24 April 2026).

Richter, H. (2023). Looking at the Data Governance Act and beyond: How to better integrate data intermediaries in the market order for data sharing. *GRUR International*, 72(5), 458–470. https://doi.org/10.1093/grurint/ikad014

Schweihoff, J., Lipovetskaja, A., Jussen-Lengersdorf, I., & Möller, F. (2024). Stuck in the middle with you: Conceptualizing data intermediaries and data intermediation services. *Electronic Markets*, 34(1), Article 48. https://doi.org/10.1007/s12525-024-00729-9

von Ditfurth, L., & Lienemann, G. (2022). The Data Governance Act: Promoting or restricting data intermediaries? *Competition and Regulation in Network Industries*, 23(4), 270–295. https://doi.org/10.1177/17835917221141324

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., et al. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, 3, Article 160018. https://doi.org/10.1038/sdata.2016.18

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Thousand Oaks, CA: SAGE Publications.

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

ICT SERVICES TRADE, DIGITAL ADOPTION, LABOUR PRODUCTIVITY AND EMPLOYMENT IN ADVANCED AND DEVELOPING ECONOMIES: A PANEL DATA ANALYSIS

Andrii Oliinyk[1], Tetiana Melnyk[1], Liudmyla Huliaieva[2], Liudmyla Sierova[1], Olena Kravchenko[5], Yuliia Tunitska[1]

Received 27.02.2026. | Send to review 14.03.2026. | Accepted 13.08.2026.

Original Article

CC BY NC ND

[1] State University of Trade and Economics, Faculty of International Trade and Law, Department of International Management, Ukraine

[2] Academy of Labour, Social Relations and Tourism, Faculty of Economics, Social Management and Tourism, Ukraine

[5] University "Ukraine", Ukraine

***Corresponding Author:**
Andrii Oliinyk

Email:
oliynik12@gmail.com

JEL Classification:
C23, F14; J21, O33, O47, O57

Doi: 10.61432/CPNE04010850

UDK: 31.5.024.52(4672EU):004.738.5

ABSTRACT

This article examines the relationship between ICT services trade, digital adoption, employment, and labour productivity in advanced and developing economies. The analysis uses panel data for 100 economies from 2006 to 2024, comprising 31 advanced and 69 developing economies classified according to the IMF World Economic Outlook.

The empirical approach applies fixed-effects panel regressions with country and year effects, country-clustered robust standard errors, and inverse hyperbolic sine transformations. Separate models are estimated for advanced and developing economies using two dependent variables: the employment-to-population ratio and GDP per person employed. The results reveal substantial differences between the two country groups. In advanced economies, ICT services exports and Internet use are positively associated with employment, while ICT-related variables show no stable relationship with labour productivity. In developing economies, ICT services exports and imports are not statistically significant in either model. However, Internet use is negatively associated with employment and positively associated with labour productivity, suggesting that digital adoption may support productivity-enhancing transformation while contributing to labour-market restructuring. Robustness checks excluding GDP per capita and using one-year lags confirm the consistent role of Internet use. By contrast, ICT services imports show no robust association with either employment or productivity. The findings underline the importance of distinguishing between ICT services trade and broader digital adoption when assessing labour-market and productivity outcomes.

Keywords: *ICT services trade, digital adoption, Internet use, employment, labour productivity, advanced economies, developing economies, panel data*

1. INTRODUCTION

The rapid expansion of information and communication technologies (ICT) has become a defining feature of contemporary economic development. ICT no longer functions solely as infrastructure supporting production and exchange; it increasingly shapes productivity, firm organisation, international competitiveness, and labour-market structures. As a general-purpose technology, ICT affects economic performance through efficiency gains, lower transaction costs, innovation, organisational change, and improved access to infor-

mation (Cardona, Kretschmer, & Strobel, 2013). At the macroeconomic level, the ICT revolution is widely recognised as an important driver of global economic growth, although its effects depend on complementary factors such as skills, institutional quality, business practices, and market openness (Jorgenson & Vu, 2016; OECD, 2019).

The expansion of ICT services trade has added a further dimension to digital transformation. Cross-border ICT-enabled services have increased the tradability of knowledge-intensive activities and reduced barriers to service delivery. Earlier studies show that Internet expansion promotes trade in services and supports both exports and imports (Freund & Weinhold, 2002; Choi, 2010). More recent evidence indicates that participation in ICT services markets is associated not only with trade performance but also with broader macroeconomic outcomes, including economic growth (Oliinyk, 2023). ICT services exports and imports may therefore represent important channels through which digitalisation influences employment and labour productivity.

Despite a substantial body of research, several issues remain insufficiently explored. Much of the literature focuses on aggregate growth or productivity, while the employment effects of ICT remain more ambiguous and context-dependent (Acemoglu & Restrepo, 2019; Goaied & Sassi, 2019). Moreover, many studies examine ICT capital, Internet diffusion, or digital adoption separately, while relatively few integrate these dimensions with ICT services trade within a unified empirical framework. The effects of ICT are also likely to vary across country groups because digitalisation interacts with levels of development, absorptive capacity, skills, and institutional conditions (Papaioannou & Dimelis, 2007; Oliinyk et al., 2024; Nayyar et al., 2024). In advanced economies, ICT may contribute more strongly to productivity growth and service-sector upgrading, whereas in developing economies it may have more immediate implications for labour-market access, inclusion, and structural transformation (Peña, Cusolito, & Lederman, 2020; World Bank, 2016; UNCTAD, 2024).

Against this background, this article examines the relationship between ICT services trade, digital adoption, employment, and labour productivity in advanced and developing economies. The analysis uses annual panel data for 100 economies from 2006 to 2024, comprising 31 advanced and 69 developing economies. The empirical framework draws on a reduced-form interpretation of the Solow growth model. ICT services exports, ICT services imports, and Internet use are employed as technology-related indicators, while gross capital formation, education, services value added, demographic structure, institutional quality, and other relevant factors are included as control variables.

The main objective is to determine whether ICT services exports, ICT services imports, and Internet use are associated differently with employment and labour productivity across economies at different stages of development. Rather than treating digitalisation as a homogeneous process, the study distinguishes between external digital integration, reflected in ICT services trade, and domestic digital diffusion, captured by Internet use. This distinction is important because these dimensions represent different mechanisms of digital transformation and may produce different labour-market and productivity outcomes.

The article contributes to the literature in three ways. First, it analyses ICT services trade and domestic digital adoption within a common empirical framework. Second, it examines both employment and labour productivity rather than focusing on only one dimension of economic performance. Third, it compares advanced and developing economies, allowing the relationship between digitalisation and economic outcomes to vary according to the level of development.

The remainder of the article is organised as follows. The next section reviews the literature on ICT, productivity, employment, and ICT services trade. The subsequent section

describes the data, variables, methodology, and econometric specification. The empirical results and robustness checks are then presented and discussed. The final section summarises the main conclusions and policy implications.

2. LITERATURE REVIEW

A substantial body of research examines ICT as a general-purpose technology that can improve economic performance through efficiency gains, innovation, organisational change, lower transaction costs, and better access to information. However, the empirical evidence is not uniform. Cardona et al. (2013) find that ICT is generally positively associated with productivity, but the estimated effects depend on the level of aggregation, ICT measurement, model specification, and the availability of complementary capabilities. Jorgenson and Vu (2016) identify ICT as an important source of global economic growth, while OECD (2019) stresses that stronger outcomes require complementary skills, managerial capacity, institutional quality, and openness. ICT should therefore not be treated as an isolated technological input, since its relationship with productivity and employment depends on the broader economic environment.

Cross-country studies provide important evidence on the macroeconomic role of ICT, although their conclusions vary with the indicators and estimation methods used. Papaioannou and Dimelis (2007), applying an augmented production-function framework, find that ICT contributes to labour productivity growth in both developed and developing economies. Vu (2011) similarly reports a positive contribution of ICT to economic growth. Niebel (2018), however, finds a positive relationship between ICT capital and GDP growth but no statistically significant differences in ICT output elasticities across developing, emerging, and developed economies. This suggests that differences between country groups may be less visible when ICT is measured primarily through capital or investment. Results may also vary depending on whether studies use cross-sectional averages, pooled observations, fixed effects, or other panel-data techniques.

Firm-level research provides more detailed evidence on the underlying mechanisms. Commander et al. (2011) report a positive relationship between ICT capital and productivity in Brazil and India, while Gal et al. (2019) find that digital adoption improves productivity among European firms, although the gains are weaker where skills are limited. Borowiecki et al. (2021) and Nucci et al. (2023) also identify positive productivity effects, particularly in service industries. These studies highlight the importance of management quality, skills, innovation, and sectoral characteristics. They also help explain why macroeconomic results may differ, since national indicators aggregate firms and sectors with widely varying digital capabilities.

Another strand of the literature links digital connectivity to international trade in services. Freund and Weinhold (2002) show that the Internet promotes international services trade by reducing communication costs and barriers to cross-border delivery. Choi (2010) confirms that Internet expansion increases total services trade, exports, and imports. More recently, Oliinyk (2023) finds that participation in ICT services markets is associated with broader macroeconomic outcomes, including economic growth, inflation, and exchange-rate movements. These findings support the inclusion of ICT services trade in macroeconomic analysis. Nevertheless, most studies focus on trade or aggregate growth, leaving the employment and productivity implications of ICT services exports and imports comparatively underexplored.

ICT services exports and imports may also operate through different channels. Exports may reflect domestic digital competitiveness, the capacity to produce knowledge-intensive services, and integration into global digital markets. Imports may facilitate access to

foreign technology and digital inputs, but they may also indicate dependence on external ICT solutions. Imported services can improve efficiency and technology diffusion when domestic firms possess sufficient absorptive capacity. Their effects may be weak or negative when imported inputs are poorly integrated or substitute for domestic production. ICT services exports and imports should therefore be analysed separately rather than combined into a single measure of digitalisation.

The employment effects of digitalisation are even more ambiguous than its productivity effects. Acemoglu and Restrepo (2019) argue that technology can displace labour through automation while also creating new tasks through reinstatement effects. Goaied and Sassi (2019) identify labour-saving effects of ICT adoption, whereas Hjort and Poulsen (2019) find that access to fast Internet increased employment in Africa, including among less-educated workers. These contrasting findings indicate that employment effects depend on the type of technology, labour-market structure, skill composition, and stage of development. A positive relationship with productivity therefore does not necessarily imply a positive relationship with employment.

Recent studies similarly emphasise that digitalisation can support productivity and inclusion only under favourable conditions. Nayyar et al. (2024) argue that digital technologies can improve labour-market matching, reduce business inefficiencies, and support intangible-capital accumulation, but their effects on employment and wages remain uneven. Peña et al. (2020) show that digital-technology adoption is associated with higher productivity and changes in factor demand in developing economies, although these gains depend on firm capabilities and the business environment. The World Bank (2016, 2023) and UNCTAD (2024) likewise stress that digital access alone is insufficient for inclusive development. Complementary investments in skills, institutions, business upgrading, and productive capacity remain essential.

Several methodological and conceptual differences help explain the inconsistency of previous findings. First, ICT capital, investment, Internet use, digital readiness, and ICT services trade capture different dimensions of digital transformation. Second, GDP growth, labour productivity, employment, wages, and trade flows respond through different mechanisms. Third, firm-level studies identify microeconomic channels, while country-level studies capture broader structural relationships. Fourth, cross-sectional models largely reflect differences between countries, whereas fixed-effects models focus on changes within countries over time. Finally, endogeneity remains a persistent challenge because ICT adoption, productivity, employment, and income may be jointly determined.

The present study addresses these gaps in several ways. It distinguishes among ICT services exports, ICT services imports, and Internet use rather than treating digitalisation as a single aggregate factor. It examines both employment and labour productivity and compares advanced and developing economies using a consistent IMF-based classification. The empirical analysis applies country and year fixed effects to control for time-invariant national characteristics and common global shocks. It also includes controls for capital formation, education, services value added, institutional quality, and demographic structure, reflecting the complementary conditions emphasised in the literature.

Overall, the literature indicates that ICT is relevant to economic performance, but its effects are heterogeneous, conditional, and sensitive to measurement and methodology. Productivity effects are more consistently documented than employment effects, while the labour-market consequences of digitalisation remain context-dependent. Limited attention has been given to studies that jointly examine ICT services exports, ICT services imports, Internet use, employment, and labour productivity across advanced and developing economies. This study addresses that gap within a unified panel-data frame-

work and interprets the estimated relationships as conditional associations rather than causal effects.

3.METHODOLOGY

3.1. RESEARCH DESIGN AND THEORETICAL BACKGROUND

This study applies a panel-data regression framework to examine the relationship between ICT services trade, digital adoption, labour productivity, and employment in advanced and developing economies over the period 2006-2024.

The models are estimated separately for the two country groups to identify whether the associations between ICT-related variables and labour-market outcomes differ by level of development. This distinction is important because advanced economies generally have stronger absorptive capacity, more developed service sectors, better digital infrastructure, and more mature labour markets. In developing economies, digital transformation may operate through different channels, including labour-market restructuring, service-sector expansion, deeper trade integration, and the gradual diffusion of Internet use.

The theoretical framework draws on a reduced-form interpretation of the Solow growth model (Solow, 1957). In the standard Cobb-Douglas production function, output is determined by capital, labour, and technology:

$$Y_{it} = A_{it} \times K_{it}^{\alpha} \times L_{it}^{1-\alpha} \quad (1)$$

where (Y) denotes output, (A) represents technology or total factor productivity, (K) is capital, (L) is labour, and (\alpha) is the output elasticity of capital.

The Solow framework guides the selection of variables representing technology, capital accumulation, labour-market outcomes, and broader macroeconomic conditions. ICT services exports, ICT services imports and Internet use are used as technology-related indicators, while gross capital formation serves as a proxy for capital accumulation. Education, services value added, demographic structure, and institutional quality are included as complementary control variables.

3.2. COUNTRY SAMPLE

The analysis is based on a cross-country panel dataset covering the period 2006-2024. Countries are divided into two groups according to the International Monetary Fund classification used in the World Economic Outlook: advanced economies and emerging market and developing economies. For the purposes of this article, the IMF category "emerging market and developing economies" is referred to as "developing economies" (International Monetary Fund, 2025). The final sample includes 100 economies: 31 advanced economies and 69 developing economies (Table 1).

Table 1. Data description

Group	Countries
Advanced economies (31)	Australia; Austria; Belgium; Canada; Croatia; Cyprus; Czechia; Denmark; Estonia; Finland; Germany; Iceland; Israel; Italy; Japan; Korea, Republic of; Latvia; Lithuania; Netherlands; New Zealand; Norway; Poland; Portugal; Singapore; Slovakia; Slovenia; Spain; Sweden; Switzerland; United Kingdom; United States of America.
Developing economies (69)	Algeria; Argentina; Azerbaijan; Bahrain; Bangladesh; Belarus; Benin; Bosnia and Herzegovina; Botswana; Brazil; Brunei Darussalam; Bulgaria; Burkina Faso; Cameroon; Chile; Colombia; Comoros; Congo; Congo, Democratic Republic of the; Costa Rica; Côte d'Ivoire; Dominican Republic; Ecuador; Egypt; Ethiopia; Georgia; Guatemala; Guinea; Honduras; Hungary; Indonesia; Iran, Islamic Republic of; Kazakhstan; Kenya; Kyrgyzstan; Lesotho; Macedonia, North; Madagascar; Malaysia; Maldives; Mali; Malta; Mauritania; Mauritius; Moldova, Republic of; Montenegro; Namibia; Niger; Oman; Pakistan; Panama; Romania; Russian Federation; Rwanda; Saudi Arabia; Senegal; Serbia; South Africa; Sri Lanka; Tajikistan; Tanzania, United Republic of; Thailand; Togo; Tunisia; Uganda; Ukraine; United Arab Emirates; Uruguay; Uzbekistan.

Source: authors' compilation

3.3. VARIABLES AND DATA SOURCES

The study uses two dependent variables to capture labour-market performance and labour productivity. The employment-to-population ratio for individuals aged 15 and above (EMPL) is measured as a percentage of the population aged 15+, based on modelled ILO estimates from World Bank Open Data (2026). Labour productivity is represented by GDP per person employed (GDPpPE), measured in constant 2021 purchasing power parity dollars and obtained from World Bank Open Data (2026).

The main explanatory variables capture ICT services trade and digital adoption. ICT services exports (ICTExport) and ICT services imports (ICTImport) are measured as percentages of GDP using data from UNCTADstat (2026). Internet use (IntUser) is measured as the percentage of individuals using the Internet and is obtained from World Bank Open Data (2026).

The models also include several control variables. GDP growth (GDP), measured as the annual percentage change in GDP, captures short-term economic dynamics. GDP per capita (GDPpC), expressed in current U.S. dollars, controls for the level of economic development. Both variables are obtained from World Bank Open Data (2026). Inflation is represented by the annual percentage change in the consumer price index (CPI), while trade openness (TO) is measured as the sum of exports and imports of goods and services as a percentage of GDP. Both indicators are obtained from UNCTADstat (2026).

Political Stability and Absence of Violence/Terrorism (PS) controls for the institutional and political environment. Gross capital formation (GCF) captures investment and capital accumulation, while tertiary school enrolment (SE) serves as a proxy for human capital. Services value added (ServVA) controls for the sectoral structure of the economy, and the age dependency ratio (ADR) captures demographic pressure on the working-age population. The relevant control-variable data are obtained from World Bank Open Data and UNCTADstat (2026).

Table 2. Variables used in the regression model

Variable type	Code	Indicator	Measurement	Source
Dependent	EMPL	Employment to population ratio, 15+, total	% of population aged 15+	World Bank Open Data (2026)
Dependent	GDPpPE	GDP per person employed	constant 2021 PPP $	World Bank Open Data (2026)
Independent	IntUser	Individuals using the Internet	% of population	World Bank Open Data (2026)
Independent	ICTExport	ICT services exports	% of GDP	UNCTADstat (2026)
Independent	ICTImport	ICT services imports	% of GDP	UNCTADstat (2026)
Control	GDP	GDP growth	annual %	World Bank Open Data (2026)
Control	GDPpC	GDP per capita	current US$	World Bank Open Data (2026)
Control	CPI	Consumer price index	annual consumer price change / price-level indicator	UNCTADstat (2026)
Control	TO	Trade openness	trade in goods and services as % of GDP	UNCTADstat (2026)
Control	PS	Political Stability and Absence of Violence/Terrorism	estimate from (-2,5) to (2,5)	World Bank Open Data (2026)
Control	GCF	Gross capital formation	% of GDP	World Bank Open Data (2026)
Control	SE	School enrollment, tertiary	% gross	World Bank Open Data (2026)
Control	ServVA	Services, value added	% of GDP	World Bank Open Data (2026)
Control	ADR	Age dependency ratio	% of working-age population	World Bank Open Data (2026)

Source: authors' compilation

3.4. DATA TRANSFORMATION

The study covers the period from 2006-2024. To improve model quality and facilitate interpretation, the variables were transformed using inverse hyperbolic sine transformation, which is applied to all variables:

$$IHS(x) = \text{asinh}(x) = \ln\left(x + \sqrt{x^2 + 1}\right) \quad (2)$$

where x denotes the original value of the variable.

1.1. BASELINE ECONOMETRIC SPECIFICATION

The baseline empirical model is estimated separately for each dependent variable and each country group. The two dependent variables are employment and labour productivity. The baseline panel specification is as follows:

$$\begin{aligned} IHS(Y_{it}) = {} & \beta_o + \beta_1 IHS(ICTexport_{it}) + \beta_2 IHS(ICTimport_{it}) + \beta_3 IHS(IntUser_{it}) + \\ & + \beta_4 IHS(GDP_{it}) + \beta_5 IHS(GDPpC_{it}) + \beta_6 IHS(CPI_{it}) + \beta_7 IHS(TO_{it}) + \\ & + \beta_8 SL(PS_{it}) + \beta_9 IHS(GCF_{it}) + \beta_{10} IHS(SE_{it}) + \beta_{11} IHS(SEervVA_{it}) + \\ & + \beta_{12} IHS(ADR_{it}) + \mu_i + \lambda_i + \in_i \end{aligned} \quad (3)$$

where Y_{it} denotes either employment or labour productivity in country i and year t. The term μ_i represents country fixed effects, λ_i represents year fixed effects, and $\in_i$ is the error term.

The same specification is estimated separately for four country–outcome combinations: advanced economies with EMPL and GDPpPE as the dependent variables, and developing economies with EMPL and GDPpPE as the dependent variables.

Country fixed effects control for unobserved time-invariant characteristics, including geography, long-term institutional traditions, historical economic structures, and persistent differences in labour-market organisation. Year fixed effects account for global shocks and common time-specific influences, such as the global financial crisis, the COVID-19 pandemic, digitalisation trends, and other international macroeconomic developments affecting all countries in a given year.

3.5. ESTIMATION STRATEGY AND MODEL SELECTION

The empirical analysis employs a panel-data estimation strategy. Because the dataset contains repeated observations for each country over time, three alternative specifications are considered: pooled ordinary least squares, fixed effects, and random effects. This allows comparison between a pooled model and specifications that account for unobserved country-specific heterogeneity.

The starting point of the estimation strategy is the pooled OLS model (Fisher, 1925):

$$IHS(Y_{it}) = \beta_o + \beta X_{it} + \in_{it} \quad (4)$$

where Y_{it} denotes either employment or labour productivity in country i and year t, is the vector of explanatory variables, β is the vector of estimated coefficients, and $\in_{it}$ is the error term.

The pooled OLS model treats all country-year observations as homogeneous after controlling for the included explanatory variables. This assumption may be restrictive in cross-country macroeconomic analysis because countries differ in persistent characteristics, including institutional traditions, labour-market structures, geography, historical development paths, and technological capacity. When these unobserved characteristics are correlated with the regressors, pooled OLS estimates may be biased.

To address this limitation, the study also estimates a fixed-effects model, specified as follows:

$$IHS(Y_{it}) = \beta X_{it} + \mu_i + \lambda_i + \in_{it} \quad (5)$$

where μ_i denotes country-specific effects and λ_i denotes year-specific effects. Country effects capture time-invariant unobserved heterogeneity across economies, while year effects control for common shocks affecting all countries in a given year, such as global crises, technological waves, or worldwide macroeconomic changes. The fixed effects estimator therefore focuses on within-country variation over time.

In addition, the random effects model is estimated (Wallace & Hussain, 1969):

$$IHS(Y_{it}) = \beta X_{it} + \alpha_i + \epsilon_{it} \quad (6)$$

where α denotes the unobserved country-specific random effect. The random-effects model assumes that these country effects are uncorrelated with the explanatory variables. When this assumption holds, the random-effects estimator is more efficient than the fixed-effects estimator because it uses both within-country and between-country variation. When the assumption is violated, the fixed-effects estimator is preferred because it remains consistent in the presence of correlation between unobserved country characteristics and the regressors.

Several diagnostic tests are used to select the appropriate model specification, with the results reported in the empirical section. First, the F-test compares pooled OLS with the fixed-effects model by testing whether the country-specific effects are jointly equal to zero. Under the null hypothesis, no significant country effects are present and pooled OLS is adequate. Rejection of the null indicates that country-specific effects are significant and that the fixed-effects model is more appropriate.

The test statistic is expressed as:

$$F = \frac{(RSS_{OLS} - RSS_{FE}) / q}{RSS_{FE} / (NT - n - k)} \quad (7)$$

where RSS_{OLS} and RSS_{FE} denote the residual sums of squares from the pooled OLS and fixed-effects models, respectively; (N) is the number of countries; (T) is the number of time periods; ($q=N-1$) is the number of restrictions; and (k) is the number of explanatory variables. Rejection of the null hypothesis indicates that country-specific effects are relevant and that the fixed-effects model is preferable to pooled OLS.

The Breusch–Pagan Lagrange Multiplier test compares pooled OLS with the random-effects model by testing whether the variance of the unobserved country-specific component is equal to zero. Under the null hypothesis, no random effects are present and pooled OLS is appropriate. Rejection of the null indicates that country-level heterogeneity is statistically significant and that the random-effects model is preferable to pooled OLS (Breusch & Pagan, 1980). The test therefore determines whether the panel structure of the data should be explicitly incorporated into the estimation.

The Hausman test is used to choose between the fixed-effects and random-effects models. It examines whether the unobserved country-specific effects are correlated with the explanatory variables. Under the null hypothesis, the random-effects estimator is consistent and efficient because the individual effects are uncorrelated with the regressors. Rejection of the null indicates that the random-effects estimator is inconsistent and that the fixed-effects model should be preferred (Hausman, 1978).

4. RESULTS

4.1. DESCRIPTIVE STATICTICS AND MODEL DIAGNOSTICS

The empirical analysis uses an unbalanced panel covering the period 2006–2024. The baseline sample comprises 513 country-year observations for 31 advanced economies and 1,024 observations for 69 developing economies. The unbalanced structure reflects

differences in data availability across countries and indicators, which are common in cross-country macroeconomic datasets.

Table 3 reports descriptive statistics for the variables included in the baseline models. The results reveal substantial structural differences between the two country groups. Advanced economies exhibit higher average labour productivity, Internet use, ICT services export intensity, GDP per capita, tertiary education enrolment, and political stability. Average GDP per person employed is approximately USD 105,4 thousand in advanced economies, compared with USD 43,7 thousand in developing economies. The average share of Internet users is 81,9% and 43,5%, respectively, while ICT services exports account for an average of 1,87% of GDP in advanced economies and 0,70% in developing economies.

Developing economies display greater dispersion across most indicators, particularly labour productivity, Internet use, GDP per capita, tertiary education, and the age dependency ratio. This variation reflects the heterogeneity of the group in terms of income, institutional development, demographic structure, digital infrastructure, and integration into international services trade. It also supports the decision to estimate separate models for advanced and developing economies.

The correlation analysis shows that ICT services exports, ICT services imports, and Internet use are not strongly correlated and therefore capture distinct dimensions of digitalisation. In advanced economies, the correlations are 0,089 between ICTExport and ICTImport, 0,195 between ICTExport and IntUser, and 0,315 between ICTImport and IntUser. The corresponding values for developing economies are 0,041, 0,225, and 0,226.

Among advanced economies, the strongest correlations are observed between GDP growth and trade openness (-0,575), Internet use and GDP per capita (0,564), and ICT services exports and trade openness (0,515). These values are moderate and do not suggest severe linear dependence among the regressors.

Stronger correlations are present in the developing-economy sample. GDP per capita is negatively correlated with the age dependency ratio (-0,810), while Internet use is positively correlated with tertiary enrolment (0,778), and GDP per capita is positively correlated with tertiary enrolment (0,775). These relationships indicate that income, education, Internet diffusion, and demographic structure are closely connected in developing economies. They should therefore be considered jointly in the regression analysis, although the relatively high correlations also warrant formal multicollinearity checks.

Table 3. Descriptive statistics of IHS-transformed variables, baseline sample, 2006-2024

Variable	Advanced economies: Mean	Advanced economies: SD	Developing economies: Mean	Developing economies: SD
EMPL	4,7394	0,1126	4,7011	0,2079
GDPpPE	12,2200	0,2794	11,0118	0,9531
ICTExport	1,1093	0,7058	0,5526	0,5275
ICTImport	0,7430	0,5841	0,4779	0,4627
IntUser	5,0818	0,1917	4,0083	1,2079
GDP	27,2141	1,6293	25,3709	1,6090
GDPpC	11,1717	0,5457	9,0122	1,1646
CPI	1,3287	0,9117	1,9766	1,1363
TO	5,2398	0,4656	4,9435	0,5803
PS	0,6653	0,4249	-0,2780	0,6550
GCF	3,8385	0,1736	3,8745	0,3506
SE	4,9945	0,1964	3,9491	0,9416
ServVA	4,8445	0,0919	4,6260	0,1859
ADR	4,6160	0,1509	4,7215	0,3009

Source: authors' calculations

To assess multicollinearity more formally, variance inflation factors were calculated for all explanatory variables. In the advanced-economy sample, the maximum VIF is 3,103, indicating that multicollinearity is not a serious concern. In the developing-economy sample, the highest VIF is 6,415 for GDP per capita. This suggests moderate overlap with other development-related variables, particularly tertiary education, Internet use, and the age dependency ratio, but does not indicate severe multicollinearity.

The next stage is to determine whether pooled OLS, fixed effects, or random effects provide the most appropriate panel specification. Because the dataset contains repeated observations for the same countries over time, ignoring country-specific heterogeneity may produce biased estimates. As reported in Table 4, pooled OLS is first compared with the fixed-effects model using the F-test. The null hypothesis states that the country and year effects are jointly equal to zero and that pooled OLS is adequate. Rejection of the null indicates that unobserved effects are statistically significant and that the fixed-effects model is more appropriate.

Table 4. F-test for fixed effects against pooled OLS

Group	Dependent variable	F-statistic	p-value
Advanced economies	EMPL	105,523	<0,001
Advanced economies	GDPpPE	150,149	<0,001
Developing economies	EMPL	206,000	<0,001
Developing economies	GDPpPE	169,481	<0,001

Source: authors' calculations

The F-test strongly rejects pooled OLS in all four baseline models, indicating that country and year effects are jointly significant. Pooled OLS is therefore unsuitable as the main estimator because it does not adequately account for unobserved country heterogeneity or common time shocks.

Random effects models were also considered. The random-intercept specification confirms that country-level heterogeneity is statistically significant relative to pooled OLS. However, the random-effects estimator assumes that unobserved country-specific effects are uncorrelated with the explanatory variables. This assumption is restrictive in cross-country macroeconomic analysis, since ICT services trade, Internet use, GDP per capita, education, institutional quality, and sectoral structure are likely to be related to persistent country characteristics.

The Hausman test was therefore used to compare the fixed-effects and random-effects estimators. The results are reported in Table 5.

Table 5. Hausman test for fixed effects versus random effects

Group	Dependent variable	Hausman statistic	p-value	Interpretation
Advanced economies	EMPL	15,201	0,231	Random effects are statistically acceptable, but FE is retained as conservative baseline
Advanced economies	GDPpPE	61,299	<0,001	Fixed effects preferred
Developing economies	EMPL	51,742	<0,001	Fixed effects preferred
Developing economies	GDPpPE	—	—	Test inconclusive due to covariance-matrix limitations; FE retained as conservative baseline

Source: authors' calculations

The Hausman diagnostics provide further support for using fixed effects as the main specification. The test rejects the random-effects assumption for the labour-productivity model in advanced economies and the employment model in developing economies, indicating that unobserved country-specific factors are correlated with the regressors. For the advanced-economy employment model, random effects remain statistically admissible, but fixed effects are retained to ensure consistency across specifications and because the analysis focuses on within-country changes over time. For the developing-economy productivity model, the Hausman test is inconclusive because the covariance-difference matrix is not positive definite. Fixed effects are therefore retained as the more conservative option, since they do not require the orthogonality assumption imposed by random effects.

These diagnostics determine the final estimation strategy. Pooled OLS is reported only as a benchmark because the F-tests reject the absence of country and year effects. Random effects are also considered, but their identifying assumption is restrictive in this cross-country setting. Fixed effects are therefore used as the baseline estimator because they control for unobserved time-invariant country characteristics and common year-specific shocks.

Heteroskedasticity was assessed using the Breusch–Pagan test. The null hypothesis of homoskedasticity is rejected in all four baseline models. The test statistics are 118,71 for advanced economies with employment, 156,46 for advanced economies with labour productivity, 105,87 for developing economies with employment, and 63,04 for developing economies with labour productivity, with ($p<0,001$) in every case. Accordingly, inference is based on country-clustered robust standard errors, which account for heteroskedasticity and within-country dependence over time.

Overall, the descriptive and diagnostic results support the use of fixed-effects models with country-clustered robust standard errors. The descriptive statistics confirm substantial differences between advanced and developing economies, while the correlation and VIF diagnostics indicate that multicollinearity is not severe. Nevertheless, GDP per capita warrants additional robustness analysis in the developing-economy sample. The model-selection tests reject pooled OLS, and the Hausman diagnostics generally favour fixed effects as the main empirical specification.

4.2. REGRESSION ANALYSIS

Table 6 presents the baseline fixed effects regression results for advanced and developing economies over the period 2006-2024. The reported p-values are based on country-clustered robust standard errors. The models include both country and year fixed effects, which makes it possible to control for unobserved time-invariant country characteristics and common shocks affecting all countries in particular years.

Table 6. Fixed effects regression results, 2006-2024

Variable	Advanced economies EMPL	Advanced economies GDPpPE	Developing economies EMPL	Developing economies GDPpPE
ICTExport	0,011** (0,043)	-0,001 (0,878)	0,013 (0,455)	-0,023 (0,301)
ICTImport	0,013 (0,143)	-0,012 (0,194)	0,005 (0,689)	-0,016 (0,459)
IntUser	0,061*** (0,003)	0,004 (0,935)	-0,021** (0,043)	0,030** (0,048)
GDP	-0,052 (0,381)	-0,152* (0,092)	-0,090 (0,391)	-0,043 (0,786)
GDPpC	0,205*** (0,000)	0,434*** (0,000)	0,154 (0,120)	0,327** (0,039)
CPI	0,007*** (0,006)	0,011*** (0,004)	0,003 (0,287)	-0,004 (0,567)
TO	0,092*** (0,001)	0,153*** (0,001)	0,012 (0,447)	-0,024 (0,407)
PS	0,012 (0,294)	0,007 (0,735)	-0,004 (0,776)	0,051** (0,042)
GCF	0,088*** (0,000)	-0,048** (0,045)	0,019 (0,378)	0,048 (0,104)
SE	-0,038 (0,120)	-0,060** (0,048)	0,031* (0,094)	0,013 (0,674)
ServVA	-0,064 (0,350)	0,177* (0,094)	0,134** (0,013)	-0,282*** (0,007)
ADR	0,082 (0,168)	0,142 (0,180)	0,010 (0,909)	0,387*** (0,000)
Observations	513	513	1 024	1 024
Countries	31	31	69	69
R-squared	0,734	0,844	0,231	0,707
Adjusted R-squared	0,717	0,834	0,208	0,698
Significance F	<0,001	<0,001	<0,001	<0,001

Note: p-values are reported in parentheses. All regressions include country and year fixed effects. P-values are based on country-clustered robust standard errors. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

Source: authors' calculations

The results show that ICT-related variables are associated differently with employment and labour productivity in advanced economies. ICT services exports are positively and statistically significantly associated with employment ((0,011), (p<0,05)). This suggests that stronger ICT services export intensity may support employment in high-value and knowledge-intensive activities, including software development, professional services, and digital business services.

Internet use also has a positive and highly significant association with employment ((0,061), (p<0,01)). Broader Internet diffusion may facilitate access to digital jobs, remote work, online services, platform-based activities, and more flexible forms of employment. The stronger statistical significance of IntUser suggests that domestic digital diffusion may be more closely associated with employment than external ICT services trade.

By contrast, ICT services imports are not significantly associated with employment ((0,013), (p=0,143)). Imported ICT services may support existing production and service processes without necessarily generating additional domestic employment.

The results differ for labour productivity. ICTExport, ICTImport, and IntUser are all statistically insignificant in the GDPpPE model, with coefficients of (-0,001), (-0,012), and (0.004),

respectively. Thus, after controlling for country and year effects and other macroeconomic, institutional, structural, and demographic factors, ICT services trade and Internet use show no statistically confirmed association with labour productivity in advanced economies.

Instead, labour productivity is more strongly associated with broader economic and structural factors. GDP per capita ((=0,434), (p<0,01)) and trade openness ((=0,153), (p<0,01)) are positively associated with productivity. CPI is also positive and significant, while gross capital formation and tertiary education have negative and statistically significant coefficients. These findings suggest that productivity variation in advanced economies is more closely related to income levels, openness, macroeconomic conditions, and structural characteristics than to ICT-related variables alone. One possible explanation is that advanced economies have reached relatively high levels of digital maturity, so further increases in ICT services trade or Internet use do not automatically produce measurable productivity gains.

The results for developing economies reveal a distinct pattern. ICT services exports and imports are not statistically significant in the employment model. The coefficients for ICTExport and ICTImport are 0,013 and 0,005, respectively, with (p>0,10) in both cases. Unlike advanced economies, developing economies therefore show no significant association between ICT services trade and employment. This may reflect weaker absorptive capacity, limited participation in high-value ICT services, less developed digital ecosystems, and a larger share of informal or low-productivity employment.

Internet use, by contrast, is negatively associated with employment in developing economies ((=-0,021), (p<0,05)). This result should not be interpreted as evidence that Internet use directly reduces employment. Rather, digital diffusion may accompany labour-market restructuring through automation, sectoral reallocation, changes in informal employment, and a shift from low-skilled to more digitally intensive activities. The negative short- and medium-term association may therefore coexist with longer-term structural transformation.

The control variables support this interpretation. Tertiary education is positively and weakly associated with employment ((0,031), (p<0,10)), while services value added has a positive and statistically significant coefficient ((0,134), (p<0,05)). This suggests that the employment effects of digitalisation depend partly on complementary conditions, particularly human capital and economic structure.

For labour productivity, Internet use has a positive and statistically significant coefficient ((0,030), (p<0,05)). Combined with its negative employment coefficient, this finding suggests that digital adoption in developing economies is more closely associated with productivity-enhancing transformation than with immediate employment expansion. Internet diffusion may improve access to information, reduce transaction costs, increase business efficiency, and facilitate technology diffusion without proportionally increasing total employment.

ICTExport and ICTImport remain statistically insignificant in the productivity model, with coefficients of (-0,023) and (-0,016), respectively. This may indicate that ICT services trade remains too limited or concentrated in activities that do not yet generate economy-wide productivity gains.

Several control variables are significant. GDP per capita ((0,327), (p<0,05)) and political stability ((0,051), (p<0,05)) are positively associated with labour productivity. The age dependency ratio also has a positive and highly significant coefficient ((0,387), (p<0,01)), while services value added is negatively associated with productivity ((-0,282), (p<0,01)). The latter result may reflect the predominance of low-productivity, informal, or labour-intensive services in some developing economies.

The comparison between country groups highlights important differences. In advanced economies, ICT services exports and Internet use are positively associated with employ-

ment. In developing economies, ICT services trade is not significantly related to either outcome, while Internet use is negatively associated with employment and positively associated with productivity. Digitalisation therefore appears to operate through different channels depending on the level of development.

Pooled OLS and random-effects models were estimated as auxiliary specifications. The pooled results are less stable and partly reflect between-country differences, while the random-effects estimates broadly confirm the main Internet-use relationships. Nevertheless, the Hausman diagnostics support fixed effects as the preferred baseline specification.

Overall, the findings show that ICT services exports, ICT services imports, and Internet use capture different dimensions of digital transformation. ICTExport is relevant primarily for employment in advanced economies, ICTImport is insignificant across the baseline models, and Internet use is the most consistent ICT-related variable. Its relationship, however, varies across country groups and outcomes, supporting the separate analysis of advanced and developing economies.

4.3. ROBUSTNESS CHECK

To assess the stability of the baseline fixed-effects results, two additional specifications were estimated (Table 7). First, the models were re-estimated without GDP per capita, since GDPpC is a broad development indicator that may overlap with Internet use, tertiary education, capital formation, and services value added. Second, the main ICT-related variables-ICTExport, ICTImport, and IntUser were introduced with a one-year lag, while the control variables remained contemporaneous. This specification tests whether ICT-related factors affect employment and labour productivity with a delay.

The results without GDPpC confirm the main baseline findings. In the advanced-economy employment model, ICTExport remains positive and statistically significant ((0,014), ($p<0,05$)), indicating that its relationship with employment is not driven by the inclusion of GDP per capita. IntUser also remains positive and highly significant ((0,080), ($p<0,01$)), confirming the stability of the association between Internet diffusion and employment in advanced economies.

For developing economies, IntUser remains negatively associated with employment ((0,024), ($p<0,05$)), showing that this relationship is also robust to the exclusion of GDPpC. At the same time, Internet use remains positively associated with labour productivity, although the coefficient is significant only at the 10% level ((0,024), ($p<0,10$)). Overall, these results reinforce the view that Internet diffusion in developing economies is more closely linked to productivity-enhancing structural transformation than to immediate employment growth.

Table 7. Robustness checks, fixed effects results, 2006-2024

Variable	Adv. EMPL Without GDPpC	Adv. EMPL Lag 1	Adv. GDPpPE Without GDPpC	Adv. GDPpPE Lag 1	Dev. EMPL Without GDPpC	Dev. EMPL Lag 1	Dev. GDPpPE Without GDPpC	Dev. GDP-pPE Lag 1
ICTExport	0,014** (0,029)	0,008 (0,213)	0,005 (0,584)	-0,008 (0,276)	0,020 (0,248)	0,012 (0,571)	-0,007 (0,730)	-0,036 (0,147)
ICTImport	0,005 (0,511)	0,011 (0,217)	-0,028** (0,047)	-0,013 (0,226)	0,007 (0,580)	0,005 (0,697)	-0,012 (0,590)	-0,014 (0,530)
IntUser	0,080*** (0,000)	0,057*** (0,006)	0,044 (0,439)	-0,002 (0,965)	-0,024** (0,031)	-0,020** (0,029)	0,024* (0,058)	0,034** (0,020)
GDP	0,146*** (0,000)	-0,071 (0,286)	0,267*** (0,000)	-0,138 (0,147)	0,066*** (0,005)	-0,070 (0,497)	0,287*** (0,000)	-0,103 (0,520)
GDPpC	—	0,221*** (0,000)	—	0,429*** (0,000)	—	0,136 (0,172)	—	0,375** (0,019)
CPI	0,007** (0,016)	0,007*** (0,005)	0,011*** (0,005)	0,011*** (0,001)	0,003 (0,170)	0,003 (0,265)	-0,002 (0,759)	-0,003 (0,615)
TO	0,123*** (0,000)	0,097*** (0,000)	0,218*** (0,000)	0,167*** (0,000)	0,017 (0,264)	0,012 (0,449)	-0,015 (0,626)	-0,026 (0,335)
PS	0,019* (0,095)	0,012 (0,277)	0,021 (0,357)	0,005 (0,800)	0,002 (0,886)	-0,005 (0,678)	0,063** (0,010)	0,051** (0,043)
GCF	0,085*** (0,000)	0,091*** (0,000)	-0,054** (0,035)	-0,046* (0,078)	0,013 (0,495)	0,018 (0,397)	0,037 (0,226)	0,053* (0,054)
SE	-0,062** (0,033)	-0,036 (0,166)	-0,111** (0,020)	-0,057* (0,070)	0,019 (0,336)	0,029 (0,125)	-0,013 (0,657)	0,015 (0,631)
ServVA	-0,109 (0,130)	-0,054 (0,363)	0,081 (0,588)	0,165 (0,117)	0,137*** (0,008)	0,143*** (0,008)	-0,276** (0,010)	-0,278*** (0,008)
ADR	0,156** (0,012)	0,087 (0,129)	0,296** (0,030)	0,144 (0,168)	0,094 (0,313)	0,028 (0,749)	0,566*** (0,000)	0,370*** (0,001)
Observations	513	506	513	506	1 024	1 010	1 024	1 010
Countries	31	31	31	31	69	69	69	69
R-squared	0,710	0,738	0,813	0,844	0,210	0,226	0,692	0,709
Adjusted R-squared	0,693	0,722	0,802	0,834	0,187	0,203	0,683	0,700
Significance F	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001

Note: p-values are reported in parentheses. All regressions include country and year fixed effects. P-values are based on country-clustered robust standard errors. ***, ** *and* * *denote significance at the 1%, 5% and 10% levels, respectively.*

Source: authors' calculations

After GDPpC is excluded, ICTImport becomes negative and statistically significant in the advanced-economy productivity model ((-0,028), (p<0,05)). Because this relationship is not significant in the baseline specification, it should be interpreted cautiously. The result suggests sensitivity to the inclusion of broad development-level controls but does not provide sufficiently robust evidence for a central conclusion.

The one-year lag specification provides further insight into the timing of the estimated relationships. In advanced economies, lagged Internet use remains positively associated with employment ((0,057), (p<0,01)), indicating that the relationship persists with a one-year delay. By contrast, lagged ICT services exports and imports are not statistically significant.

In developing economies, lagged Internet use remains negatively associated with employment ((-0,020), (0,05)) and positively associated with labour productivity ((0,034), (p<0,05)). These results reinforce the interpretation that Internet diffusion is associated with labour-market restructuring and productivity-enhancing transformation rather than immediate employment expansion.

Lagged ICTExport and ICTImport are insignificant in most specifications, indicating no stable delayed relationship with either employment or labour productivity. Overall, the robustness analysis confirms Internet use as the most consistent ICT-related variable, while ICT services exports show a narrower association, primarily with employment in advanced economies.

5. DISCUSSION

The findings show that ICT services exports, ICT services imports, and Internet use are associated with employment and labour productivity in different ways across advanced and developing economies. Digitalisation should therefore not be treated as a homogeneous process. Its economic effects depend on the level of development, absorptive capacity, sectoral structure, institutional conditions, and the specific ICT indicator considered (Cardona et al., 2013; Jorgenson & Vu, 2016; OECD, 2019).

In advanced economies, ICT services exports are positively associated with employment. The coefficient is 0,011 ((p<0,05)) in the baseline fixed-effects model and 0,014 ((p<0,05)) in the specification excluding GDP per capita. This suggests that stronger participation in ICT services exports is linked to better employment outcomes. Advanced economies may be better able to convert ICT export activity into jobs in software, professional services, digital business activities, and other knowledge-intensive sectors. This interpretation is consistent with research emphasising the importance of digital capabilities and service-sector development (Freund & Weinhold, 2002; Choi, 2010; Borowiecki et al., 2021; Nucci et al., 2023).

Internet use also shows a stable positive association with employment in advanced economies. The coefficient is 0,061 ((p<0,01)) in the baseline model, 0,080 ((p<0,01)) when GDP per capita is excluded, and 0,057 ((p<0,01)) in the one-year lag specification. Broader Internet diffusion may support labour-market participation through remote work, platform-based activity, digital services, and the expansion of ICT-enabled occupations. These findings are consistent with the view that digitalisation supports employment more effectively when combined with skills, institutional quality, and mature service-sector conditions (OECD, 2019; World Bank, 2023; Nayyar et al., 2024).

By contrast, ICT-related variables do not show a stable association with labour productivity in advanced economies. ICT services exports, ICT services imports, and Internet use are statistically insignificant in the baseline productivity model. One possible explanation is that advanced economies have reached relatively high levels of digital maturity, limiting the measurable productivity effects of further increases in ICT trade or Internet diffusion. Productivity in this group appears to depend more strongly on broader macroeconomic and structural conditions, including income levels, trade openness, capital formation, education, and sectoral composition. This is consistent with evidence that ICT-related productivity gains depend on complementary organisational, institutional, and human-capital capabilities (Cardona et al., 2013; Gal et al., 2019; Borowiecki et al., 2021).

For developing economies, ICT services exports and imports are not significantly associated with either employment or labour productivity. This suggests that ICT services trade has not yet generated broad and stable economy-wide effects in this group. Possible explanations include limited participation in high-value ICT services, weaker absorptive capacity, and greater dependence on education, institutions, demographic conditions, and sectoral structure. Previous studies similarly show that the benefits of digitalisation in developing economies depend on domestic capabilities and the wider business environment (Papaioannou & Dimelis, 2007; Peña et al., 2020; Oliinyk et al., 2024).

Internet use is the most important ICT-related variable in developing economies. It is negatively associated with employment in the baseline model ((-0,021), (p<0,05)), and

this relationship remains stable when GDP per capita is excluded and when Internet use is lagged by one year. This should not be interpreted as evidence that Internet diffusion directly reduces employment. A more cautious interpretation is that digital adoption accompanies labour-market restructuring through automation, sectoral reallocation, changes in informal employment, and shifts from routine to more digitally intensive tasks. This interpretation is consistent with the literature showing that technological change may simultaneously displace some forms of labour and create others (Acemoglu & Restrepo, 2019; Goaied & Sassi, 2019).

At the same time, Internet use is positively associated with labour productivity in developing economies. The coefficient is 0,030 ((p<0,05)) in the baseline model and 0,034 ((p<0,05)) in the one-year lag specification. Internet diffusion may therefore support productivity-enhancing transformation by improving access to information, lowering transaction costs, strengthening business efficiency, and facilitating digital service delivery. However, these gains may occur alongside employment restructuring rather than immediate employment expansion. This finding is consistent with evidence that digital adoption can improve productivity while producing uneven labour-market effects (Peña et al., 2020; Nayyar et al., 2024; UNCTAD, 2024).

Overall, the results reveal distinct development patterns. In advanced economies, ICT services exports and Internet use are positively associated with employment. In developing economies, Internet use is associated with higher labour productivity but lower employment, which may reflect structural transformation. ICT services imports do not show a robust relationship with either outcome. These findings confirm the importance of analysing ICT services trade and domestic digital adoption separately (World Bank, 2016; World Bank, 2023; UNCTAD, 2024).

The estimates should be interpreted as conditional associations rather than causal effects. Although country and year fixed effects, country-clustered robust standard errors, and lagged specifications improve the reliability of the analysis, endogeneity cannot be fully eliminated. ICT services trade, Internet use, productivity, employment, and income may be jointly determined. The results therefore identify statistically significant relationships, not direct causal impacts. This caution is consistent with previous research emphasising the sensitivity of ICT estimates to measurement, model specification, and country context (Cardona et al., 2013; Niebel, 2018; Nayyar et al., 2024).

From a policy perspective, the findings suggest that digital strategies should differ across country groups. Advanced economies may benefit from policies that strengthen ICT services export capacity and digital labour-market participation. Developing economies should combine Internet expansion with investment in skills, business upgrading, productive employment, and institutional capacity. Without these complementary conditions, digitalisation may raise productivity while contributing to labour-market restructuring rather than broad employment growth (OECD, 2019; World Bank, 2016; UNCTAD, 2024).

6. CONCLUSION

This article examined the relationship between ICT services trade, Internet use, employment, and labour productivity in advanced and developing economies over the period 2006–2024. The analysis applied fixed-effects panel models with country and year effects, country-clustered robust standard errors, and inverse hyperbolic sine transformations. Countries were classified according to the IMF World Economic Outlook.

The findings show that ICT services exports, ICT services imports, and Internet use are associated differently with labour-market and productivity outcomes. These indicators

should therefore not be treated as interchangeable measures of digitalisation. ICT services exports capture external digital competitiveness, ICT services imports reflect reliance on foreign digital inputs, and Internet use represents domestic digital diffusion. In advanced economies, ICT services exports and Internet use are positively associated with employment. These relationships remain stable in the robustness specifications, suggesting that advanced economies are better positioned to translate digital competitiveness and Internet diffusion into employment opportunities, particularly in knowledge-intensive and digitally enabled activities.

By contrast, ICT-related variables do not show a stable relationship with labour productivity in advanced economies. Productivity appears to depend more strongly on broader structural and macroeconomic conditions, including income levels, trade openness, capital formation, education, and sectoral characteristics. This may also reflect digital maturity, whereby further increases in ICT services trade or Internet use generate limited additional productivity gains. Developing economies display a different pattern. ICT services exports and imports are not significantly associated with either employment or labour productivity. Their limited role may reflect weaker integration into high-value ICT services, lower absorptive capacity, and greater dependence on institutional, educational, and structural conditions. Internet use is the most important ICT-related variable in developing economies. It is negatively associated with employment but positively associated with labour productivity, and this pattern remains broadly stable across the robustness checks. These results should not be interpreted as evidence that Internet diffusion directly reduces employment. Rather, they suggest that digital adoption may support productivity-enhancing transformation while contributing to labour-market restructuring, sectoral reallocation, and changes in the composition of employment.

The robustness analysis confirms the main findings. Excluding GDP per capita does not alter the principal employment results for advanced economies or the main Internet-use relationships for developing economies. The one-year lag specification also confirms Internet use as the most stable ICT-related variable. ICT services imports, in contrast, do not show a robust association with either outcome. The study has several limitations. The estimates identify conditional associations rather than causal effects, since ICT services trade, Internet use, productivity, and employment may be jointly determined. The use of country-level data also prevents the identification of firm-level and sector-specific mechanisms. In addition, developing economies form a highly heterogeneous group.

Future research could distinguish between income groups, regions, and forms of digital specialisation, while also applying dynamic panel models, instrumental-variable methods, or sector-level data. The policy implications differ across country groups. Advanced economies may strengthen employment by supporting ICT services exports, digital business ecosystems, and Internet-enabled labour-market participation. Developing economies should combine Internet expansion with investment in skills, business upgrading, institutional capacity, and productive employment. Without these complementary conditions, digitalisation may raise productivity while intensifying labour-market restructuring rather than generating broad employment growth.

REFERENCES

Acemoglu, D., & Restrepo, P. (2019). Automation and new tasks: How technology displaces and reinstates labor. *Journal of Economic Perspectives, 33*(2), 3–30. https://doi.org/10.1257/jep.33.2.3

Borowiecki, M., Pareliussen, J., Glocker, D., Kim, E. J., Polder, M., & Rud, I. (2021). *The impact of digitalisation on productivity: Firm-level evidence from the Netherlands*. *OECD Economics Department Working Papers*, No. 1680. OECD Publishing. https://doi.org/10.1787/e800ee1d-en

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies, 47(1), 239–253. https://doi.org/10.2307/2297111

Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. *Information Economics and Policy, 25*(3), 109–125. https://doi.org/10.1016/j.infoecopol.2012.12.002

Choi, C. (2010). The effect of the Internet on service trade. *Economics Letters, 109*(2), 102–104. https://doi.org/10.1016/j.econlet.2010.08.005

Commander, S., Harrison, R., & Menezes-Filho, N. (2011). ICT and productivity in developing countries: New firm-level evidence from Brazil and India. *Review of Economics and Statistics, 93*(2), 528–541. https://doi.org/10.1162/REST_a_00080

Fisher, R. A. (1925). Statistical Methods for Research Workers. Oliver and Boyd.

Freund, C., & Weinhold, D. (2002). The Internet and international trade in services. *American Economic Review, 92*(2), 236–240. https://doi.org/10.1257/000282802320189320

Gal, P., Nicoletti, G., Renault, T., Sorbe, S., & Timiliotis, C. (2019). Digitalisation and productivity: In search of the holy grail – Firm-level empirical evidence from EU countries. *OECD Economics Department Working Papers*, No. 1533. Paris: OECD Publishing. https://doi.org/10.1787/5080f4b6-en

Goaied, M., & Sassi, S. (2019). The effect of ICT adoption on labour demand: A cross-region comparison. *Papers in Regional Science, 98*(1), 3–16. https://doi.org/10.1111/pirs.12321

Hausman, J. A. (1978). Specification tests in econometrics. Econometrica, 46(6), 1251–1271. https://doi.org/10.2307/1913827

Hjort, J., & Poulsen, J. (2019). The arrival of fast Internet and employment in Africa. *American Economic Review, 109*(3), 1032–1079. https://doi.org/10.1257/aer.20161385

International Monetary Fund. (2025). World Economic Outlook Database: Groups and Aggregates Information, April 2025. International Monetary Fund. https://www.imf.org/en/publications/weo/weo-database/2025/april/groups-and-aggregates

Jorgenson, D. W., & Vu, K. M. (2016). The ICT revolution, world economic growth, and policy issues. *Telecommunications Policy, 40*(5), 383–397. https://doi.org/10.1016/j.telpol.2016.01.002

Kovtoniuk, K., Molchanova, E., Oliinyk, A., Huliaieva, L., Kulyk, Y., & Demkiv, Y. (2024). Cost-effectiveness of digitalisation in Europe. In *2024 14th International Conference on Advanced Computer Information Technologies (ACIT)* (pp. 280–283). IEEE. https://doi.org/10.1109/ACIT62333.2024.10712585

Nayyar, G., Pleninger, R., Vorisek, D., & Yu, S. (2024). *Digitalization and inclusive growth: A review of the evidence*. *World Bank Policy Research Working Paper*, No. 10941. https://doi.org/10.1596/1813-9450-10941

Niebel, T. (2018). ICT and economic growth – Comparing developing, emerging and developed countries. *World Development, 104*, 197–211. https://doi.org/10.1016/j.worlddev.2017.11.024

Nucci, F., Puccioni, C., & Ricchi, O. (2023). Digital technologies and productivity: A firm-level investigation. *Economic Modelling, 128*, 106524. https://doi.org/10.1016/j.econmod.2023.106524

OECD. (2019). *Going digital: Shaping policies, improving lives*. Paris: OECD Publishing. https://doi.org/10.1787/9789264312012-en

OECD. (2024). *OECD Digital Economy Outlook 2024 (Volume 2): Strengthening Connectivity, Innovation and Trust*. OECD Publishing, Paris. https://doi.org/10.1787/3adf705b-en

Oliinyk, A. (2023). The Impact of Countries' Participation in The ICT Services Market on Economi Growth, CPI, and Exchange Rates. *ECONOMICS - Innovative and Economics Research Journal*, 11(1), 269-287. https://doi.org/10.2478/eoik-2023-0009

Oliinyk, A., Melnyk, T., Kovtoniuk, K., Huliaieva, L., Molchanova, E., & Tkachenko, I. (2024). ICT investment impact on economic growth: Comparing developing and advanced economies. In 2024 14th International Conference on Advanced Computer Information Technologies (ACIT) (pp. 197–202). IEEE. https://doi.org/10.1109/ACIT62333.2024.10712512.

Papaioannou, S. K., & Dimelis, S. P. (2007). Information technology as a factor of economic development: Evidence from developed and developing countries. *Economics of Innovation and New Technology, 16*(3), 179–194. https://doi.org/10.1080/10438590600661889

Peña, J., Cusolito, A. P., & Lederman, D. (2020). *The effects of digital-technology adoption on productivity and factor demand: Firm-level evidence from developing countries. World Bank Policy Research Working Paper*, No. 9333. https://doi.org/10.1596/1813-9450-9333

Solow, R. (1957): "Technical Change and the Aggregate Production Function", Review of Economics and Statistics, 39(3), 312-320. https://doi.org/10.2307/1926047

UN Trade and Development (UNCTAD). (2024). *Digital economy report 2024: Shaping an environmentally sustainable and inclusive digital future*. Geneva: United Nations. https://doi.org/10.18356/9789213589779

UNCTADstat (2026). https://unctadstat.unctad.org/EN/

Vu, K. M. (2011). ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 period. *Telecommunications Policy, 35*(4), 357–372. https://doi.org/10.1016/j.telpol.2011.02.008

Wallace, T. D., & Hussain, A. (1969). The use of error components models in combining cross section with time series data. Econometrica, 37(1), 55–72. https://doi.org/10.2307/1909205

World Bank Open Data (2026). https://data.worldbank.org/

World Bank. (2016). *World Development Report 2016: Digital dividends*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-0671-1

World Bank. (2024). *Digital Progress and Trends Report 2023*. World Bank. https://doi.org/10.1596/978-1-4648-2049-6

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

DESIGN AND IMPLEMENTATION OF A MULTI-MODEL AI-BASED CONTENT MODERATION SYSTEM IN A PRODUCTION ENVIRONMENT

Maksym Nenashev[1*]

Received 01.03.2026. | Send to review 18.03.2026. | Accepted 19.08.2026.

Original Article

[1] Wyższa Szkoła Biznesu - National Louis University (WSB-NLU)

***Corresponding Author:**
Maksym Nenashev

Email:
manenashev@wsb-nlu.edu.pl

JEL Classification:
C45, L86, O33

Doi: 10.61432/CPNE0401105n

UDK: 004.896:351.824.11(4)

ABSTRACT

This paper presents the design and implementation of an AI-based multimodal content moderation system deployed in a real-world production environment. The study addresses the scalability and effectiveness challenges associated with moderating large volumes of user-generated text and image content. The proposed system integrates natural language processing, convolutional neural networks, and embedding-based facial recognition within an ensemble of eight parallel models to improve classification accuracy, robustness, and redundancy.

Experimental results demonstrate strong performance, with text-classification accuracy exceeding 90% and image-detection accuracy reaching 92%, while maintaining end-to-end latency below one second. These findings confirm the practical value of multimodel architectures for large-scale digital platforms and highlight their potential to improve platform safety, operational efficiency, and broader socio-economic outcomes.

Keywords: *Artificial Intelligence, Content Moderation, Multi-model Architecture, NLP, Computer Vision, Face Recognition, MLOps, Risk Control*

1. INTRODUCTION

The rapid expansion of global online platforms and social media ecosystems has generated an unprecedented volume of user-generated content. This growth has intensified the challenges associated with content moderation, particularly the detection of inappropriate, violent, harmful, or sensitive material. Manual moderation is no longer sufficient because it cannot provide the scalability, consistency, and response speed required by high-traffic digital platforms (Vankov & Lukarev, 2025). Consequently, automated AI-driven moderation systems have become essential for maintaining platform safety and operational efficiency (Nassanbekova et al., 2026). This study presents the design and deployment of a multimodel content moderation system in a live production environment.

Although single-model architectures have been widely examined, recent advances in machine learning operations (MLOps) and ensemble learning underscore the importance of multimodal approaches in production settings (Goodfellow et al., 2016). Reliance on isolated classifiers may result in high false-positive rates, limited robustness, and increased vulnerability to concept drift in continuously evolving user-generated content. Integrating natural language processing, computer vision (He et al., 2016), and ensemble-learn-

ing techniques (Dietterich, 2000) can improve classification reliability, fault tolerance, and system resilience.

This study contributes to this practical research domain by presenting a scalable MLOps pipeline that connects theoretical multimodel architectures with high-load production deployment (Mäkinen et al., 2021). To address localized concept drift and multilingual variation, the proposed architecture also supports dedicated contextual language models tailored to specific linguistic groups. This design enables more precise and context-sensitive moderation across diverse user populations.

2.PROBLEM FORMULATION

Modern digital ecosystems generate vast volumes of real-time data, requiring content moderation frameworks that provide:

- high scalability to accommodate fluctuating traffic volumes;
- rapid processing to support real-time user interactions;
- high classification accuracy to preserve platform integrity; and
- fault tolerance and robustness against classification errors.

The diversity of user-generated content, ranging from text and images to complex multimodal inputs, further increases the technical and operational complexity of the moderation process (Bouzaidi et al., 2026).

3. SYSTEM ARCHITECTURE

The technical architecture of the proposed moderation framework is designed around the principles of distributed processing and model redundancy. Unlike traditional monolithic systems that process data sequentially, this architecture separates user interactions from heavy analytical tasks. The primary objective of this design is to ensure transparent, reliable, and predictable system outcomes while maintaining continuous platform availability even during unexpected operational loads.

By isolating individual system components, the framework guarantees that a peak load or a temporary slowdown in one module - such as the image analysis or biometric processing units - does not degrade the overall user experience. This high degree of modularity allows the platform to balance computational resources dynamically, ensuring that critical safety checks are completed efficiently without impacting the core business operations of the digital ecosystem.

3.1. DATA PROCESSING LAYER

The underlying infrastructure supports the production environment of FindWay, a specialized social platform and international search network. As a fully functional social platform, it processes a diverse and continuous stream of user-generated content, including user profiles, media attachments, public comment sections, and direct messaging. Managing these real-time collaborative interactions requires a robust data management strategy capable of handling complex data packets without causing backend latency or service interruptions.

To achieve this stability, the system employs an asynchronous data-processing pipeline based on distributed queues. When a user uploads a post or sends a message, the content is temporarily placed in a secure queue and immediately released to the front-end interface, while heavy AI classification models process the payload in the background. This structural approach eliminates server overloads, reduces continuous infrastructure maintenance costs, and ensures a seamless, real-time user experience across all interactive features of the network.

3.2. COMPUTER VISION MODULE

For image analysis and the detection of Not Safe for Work (NSFW) content, the system employs the EfficientNet-B0 architecture (Tan & Le, 2019). This model was selected because it provides an effective balance between computational efficiency and classification accuracy, making it suitable for high-volume production environments.

3.3. NATURAL LANGUAGE PROCESSING MODULE

The natural language processing module is designed to detect toxic content and perform semantic classification across diverse linguistic environments. To ensure high precision, the module utilizes an ensemble of eight specialized models (versions v3 through v6.1). Each model is calibrated for specific linguistic groups and contextual settings, allowing the system to maintain consistent moderation accuracy despite regional dialectal variations. This tiered approach provides complementary and overlapping coverage, enabling the platform to adapt to evolving user-generated content. Future development will focus on integrating additional contextual models to further refine this classification capability and expand support for emerging languages.

3.4. MULTI-MODEL ENSEMBLE

The system's final decision layer consists of eight AI models operating in parallel. This ensemble architecture provides three principal advantages:

- Redundancy: Overlapping model functions reduce dependence on individual classifiers and prevent single points of failure.
- Individual calibration: Each model is independently tuned to reduce false-positive rates and improve risk-sensitive classification.
- Aggregated decision-making: Model outputs are combined to generate the final moderation decision, thereby improving robustness, consistency, and overall system stability.

Figure 1. High-level architecture of the multi-model moderation system

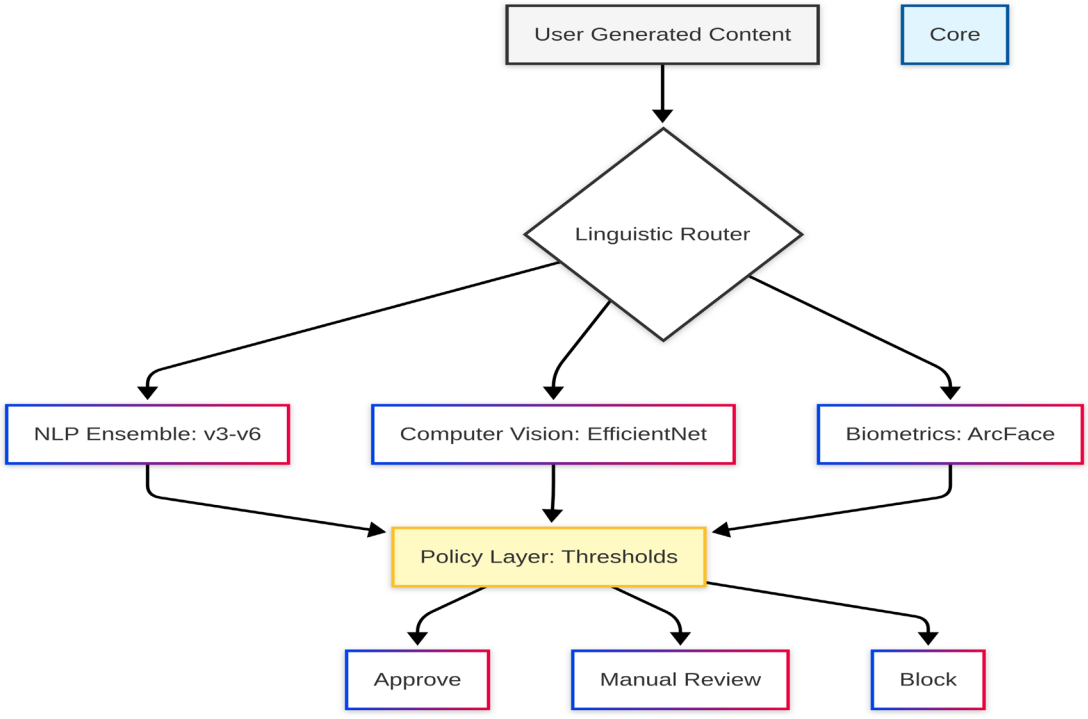


Figure1: The diagram illustrates the asynchronous data flow starting from user-generated content, passing through a linguistic router for model isolation, and reaching the ensemble core (NLP, Computer Vision, and Biometrics). The final decision is governed by the Policy Layer based on calibrated confidence thresholds.

Source: Author's elaboration

As illustrated in Figure 1, the system architecture prioritizes computational efficiency through the Linguistic Router, which ensures that only relevant language models are activated for a given input. The Ensemble Core provides necessary redundancy, where eight models operate in parallel to mitigate single-model classification errors. The final stage, the Policy Layer, acts as the central authority, applying calibrated thresholds to translate raw AI scores into definitive moderation actions: Approve, Manual Review, or Block.

3.5. IDENTIFICATION AND BIOMETRIC MODULE

The system incorporates an embedding-based facial recognition model, ArcFace, to generate compact facial representations for identity verification and vector-based similarity matching. These embeddings enable efficient comparison between facial images while supporting scalable identity-matching operations (Deng et al., 2019).

4.IMPLEMENTATION DETAILS

The system was implemented in Python using PyTorch and Scikit-learn and deployed through Docker containers to ensure reproducibility, environmental isolation, and horizontal scalability. The infrastructure uses Amazon S3 for model-weight storage and dedicated GPU nodes for high-performance asynchronous inference.

4.1. DATASET AND TRAINING PARAMETERS

The visual safety module applies transfer learning using an EfficientNet-B0 backbone pretrained on the ImageNet dataset. To adapt the model to the platform's specific content and operational requirements, it was fine-tuned on a carefully curated custom dataset.

The dataset contains validated samples representing explicit or Not Safe for Work (NSFW) content, violent imagery, and abusive visual patterns, together with benign media collected from the platform. The inclusion of both harmful and non-harmful samples supports more accurate differentiation between policy violations and legitimate user-generated content.

To reduce overfitting and improve generalisation, on-the-fly data augmentation was incorporated into the training pipeline. The applied transformations included random rotations, horizontal flipping, shearing, and brightness adjustments. The model was trained using the Adam optimiser, an initial learning rate of 0.0001, dynamic learning-rate scheduling, and a weighted cross-entropy loss function. Class weights were adjusted to reduce costly classification errors, with particular attention given to limiting false-positive content restrictions.

4.2. NLP ENSEMBLE VOTING LOGIC

To strengthen risk control and reduce false-positive moderation decisions, the policy layer applies a Weighted Confidence Thresholding mechanism rather than a simple majority-voting procedure.

The NLP ensemble consists of eight models operating in parallel. Each model produces an individual confidence score between 0 and 1, where 0 indicates content classified as safe and 1 indicates a high-confidence policy violation. Because the models differ in accuracy and reliability, each is assigned a weight based on its historical precision and validation performance. The sum of all reliability weights is equal to 1.

The aggregated confidence score is calculated as follows:

$$\textit{Aggregated Score} = (\textit{Model 1 Score} \times \textit{Weight 1}) + (\textit{Model 2 Score} \times \textit{Weight 2}) + \ldots + \\ + (\textit{Model 8 Score} \times \textit{Weight 8})$$

where (s_i) denotes the confidence score generated by model (i), and (w_i) represents its assigned reliability weight.

The resulting score determines the appropriate moderation action according to three operational thresholds:

- Approve (Aggregated Score < 0.40): The content is cleared immediately for production deployment as safe.
- Manual Review / Uncertainty Zone (0.40 ≤ Aggregated Score < 0.85): The content is routed to an asynchronous review queue for human verification. This completely mitigates the risk of false censorship and handles borderline cases safely.
- Block (Aggregated Score ≥ 0.85): Immediate autonomous restriction and isolation of the content.

This design ensures that automatic blocking is applied only when the combined outputs of the most reliable models exceed a strict confidence threshold. Consequently, the ensemble reduces dependence on any single classifier, limits isolated model errors, and improves the stability and consistency of the production moderation system.

5. RESULTS AND EVALUATION

The deployment of the custom-tuned moderation architecture significantly outperformed standard baseline configurations. To validate the system's efficiency, the text and visual safety components were benchmarked against their respective standard baselines using standard classification metrics. A primary focus was placed on maximizing Precision to meet the strict operational requirement of minimizing false positives (unjustified user and content blocking).

Table 1. Performance Comparison – Standard Baselines vs. Custom Safety Framework

Metric	Single NLP Baseline	Multi-Model NLP Ensemble	Baseline CNN Classifier	Fine-Tuned CNN Classifier
Accuracy	86.2%	93.8%	84.5%	92.1%
Precision	82.4%	94.5%	81.0%	91.8%
Recall	84.1%	91.2%	83.2%	90.5%
F1-Score	83.2%	92.8%	82.1%	91.1%

Note: Metrics were evaluated on a dedicated, balance-controlled validation benchmark dataset reflecting real-world platform edge cases.

Source: Author's elaboration

As shown in Table 1, model fine-tuning and ensemble-based voting reduced classification errors relative to standard single-model configurations. Precision reached 94.5% for the multimodel NLP ensemble and 91.8% for the fine-tuned CNN classifier, indicating that the Policy Layer's weighted confidence mechanism effectively limited false-positive decisions and improved overall system reliability.

Specialised components, including the ArcFace-based biometric pipeline for facial identification and identity verification, operate as independent filters within the broader architecture. Because these components address biometric matching rather than content-safety classification, their performance is evaluated separately from the moderation metrics reported in Table 1.

Although the parallel execution of multiple models introduces additional computational demands, the distributed asynchronous processing pipeline maintained acceptable end-to-end latency under production-simulated workloads. Moderation decisions were consistently returned within the operational limits required for real-time deployment.

6. CASE STUDY: THE FINDWAY PLATFORM

The proposed system has been deployed within FindWay, an international platform designed to support the search for missing persons, animals, and personal belongings. The platform uses the content moderation engine to enhance user safety and maintain the integrity of submitted information. Its biometric recognition component applies embedding-based facial comparison to identify potential matches between uploaded records. When a sufficiently strong match is detected, the system generates an automated notification for further verification, potentially reducing the time required to identify relevant cases.

7. SOCIO-ECONOMIC IMPACT AND FUTURE WORK

Beyond its technical performance, the system may generate broader social and economic benefits by:

- supporting efforts to locate missing persons;
- facilitating faster responses in urgent and crisis-related situations; and
- improving the safety, operational efficiency, and economic sustainability of digital platforms by reducing the resources required for manual moderation.

Future development will focus on expanding the range of specialised models, improving multilingual and context-sensitive classification, strengthening biometric matching accuracy, and exploring responsible integration with relevant public-safety institutions.

7.1. ETHICAL CONSIDERATIONS AND PRIVACY COMPLIANCE

Given the use of biometric identification, privacy, data protection, and responsible governance are central design considerations. The system is intended to operate in accordance with applicable data-protection requirements, including the principles established by the General Data Protection Regulation where relevant.

The biometric module converts facial features into high-dimensional numerical embeddings used for similarity comparison. Raw facial images are not retained within the biometric matching database after processing, provided that no separate legal or operational requirement justifies their storage. Nevertheless, biometric embeddings remain sensitive personal data because they may enable individuals to be distinguished or identified. Their processing therefore requires an appropriate legal basis, clearly defined retention periods, access controls, encryption, audit mechanisms, and procedures for data-subject rights.

Although embedding-based processing can reduce exposure associated with retaining raw images, it does not eliminate privacy, security, or algorithmic-bias risks. Regular security assessments, demographic performance testing, human verification of potential matches, and transparent governance procedures are therefore necessary to support lawful, fair, and accountable system operation (Hai & Lan, 2026).

8. CONCLUSION

This study demonstrates the practical applicability of a multimodel AI architecture in a high-stakes production environment. By integrating natural language processing, computer vision, ensemble-based decision logic, and biometric embeddings, the proposed system provides a scalable and robust approach to contemporary content moderation and identity-matching challenges. The findings further indicate that distributed processing, model redundancy, confidence-based decision thresholds, and human review can improve system reliability while reducing dependence on individual classifiers. However, the responsible deployment of such systems requires continuous performance monitor-

ing, privacy safeguards, bias assessment, and transparent oversight, particularly when biometric data and automated moderation decisions are involved.

REFERENCES

Bouzaidi, T. D., Daoui, F., Solhi, S., & Tounsi, S. (2026). Economic Convergence in Africa Put to the Test of Productive Complexity: An Empirical Analysis Using System GMM Panel Data and Markov Chains. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 145-163. https://doi.org/10.2478/eoik-2026-0030

Deng, J., Guo, J., Xue, N., & Zafeiriou, S. (2019). ArcFace: Additive angular margin loss for deep face recognition. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)* (pp. 4690-4699). https://doi.org/10.1109/CVPR.2019.00482

Dietterich, T. G. (2000). Ensemble methods in machine learning. In International workshop on multiple classifier systems (pp. 1-15). Springer. https://doi.org/10.1007/3-540-45014-9_1

Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep learning. MIT Press. https://www.deeplearningbook.org/

Hai, T. V., & Lan, T. T. (2026). Determinants of Economic and Corporate Social Responsibility Performance of Securities Companies. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 165-187. https://doi.org/10.2478/eoik-2026-0031

He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep residual learning for image recognition. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR) (pp. 770–778). https://doi.org/10.1109/CVPR.2016.90

Mäkinen, S., et al. (2021). Who Needs MLOps: What Data Scientists Seek to Accomplish and How Can MLOps Help? arXiv preprint arXiv:2103.08942. https://doi.org/10.48550/arXiv.2103.08942

Nassanbekova, S., Yeshenkulova, G., Nurguzhina, A., Ibrahim, M., & Ibadildin, N. (2026). Understanding Student Adoption of Generative AI Chatbots in Higher Education: An Integrated TAM–TRI Approach. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 293-307. https://doi.org/10.2478/eoik-2026-0037

Tan, M., & Le, Q. (2019). EfficientNet: Rethinking model scaling for convolutional neural networks. In Proceedings of the 36th International Conference on Machine Learning (ICML) (pp. 6105–6114). http://proceedings.mlr.press/v97/tan19a.html

Vankov, N., & Lukarev, V. (2025). Implementation of smart IoT technologies on the Bulgarian market: An innovative approach for economic sustainability and environmental benefits. *Collection of Papers New Economy, 3*(1), 101–116. https://doi.org/10.61432/CPNE0301101v

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

PREDICTORS OF EMPLOYEE PSYCHOLOGICAL ADAPTATION TO AI SYSTEMS IN IT ORGANIZATIONS

Oleksii Nahorniak[1*], Vasyl Osodlo[1]

Received 25.02.2026. | Send to review 18.03.2026. | Accepted 12.08.2026.

Original Article

[1] State University of Trade and Economics, Department of Psychology, Kyiv, Ukraine

***Corresponding Author:**
Oleksii Nahorniak

Email:
o.nahorniak@knute.edu.ua

JEL Classification:
O33, M12, J24, L86, D23, J62

Doi: 10.61432/CPNE0401113n

UDK: 316.323.6:004.738.5

ABSTRACT
The integration of artificial intelligence (AI) into IT organizations has reshaped workplace dynamics, requiring employees to adjust both technically and psychologically. This study explores the main factors influencing employees' psychological adaptation to AI systems in IT environments. Drawing on technology acceptance, organizational behavior, and cognitive psychology, it develops a conceptual model based on perceived usefulness, trust in AI, psychological readiness, perceived job security, and organizational support. The study uses an integrative narrative review of recent literature on AI adoption and employee adaptation. It is not a systematic review or meta-analysis and does not follow PRISMA 2020 procedures, such as protocol registration, exhaustive search documentation, or formal quality scoring. The reviewed literature suggests that trust in AI and organizational support are among the most important factors supporting successful adaptation, while psychological readiness and perceived usefulness also contribute to positive outcomes. Perceived job security is proposed as a moderating factor that may influence these relationships when employees view AI as a threat to employment stability. The model offers practical guidance for IT managers and HR professionals seeking to reduce resistance, uncertainty, and workplace stress during AI implementation. It also provides testable propositions for future longitudinal, cross-cultural, and industry-specific research.

Keywords: *Artificial Intelligence, Psychological Adaptation, IT Organizations, Employee Behavior, Technology Adoption, Organizational Management, Trust, Job Security*

1. INTRODUCTION

The rapid development of artificial intelligence has significantly changed the structure and operation of IT organizations worldwide. AI is increasingly used for automation, decision support, predictive analytics, natural language processing, and process optimization. Recent estimates indicate that organizational AI adoption increased from below 20% in 2017 to more than 70% by the mid-2020s (AIPRM, 2026). Although AI can improve efficiency and productivity, it may also create psychological pressures for employees, including job insecurity, fear of displacement, cognitive overload, and the continuous need to update professional skills (Brynjolfsson & Mitchell, 2017).

Unlike earlier technologies, AI systems can generate recommendations, assess performance, support decisions, and operate with a certain level of autonomy. Employees therefore interact with AI not only as a tool but increasingly as a workplace collaborator. This development may require them to reconsider their professional roles, competencies, identity, and contribution to the organization (Davenport & Ronanki, 2018).

Employee adaptation to AI is therefore more than a technical adjustment. It involves cognitive, emotional, and behavioral changes. Cognitive adaptation concerns how employees understand AI and reinterpret their own roles (Nassanbekova et al., 2026). Emotional adaptation includes managing anxiety, uncertainty, distrust, and ambivalence. Behavioral adaptation refers to changes in work routines, decision-making practices, and willingness to rely on AI-generated outputs.

In this review, psychological adaptation is defined as an ongoing process through which employees revise their understanding of work, regulate emotional responses, and modify their behavior to function effectively alongside AI systems. This concept is broader than technology acceptance, intention to use, or actual system use. It is also distinct from well-being, resistance, and job performance, although it may influence each of these outcomes. Psychological adaptation is thus treated as an underlying process that may lead to acceptance, resistance, changes in well-being, or improved or reduced performance.

Organizations often focus primarily on technical implementation, system performance, and expected returns while paying insufficient attention to employees' psychological responses. However, limited adaptation may result in underuse of AI systems, passive resistance, reduced data quality, and rejection of organizational change, thereby weakening the expected benefits of AI adoption (Jarrahi, 2018).

The IT sector provides an especially relevant context for examining these issues. Although IT professionals are generally familiar with rapid technological change, technical expertise does not necessarily protect them from anxiety related to automation and role transformation. Their greater awareness of AI capabilities may even intensify concerns about professional relevance and future employment (Kellogg, Valentine, & Christin, 2020). Nevertheless, much of the available evidence comes from general employee and knowledge-worker samples (Alsharaideh et al., 2026). Therefore, its application to IT professionals should be viewed as an informed interpretation rather than direct IT-specific evidence.

This study identifies and discusses potential predictors of employees' psychological adaptation to AI in IT organizations. It adopts an integrative narrative review rather than a PRISMA-based systematic review. The analysis is guided by three research questions: which individual and organizational factors are most frequently associated with psychological adaptation to AI; how these factors may interact as predictors, mediators, or moderators; and what the reviewed evidence implies for organizational practice and future empirical testing. The proposed conceptual model is presented as a set of testable propositions rather than as a confirmed causal framework.

2. LITERATURE REVIEW

2.1. THEORETICAL FOUNDATIONS OF TECHNOLOGY ACCEPTANCE

Research on technology adoption has a long tradition in information systems and organizational psychology. The Technology Acceptance Model developed by Davis (1989) identifies perceived usefulness and perceived ease of use as the main factors influencing technology adoption. The Unified Theory of Acceptance and Use of Technology extends this approach by including performance expectancy, effort expectancy, social influence, and facilitating conditions as predictors of behavioral intention (Venkatesh et al., 2003). These frameworks remain important for understanding AI adoption in organizations.

Nevertheless, traditional acceptance models may not fully capture the distinctive characteristics of AI systems. Unlike conventional software, AI often produces probabilistic, changing, and difficult-to-explain outputs. Meske et al. (2022) therefore emphasize explainability as an important element of AI acceptance. Employees may consider an AI system useful and easy to operate but still hesitate to rely on it when its decisions cannot be understood. This distinction separates basic acceptance from the deeper integration of AI into everyday professional practice.

Cognitive load theory also helps explain employee adaptation to AI. Workers must continue performing their usual duties while learning how to interpret, verify, and apply AI-generated information. When these additional demands exceed employees' cognitive capacity, they may experience overload, avoid AI tools, or use them only superficially. Tarafdar et al. (2007) describe this problem through the concept of technostress, showing that technological complexity can increase role stress and reduce productivity. Similarly, the meta-analysis by Nastjuk et al. (2023) confirms that technology-related stress is generally associated with lower employee well-being and reduced use of information systems. These findings highlight the need to consider cognitive demands and technostress when designing AI implementation strategies.

2.2. PSYCHOLOGICAL AND ORGANIZATIONAL DIMENSIONS

Organizational change literature provides an additional perspective on employees' adaptation to AI. Change-management models, including Lewin's (1947) force-field analysis and Kotter's (1996) eight-step framework, identify readiness for change as an important condition for successful transformation. In the context of AI, psychological readiness refers to employees' cognitive and emotional preparedness to work with intelligent systems. Individuals who are open to learning, receptive to new experiences, and less resistant to change are generally better positioned to adapt (Brougham & Haar, 2017).

Perceived job insecurity is a major obstacle to this process. Brougham and Haar (2017) found that employees who view Smart Technology, AI, Robotics, and Algorithms as threats to their occupational roles report greater anxiety and weaker organizational commitment. These concerns may be particularly strong among older employees and workers performing routine tasks. Similarly, Yam et al. (2023) show that awareness of workplace automation can increase insecurity and encourage maladaptive behavior even when no actual job losses occur. This suggests that perceived threat, rather than realized displacement, is often the central psychological mechanism.

Job insecurity can also be measured reliably through validated instruments, such as the scale developed by Vander Elst et al. (2014). It may therefore be incorporated into conceptual and empirical models of AI adaptation as a measurable predictor or moderator. In particular, strong perceptions of employment threat may weaken the positive effects of training, organizational support, and other adaptation initiatives.

At the organizational level, successful digital transformation depends not only on technological infrastructure but also on culture, leadership, and talent management (Ha, 2026). Kane et al. (2019) argue that organizations achieve stronger employee engagement when AI is presented as a means of supporting and empowering workers rather than replacing them. Such framing can reduce insecurity, increase perceived usefulness, and strengthen employees' identification with the organization.

2.3. TRUST IN AI SYSTEMS

Trust is a central factor in AI adoption and has received growing scholarly attention. Glikson and Woolley (2020) distinguish three related dimensions of trust in AI: cognitive trust, based on assessments of system accuracy and reliability; affective trust, reflecting

emotional confidence and comfort; and behavioral trust, demonstrated through willingness to rely on AI-generated recommendations. Although interconnected, these forms of trust may develop at different speeds and respond to different workplace conditions.

Research also highlights the importance of employees' first experiences with AI. Early errors, unclear outputs, or perceived unfairness can create lasting skepticism that later positive experiences may not easily overcome. By contrast, carefully managed implementation, supported by clear explanations, training, and opportunities for feedback, can establish trust and encourage long-term adaptation. Organizations should therefore place particular emphasis on employee support during the initial stages of AI deployment.

2.4. HUMAN-AI COLLABORATION AND IDENTITY

Recent research increasingly examines how AI affects professional identity and human-AI collaboration. Bankins et al. (2024) note that the psychological and relational effects of AI on employees remain less developed than research on its technical and economic consequences. This gap is especially relevant in IT organizations, where employees must continuously redefine their roles in relation to increasingly capable systems.

Jarrahi (2018) describes effective AI use as a form of human-AI symbiosis based on complementary strengths. AI is particularly effective at processing large datasets, detecting patterns, and producing predictions, whereas humans contribute contextual judgment, ethical reasoning, creativity, and social intelligence. From this perspective, successful adaptation does not require replacing human judgment but redirecting it toward more complex and higher-value tasks.

However, Raisch and Krakowski (2021) identify an automation–augmentation paradox. Although AI can improve efficiency and support decision-making, it may also reduce autonomy, weaken skills, and increase dependence on algorithmic outputs. Employees must therefore balance the benefits of AI assistance against the possible erosion of expertise and professional identity. Kellogg et al. (2020) similarly show that algorithmic management can reshape organizational power and workplace control, creating additional psychological pressure.

These effects are closely connected to employee motivation. Gagné et al. (2022) argue that algorithmic management influences motivation through employees' perceptions of autonomy, competence, and relatedness. Parent-Rocheleau and Parker (2022) further describe algorithms as active work designers that reshape task variety, feedback, and decision authority. In addition, Langer and Landers (2021) emphasize that fairness and transparency strongly influence whether employees accept automated decisions.

Dwivedi et al. (2021) conclude that successful AI integration requires alignment between technological design, organizational policies, and employee psychology. Psychological adaptation should therefore be treated as a central element of AI implementation rather than as a secondary consequence of technological change.

2.5. INDIVIDUAL DIFFERENCES AND DEMOGRAPHIC MODERATORS

In addition to organizational factors, individual differences can significantly shape employees' psychological adaptation to AI. Age is frequently identified as an important influence, as older workers may show lower initial acceptance, stronger concerns about job security, and slower adaptation. However, these effects can be reduced through appropriate training and organizational support (Brougham & Haar, 2017). Educational background and previous experience with technological change also matter, because employees who have successfully adapted to earlier innovations may be better prepared to respond to AI.

Gender differences appear less evident in IT environments, where technical competence and self-efficacy are often more evenly distributed. Personality traits may be more influential. Employees who are open to experience and comfortable with ambiguity tend to explore AI systems, seek additional information, and develop more accurate expectations about their capabilities. By contrast, individuals with higher neuroticism or lower tolerance for uncertainty may perceive AI as more threatening and require greater support.

These findings indicate that employee adaptation does not follow a single pattern. Organizations should therefore provide flexible and differentiated forms of training and support that reflect variations in age, experience, personality, and psychological readiness.

3. RESEARCH METHODOLOGY

3.1. REVIEW APPROACH: AN INTEGRATIVE, NARRATIVE CONCEPTUAL REVIEW

This study adopts an integrative narrative review rather than a PRISMA 2020 systematic review. It does not use a registered protocol, exhaustive reproducible searches, dual-reviewer screening, formal quality assessment, or quantitative evidence aggregation, and therefore does not claim the evidentiary strength of a systematic review.

Instead, the study aims to interpret and integrate a fragmented body of theoretical and empirical research into a coherent conceptual model. Narrative and integrative reviews are particularly appropriate when a field lacks a unified framework and includes diverse concepts, methods, and forms of evidence (Snyder, 2019; Torraco, 2005). As Snyder (2019) explains, such reviews may not follow a fully systematic search process and rely mainly on qualitative synthesis. This approach is suitable because research on employees' psychological adaptation to AI in IT workplaces remains dispersed and insufficiently consolidated.

3.2. LITERATURE IDENTIFICATION AND SELECTION

The literature was identified through a purposive rather than exhaustive search of Scopus, Web of Science, PsycINFO and Google Scholar. The search used combinations of terms related to psychological adaptation to AI, technology acceptance, trust in AI, job insecurity, technostress, and human-AI collaboration. It focused mainly on English-language publications from 2015 to 2026, while also including selected foundational studies, such as Davis (1989) and Lewin (1947). Sources were included when they addressed psychological, behavioral, or organizational aspects of AI adoption in professional settings. Purely technical, consumer-oriented, and non-citable materials were excluded. Additional studies were identified through backward citation tracking, which is common in narrative reviews. Because the study was not designed as a systematic review, no protocol was registered, no complete search log or screening count was maintained, and inclusion decisions were not independently verified by a second reviewer. No formal quality-assessment tool was applied. These methodological limitations are explicitly acknowledged and discussed further in Section 2.5.

3.3. ANALYTICAL STRATEGY

The analytical strategy involved three stages: identifying and grouping theoretical frameworks by disciplinary origin (information systems, organizational psychology, cognitive science, management science); organizing empirical and conceptual sources descriptively by predictor addressed, population studied (noting explicitly where a study was or was not IT-specific), evidence type, and main finding, summarized in Table 1; and synthesizing these sources qualitatively into an integrative conceptual framework proposing primary predictors, their plausible interrelationships, and their organizational implications. This coding was carried out narratively by the authors rather than through independent

dual coding with reliability statistics, and should be read as an interpretive organization of the literature rather than a quantitatively validated classification.

3.4. SECONDARY STATISTICAL DATA

Contextual statistics on AI adoption rates, reskilling patterns, and employee risk perceptions were drawn from a commercial secondary aggregator (AIPRM, 2026) and a McKinsey & Company (2025) global survey, used only to illustrate the practical scale of adaptation challenges, not as primary empirical evidence for the proposed model. The original survey samples, exact denominators, question wording, and year-on-year comparability underlying the AIPRM-aggregated figures are not fully disclosed by the aggregator and were not independently re-verified against primary survey documentation; readers seeking precise methodological detail should consult the original McKinsey State of AI materials directly. The figures in Section 3.1 should accordingly be read as indicative of general workplace patterns rather than precise, independently verified parameters.

3.5. LIMITATIONS OF THE METHODOLOGICAL APPROACH

This review has four main limitations. First, it is an integrative narrative review rather than a PRISMA-based systematic review and should not be interpreted as offering the same level of evidentiary rigor. Second, it cannot establish causal relationships. Connections among the proposed predictors are therefore presented as interpretations derived from the literature rather than as findings demonstrated by this study. Statements that individual studies demonstrate particular effects refer only to the results reported in those studies.

Third, much of the reviewed evidence is based on general employee or knowledge-worker populations rather than IT professionals specifically. Its application to IT organizations should therefore be regarded as an interpretive extension. Fourth, the contextual statistics are subject to the sourcing limitations discussed in Section 2.4.

The proposed model should consequently be understood as a theoretically grounded set of testable propositions, not as a confirmed causal framework. Future research should examine it through longitudinal studies, experiments, mixed-methods case studies, and IT-specific samples. A protocol-driven PRISMA 2020 systematic review would also provide a valuable complementary contribution once the empirical literature becomes more developed.

3.6. OVERVIEW OF KEY LITERATURE INFORMING THE CONCEPTUAL MODEL

Table 1 summarizes the sources that most directly informed the predictors and propositions in Section 3.2, indicating evidence type, context, predictor/theme, and contribution to the synthesis. It is offered as a transparency aid consistent with the narrative review approach; it is illustrative of the core literature underlying the model, not an exhaustive or systematically screened evidence base, and does not constitute a PRISMA-style included-studies table.

Table 1. Overview of Key Literature Informing the Conceptual Model

Source	Context / Evidence Type	Predictor / Theme	Contribution to This Review
Davis (1989); Venkatesh et al. (2003)	Instrument development; theoretical integration (TAM/UTAUT)	Perceived usefulness	Foundational acceptance constructs extended to AI-specific use
Meske et al. (2022)	Conceptual review	Explainability	Positions explainability as an AI-specific extension of TAM
Tarafdar et al. (2007); Nastjuk et al. (2023)	Survey (223 orgs); meta-analysis	Technostress	Empirical and aggregate evidence linking ICT stress to productivity loss
Brougham & Haar (2017); Vander Elst et al. (2014); Yam et al. (2023)	Survey; psychometric validation; multimethod	Job insecurity	Establishes job insecurity as a measurable, threat-driven moderator
Glikson & Woolley (2020)	Narrative review of trust research	Trust in AI	Cognitive/affective/behavioral trust dimensions underlying the model
Kane et al. (2019); Edmondson (1999)	Practitioner synthesis; field study (51 teams)	Organizational support	Links organizational framing and psychological safety to adaptation
Jarrahi (2018); Raisch & Krakowski (2021)	Conceptual articles	Human-AI collaboration	Symbiosis and automation-augmentation paradox framing adaptation strain
Kellogg et al. (2020); Gagné et al. (2022)	Literature review; theoretical review (SDT)	Algorithmic management	Documents control shifts and motivational mechanisms behind strain
Dwivedi et al. (2021); Bankins et al. (2024)	Multidisciplinary/ multilevel reviews	Cross-cutting	Broad socio-technical framing; identifies the gap this review addresses
Noy & Zhang (2023)	Preregistered experiment (453 professionals)	Perceived usefulness	Experimental evidence of GenAI productivity and mixed affective response

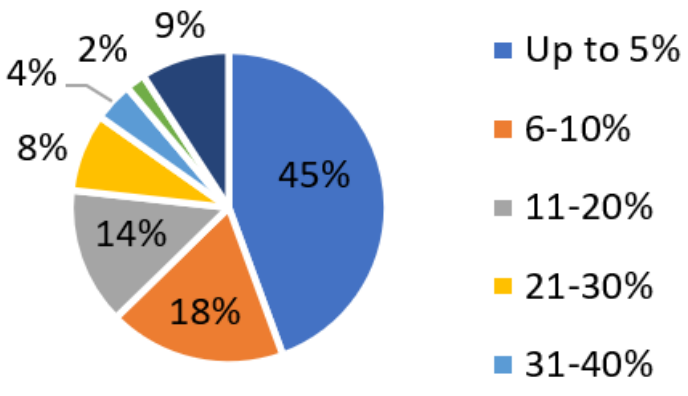
Source: Compiled by the authors based on the literature reviewed in this study

4. ANALYSIS AND RESULTS

4.1. CURRENT STATISTICAL CONTEXT OF AI ADOPTION IN THE WORKPLACE

Recent statistical evidence indicates that although corporate interest in artificial intelligence is high, the depth of workforce-level integration remains uneven and, in many organizations, still relatively limited. Data summarized by AIPRM from McKinsey's global survey (AIPRM, 2026) show that between July 2023 and July 2024, 44% of AI-using companies reskilled only up to 5% of their workforce due to AI use, while just 18% reskilled 6-10%. At the same time, 55% of organizations reskilled at least 6% of employees, suggesting that meaningful workforce transformation is taking place, albeit unevenly distributed across the corporate landscape.

Figure 1. Number of AI-using companies reskilling employees in AI, by workforce share



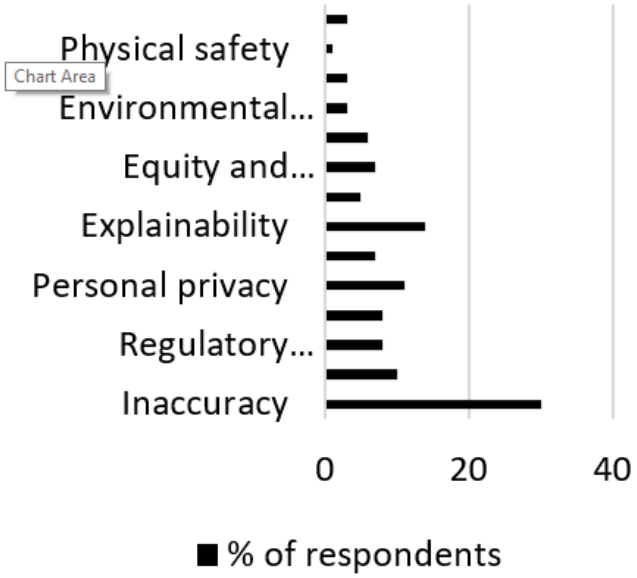
Source: https://www.aiprm.com/ai-adoption-statistics/ accessed on 01/05/2026

The IT sector is among the most intensive users of AI, with applications spanning software development, data analytics, cybersecurity, and IT operations. Consequently, IT professionals face multiple adaptation challenges, as AI functions not only as a work tool but also as a system that supports decision-making, monitors performance, and, in some cases, automates tasks previously performed by employees.

The success of AI adoption depends not only on the extent of implementation but also on employees' experiences with these systems. According to McKinsey & Company (2025), 51% of organizations using AI reported experiencing at least one negative consequence of AI adoption, with AI inaccuracy identified as one of the most common issues. Such experiences may undermine employees' initial trust and slow psychological adaptation.

Employee concerns extend beyond technical performance. McKinsey & Company (2025) reports that AI inaccuracy (30%) and limited explainability (14%) are the most frequently cited concerns, followed by personal privacy (11%), cybersecurity (10%), regulatory compliance (8%), intellectual property (8%), workforce displacement (6%), organizational reputation (5%), and equity and fairness (7%). Less frequently reported concerns include national security (3%), environmental impact (3%), political stability (3%), and physical safety (1%). Together, concerns about AI inaccuracy and explainability account for 44% of reported employee concerns, highlighting the critical role of trust, transparency, and reliable system performance in successful workplace adaptation.

Figure 2. Distribution of employee-reported concerns about AI use, by concern category



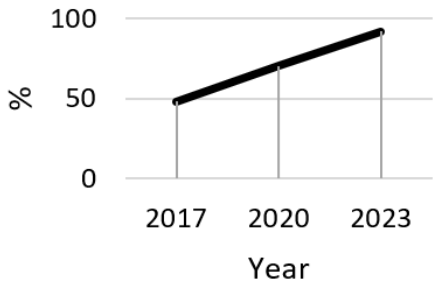
Source: https://www.mckinsey.com/capabilities/quantumblack/our-insights/the-state-of-ai accessed on 01/05/2026

These findings show that employees experience AI not only as a productivity tool but also as a socio-technical system marked by uncertainty and limited trust. Effective use therefore requires psychological adaptation, including the ability to assess AI outputs critically, recognize when human judgment should prevail, and preserve professional autonomy when working with opaque or inconsistent systems.

Despite these challenges, the economic rationale for AI adoption remains strong. AIPRM (2026) reports that the proportion of firms achieving tangible benefits from AI increased from 48.4% in 2017 to 92.1% in 2023. Experimental evidence supports this trend. Noy and Zhang (2023) found that access to generative AI improved productivity and job satisfaction, although it also temporarily increased concerns about automation.

The workplace impact of AI is therefore defined by a dual reality. AI can generate substantial organizational and individual benefits, but its effective integration depends on addressing employee uncertainty, mistrust, and perceived risks. Psychological adaptation is consequently a central condition for translating technological capability into sustained workplace value.

Figure 3. The percentage of firms that benefit from AI adoption by year



Source: https://www.aiprm.com/ai-adoption-statistics/ accessed on 01/05/2026

These implications matter for psychological adaptation as a strategic priority: organizations that focus exclusively on technical AI performance while neglecting the human dimensions of adoption frequently find business benefits undermined by disengagement, sub-optimal utilization, and unaddressed resistance, whereas those investing proportionally in both technical quality and psychological support are better positioned to realize AI's full potential. Human-centered AI implementation is thus not a social-responsibility supplement but a core component of an effective adoption strategy.

4.2. ANALYTICAL FRAMEWORK: PSYCHOLOGICAL ADAPTATION TO AI AS A DYNAMIC SYSTEM

Psychological adaptation to AI in IT organizations is a dynamic and non-linear process involving continuous interaction between cognitive evaluation, emotional response, and behavioral change. Unlike conventional technologies, AI systems often operate autonomously, generate probabilistic outputs, and lack full transparency. Employees must therefore develop new ways of understanding, evaluating, and working with these systems.

The proposed conceptual model is summarized in five propositions:

P_1: *Cognitive, affective, and behavioral trust in AI positively influences psychological adaptation and serves as a foundation for other adaptation factors.*

P_2: *Organizational support positively influences adaptation and strengthens the relationship between trust and adaptation.*

P_3: *Psychological readiness and perceived usefulness positively influence the cognitive and behavioral dimensions of adaptation.*

P_4: *Perceived job security moderates these relationships, with low job security weakening the positive effects of trust, support, readiness, and usefulness.*

P_5: *Adaptation outcomes, including AI use, resistance, well-being, and performance, influence subsequent levels of trust and readiness, creating a continuous feedback cycle.*

These propositions are derived from the narrative synthesis and remain to be tested empirically.

At the cognitive level, employees form mental models to understand what an AI system does, how reliable it is, and when it may fail. When AI is perceived as opaque, employees may repeatedly verify its outputs, restrict its use to low-risk tasks, or ignore its recom-

mendations. Explainability and appropriate training are therefore necessary for developing calibrated trust.

The emotional dimension includes reactions ranging from curiosity and confidence to anxiety and concern about professional relevance. Positive responses are more likely when AI is perceived as supporting employee capabilities without reducing autonomy. By contrast, systems associated with surveillance, job replacement, or loss of control may generate persistent resistance.

Behavioral adaptation is reflected in the frequency, depth, and context of AI use. Employees may recognize the usefulness of AI while remaining reluctant to rely on it in important decisions. Cognitive acceptance may therefore develop before meaningful behavioral integration.

These dimensions are connected through feedback loops. Positive experiences, such as accurate outputs and time savings, can strengthen trust and readiness, while unexplained errors may restore skepticism. Adaptation should consequently be viewed as an ongoing process that may need to restart when AI systems, organizational structures, or employee roles change.

4.2.1. KEY PREDICTORS AND THEIR INTERACTIONS IN ORGANIZATIONAL CONTEXT

Psychological adaptation to AI is shaped by several interrelated individual and organizational predictors.

Trust in AI appears to be one of the most important factors because it connects employees' perceptions of a system with their willingness to rely on it. Trust depends not only on accuracy but also on transparency, consistency, fairness, and predictability (Glikson & Woolley, 2020). In IT organizations, technically skilled employees may be especially sensitive to differences between expected and actual system behavior. Even an accurate system may fail to gain meaningful trust when its outputs cannot be explained. Explainability is therefore a central condition for trust, particularly during the early stages of implementation.

Organizational support includes formal resources, such as training, documentation, and technical assistance, as well as informal factors, including leadership behavior, peer support, and psychological safety. Employees are more likely to experiment with AI when they can ask questions and make mistakes without fear of appearing incompetent (Edmondson, 1999). Strong support cultures are associated with greater AI use and lower resistance, but support must continue beyond initial training (Kane et al., 2019).

Psychological readiness reflects employees' openness to change, confidence in learning, tolerance of uncertainty, and previous experience with technological change. Employees with high readiness are more likely to approach AI with curiosity and engage in self-directed learning, whereas those with low readiness may interpret it as a threat and avoid its use. Readiness may therefore influence how AI exposure affects employee well-being and adaptation (Brougham & Haar, 2017).

Perceived usefulness remains a key factor from technology acceptance theory (Venkatesh et al., 2003). In AI settings, however, usefulness depends not only on performance improvement but also on compatibility with existing workflows, interpretability, and employees' ability to recognize the contribution of AI to positive outcomes. Clear and visible benefits generally encourage adoption, while unclear or indirect benefits weaken motivation.

Perceived job security is proposed as an important moderator. When employees believe AI threatens their employment or career prospects, they may resist adoption even while recognizing its organizational value. This response may represent rational self-protection

rather than simple resistance to change. By contrast, employees are more likely to engage with AI when it is credibly presented as a tool for augmentation rather than replacement.

These predictors interact rather than operate independently. Strong organizational support may compensate for low readiness, while visible usefulness can strengthen trust. Conversely, job insecurity combined with poor communication may create a negative cycle of disengagement and resistance. Organizations may then incorrectly interpret low use as a technical problem and invest further in deployment without addressing the underlying psychological barriers.

4.2.2. STRATEGIC IMPLICATIONS FOR AI IMPLEMENTATION IN IT ORGANIZATIONS

This analysis generates five evidence-grounded strategic implications that position human factors as a primary design constraint in AI implementation, not merely a technical afterthought. First, organizations should treat explainability as a core system requirement, weighted equally with accuracy in procurement, via interfaces that communicate confidence levels and key decision factors. Second, a continuous, embedded learning approach, iterative training, peer communities, hands-on experimentation, is more durable than one-time training events, given that competence requirements evolve as AI systems are updated. Third, strategic communication should address job security, fairness, and role relevance directly rather than focusing only on AI capabilities; transparent communication that acknowledges limitations and clarifies how roles will evolve substantially reduces threat perceptions, and leaders who openly model their own learning provide particularly influential demonstrations of organizational culture. Fourth, roles should be redesigned to leverage human-AI complementarity rather than simply adding AI tools to existing job descriptions, emphasizing creative problem-solving, contextual judgment, and ethical oversight where AI cannot substitute. Fifth, organizations should implement systematic monitoring of psychological indicators, trust, anxiety, role clarity, alongside conventional performance metrics, since without such monitoring, adaptation barriers remain invisible until they surface as measurable performance deficits.

5. DISCUSSION

The proposed framework contributes to understanding psychological adaptation to AI in three main ways. First, it presents adaptation as a dynamic and multidimensional process rather than a simple transition from non-use to adoption. The feedback loops between cognitive, emotional, and behavioral dimensions in P_5 help explain why AI use may stabilize, decline, or regress after initial implementation.

Second, the framework extends TAM and UTAUT to the specific characteristics of AI. Explainability is positioned as a possible link between perceived usefulness and behavioral intention, while organizational support is treated as an ongoing process rather than a one-time facilitating condition. Third, perceived job security is proposed as a moderator in P_4. Where employees view AI as a credible threat to their employment, training, explainability, and technical support may have weaker effects unless organizations first address concerns about displacement through clear and credible communication.

Although these propositions are consistent with the reviewed literature, they require empirical testing. For example, early experiences with AI may have a lasting influence on trust, but this relationship has not yet been adequately examined through longitudinal research. Generalizability also remains uncertain because much of the evidence comes from North American and Western European contexts. Cultural factors, including power distance and uncertainty avoidance, may alter the importance of leadership support, individual readiness, and other predictors.

From a practical perspective, the framework provides HR and IT managers with a diagnostic basis for evaluating employee readiness before, during, and after AI implementation. It also highlights an ethical concern: adaptation should not require employees to accept opaque monitoring, unexplained decisions, or poorly communicated restructuring. Trust, transparency, and organizational support are therefore important not only for performance but also for the responsible governance of technological change.

6. CONCLUSION

Psychological adaptation to AI in IT organizations is a complex and dynamic process that extends beyond traditional models of technology adoption. This review suggests that adaptation is influenced by five interrelated predictors: trust in AI, organizational support, psychological readiness, perceived usefulness, and perceived job security. Rather than operating independently, these factors interact across individual and organizational levels, forming the basis of the proposed conceptual propositions (P_1-P_5), which remain to be validated through empirical research.

The study contributes theoretically by conceptualizing adaptation as a process involving continuous interaction between cognitive, emotional, and behavioral dimensions, while extending established technology acceptance frameworks to the specific characteristics of AI. From a practical perspective, the findings highlight that successful AI implementation depends not only on technological capability but also on trust, transparency, effective communication, and sustained organizational support. Although AI is delivering measurable benefits for many organizations, employee concerns regarding explainability, system accuracy, and job security continue to present significant barriers to successful adoption.

The proposed framework also emphasizes the role of leadership in facilitating adaptation. Managers must not only adopt AI themselves but also create an environment that encourages learning, trust, and open communication throughout the implementation process. Future research should test the proposed model using longitudinal and cross-cultural designs, investigate leadership as a driver of psychological adaptation, and compare adaptation processes across industries with different levels of AI adoption.

Acknowledgment

Note on use of artificial intelligence (AI): An AI language model was used in this paper for translating the original text from Ukrainian to English and for grammatical correction following translation.

REFERENCES

AIPRM. (2026). *50+ AI adoption statistics you need to know for 2025/26*. Retrieved from https://www.aiprm.com/ai-adoption-statistics/

Alsharaideh, A. M. A., Alzubi, M. M. S., Alqudah, A. M. A., Alqudah, O. M. A., & Darabah, K. (2026). AI-Enabled Frugal Innovation: Extending the Dynamic Capabilities Framework for Sustainable Development. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 435-455. https://doi.org/10.2478/eoik-2026-0044

Bankins, S., Ocampo, A. C., Marrone, M., Restubog, S. L. D., & Woo, S. E. (2024). A multilevel review of artificial intelligence in organizations: Implications for organizational behavior research and practice. *Journal of Organizational Behavior*, 45(2), 159-182. https://doi.org/10.1002/job.2735

Brougham, D., & Haar, J. (2017). Smart technology, artificial intelligence, robotics, and algorithms (STARA): Employees' perceptions of our future workplace. *Journal of Management & Organization*, *24*, 239-257. https://doi.org/10.1017/jmo.2016.55

Brynjolfsson, E., & Mitchell, T. (2017). What can machine learning do? Workforce implications. *Science*, *358*, 1530-1534. https://doi.org/10.1126/science.aap8062

Davenport, T., & Ronanki, R. (2018). Artificial intelligence for the real world. *Harvard Business Review*, *96*(1), 108-116. https://hbr.org/2018/01/artificial-intelligence-for-the-real-world

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319-340. https://doi.org/10.2307/249008

Dwivedi, Y. K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Duan, Y., Dwivedi, R., Edwards, J., Eirug, A., Galanos, V., Ilavarasan, P. V., Janssen, M., Jones, P., Kar, A. K., Kizgin, H., Kronemann, B., Lal, B., Lucini, B., ... Williams, M. D. (2021). Artificial intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, *57*, Article 101994. https://doi.org/10.1016/j.ijinfomgt.2019.08.002

Edmondson, A. C. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly*, 44(2), 350-383. https://doi.org/10.2307/2666999

Gagné, M., Parent-Rocheleau, X., Bujold, A., Gaudet, M.-C., & Lirio, P. (2022). How algorithmic management influences worker motivation: A self-determination theory perspective. *Canadian Psychology/Psychologie canadienne*, 63(2), 247-260. https://doi.org/10.1037/cap0000324

Gagné, M., Parker, S. K., Griffin, M. A., Dunlop, P. D., Knight, C., Klonek, F. E., & Parent-Rocheleau, X. (2022). Understanding and shaping the future of work with self-determination theory. *Nature Reviews Psychology*, 1(7), 378-392. https://doi.org/10.1038/s44159-022-00056-w

Glikson, E., & Woolley, A. W. (2020). Human trust in artificial intelligence: Review of empirical research. *Academy of Management Annals*, *14*, 627-660. https://doi.org/10.5465/annals.2018.0057

Ha, T. M. (2026). How Digital Capabilities Drive Innovation in Banking: Extending the Resource-Based View in the era of Digital Transformation. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 353-373. https://doi.org/10.2478/eoik-2026-0040

Jarrahi, M. H. (2018). Artificial intelligence and the future of work: Human-AI symbiosis in organizational decision making. *Business Horizons*, *61*, 577-586. https://doi.org/10.1016/j.bushor.2018.03.007

Kane, G. C., Phillips, A. N., Copulsky, J. R., & Andrus, G. R. (2019). *The technology fallacy: How people are the real key to digital transformation*. MIT Press. https://doi.org/10.7551/mitpress/11661.001.0001

Kellogg, K. C., Valentine, M. A., & Christin, A. (2020). Algorithms at work: The new contested terrain of control. *Academy of Management Annals*, *14*. https://doi.org/10.5465/annals.2018.0174

Kotter, J. P. (1996). *Leading change*. Harvard Business School Press. https://www.hbs.edu/faculty/Pages/item.aspx?num=137

Langer, M., & Landers, R. N. (2021). The future of artificial intelligence at work: A review on effects of decision automation and augmentation on workers targeted by algorithms and third-party observers. *Computers in Human Behavior*, 123, Article 106878. https://doi.org/10.1016/j.chb.2021.106878

Lewin, K. (1947). Frontiers in group dynamics: Concept, method and reality in social science; Social equilibria and social change. *Human Relations*, 1(1), 5-41. https://doi.org/10.1177/001872674700100103

McKinsey & Company. (2025). *The state of AI: McKinsey global survey*. Retrieved from https://www.mckinsey.com/capabilities/quantumblack/our-insights/the-state-of-ai

Meske, C., Bunde, E., Schneider, J., & Gersch, M. (2022). Explainable artificial intelligence: Objectives, stakeholders and future research opportunities. *Information Systems Management*, *39*, 53-63. https://doi.org/10.1080/10580530.2020.1849465

Nassanbekova, S., Yeshenkulova, G., Nurguzhina, A., Ibrahim, M., & Ibadildin, N. (2026). Understanding Student Adoption of Generative AI Chatbots in Higher Education: An Integrated TAM–TRI Approach. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 293-307. https://doi.org/10.2478/eoik-2026-0037

Nastjuk, I., Trang, S., Grummeck-Braamt, J. V., Adam, M. T. P., & Tarafdar, M. (2023). Integrating and synthesising technostress research: A meta-analysis on technostress creators, outcomes, and IS usage contexts. *European Journal of Information Systems*. Advance online publication. https://doi.org/10.1080/0960085X.2022.2154712

Noy, S., & Zhang, W. (2023). Experimental evidence on the productivity effects of generative artificial intelligence. *Science*, 381(6654), 187-192. https://doi.org/10.1126/science.adh2586

Parent-Rocheleau, X., & Parker, S. K. (2022). Algorithms as work designers: How algorithmic management influences the design of jobs. *Human Resource Management Review*, 32(3), Article 100838. https://doi.org/10.1016/j.hrmr.2021.100838

Raisch, S., & Krakowski, S. (2021). Artificial intelligence and management: The automation-augmentation paradox. *Academy of Management Review*, *46*, 192-210. https://doi.org/10.5465/amr.2018.0072

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

Tarafdar, M., Tu, Q., Ragu-Nathan, B. S., & Ragu-Nathan, T. S. (2007). The impact of technostress on role stress and productivity. *Journal of Management Information Systems*, 24(1), 301-328. https://doi.org/10.2753/MIS0742-1222240109

Torraco, R. J. (2005). Writing integrative literature reviews: Guidelines and examples. *Human Resource Development Review*, 4(3), 356-367. https://doi.org/10.1177/1534484305278283

Vander Elst, T., De Witte, H., & De Cuyper, N. (2014). The Job Insecurity Scale: A psychometric evaluation across five European countries. *European Journal of Work and Organizational Psychology*, 23(3), 364-380. https://doi.org/10.1080/1359432X.2012.745989

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Towards a unified view. *MIS Quarterly*, *27*, 425-478. https://doi.org/10.2307/30036540

Yam, K. C., Tang, P. M., Jackson, J. C., Su, R., & Gray, K. (2023). The rise of robots increases job insecurity and maladaptive workplace behaviors: Multimethod evidence. *Journal of Applied Psychology*, 108(5), 850-870. https://doi.org/10.1037/apl0001045

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

SUSTAINABILITY AT MARITIME MOBILITY: COMPARING OPEN DATA ECOSYSTEMS AND COLLABORATIVE MARITIME PLATFORMS

João Marreiros[1*], Tiago Pinho[1], Nelson Carriço[2], Ana Mendes[1], Marcela Castro[1,3]

Received 03.03.2026. | Send to review 21.03.2026. | Accepted 14.08.2026.

Original Article

CC BY NC ND

[1] Escola Superior de Ciências Empresariais, Instituto Politécnico de Setúbal, Campus do IPS - Estefanilha, Setúbal, Portugal

[2] Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Rua Conselheiro Emídio Navarro 1, Lisboa, Portugal

[3] NECE – Research Centre for Business Sciences, Department of Management and Economics, Faculty of Human and Social Sciences, Universidade da Beira Interior, Covilhã, Portugal. CIEQV - Life Quality Research Center

***Corresponding Author:**
João Marreiros

Email:
joao.marreiros07@gmail.com

JEL Classification:
R40, O33, L86, Q56, L91

Doi: 10.61432/CPNE0401127m

UDK: 005.334:338.583(4-672EU)

ABSTRACT

Maritime transport is a critical component of global supply chains and sustainable mobility systems. Ports, as interfaces between maritime and land transport, influence urban congestion, emissions, and environmental performance. Open Data Platforms (ODP) and Open Data and Collaborative Platforms (ODCP) can support transparency, data-driven decision-making, and coordination among port and urban stakeholders.

This study examines the role of ODP and ODCP in the maritime port sector and their contribution to sustainability and sustainable urban mobility. A multi-stage methodology combines bibliometric analysis with an empirical assessment of platforms associated with the world's Top 50 Container Ports. The analysis considers publication trends, sustainability dimensions, platform functions, and levels of development.

The findings indicate that research in this field remains recent, fragmented, and only partially focused on sustainability. Existing platforms vary considerably in maturity and scope, prioritizing data provision and environmental monitoring, while collaborative functions and integrated economic, environmental, and social dimensions are less consistently developed. Based on these findings, the study proposes a structured framework for evaluating and designing maritime ODP and ODCP.

The study contributes to the literature on port–city integration, sustainable mobility, and data-driven governance, while offering practical guidance for port authorities, policymakers, and platform developers.

Keywords: *open data platforms, collaborative platforms, maritime ports, sustainable mobility, port–city integration, sustainability*

1. INTRODUCTION

Maritime transport is a fundamental pillar of global trade, carrying more than 80% of the total volume of goods transported worldwide (Vu et al., 2024). Its predominance reflects its capacity to move large volumes over long distances at relatively low cost. It also offers advantages in terms of energy efficiency and environmental impact per unit transported. However, maritime transport necessarily depends on intermodal operations, as goods must be transferred between ports and inland transport networks (Mansoursamaei et al., 2023).

As a result of their central role in global trade, ports have evolved from traditional loading, unloading, and storage facilities into complex logistics hubs that coordinate and integrate supply-chain activities (Han, 2018). This transformation has increased both the number and diversity of stakeholders involved in port operations, making effective collaboration and transparent communication increasingly important (Ali et al., 2022b).

In parallel, decision-making processes are becoming more data-driven. Open Data Platforms (ODP) and Open Data and Collaborative Platforms (ODCP) support data access, transparency, innovation, and coordination across governmental and organizational contexts (Kassen, 2018). Data are considered open when they can be freely used, reused, and redistributed, including for commercial purposes, without substantial legal or technical restrictions (Ali et al., 2022a). ODP and ODCP provide digital infrastructures through which users can discover, access, exchange, and apply open data. Common examples include CKAN, DKAN, Socrata, OpenDataSoft, GitHub, Google, and Kaggle (Ali et al., 2022b).

The growing operational and institutional complexity of port systems further increases the need for shared and standardized data infrastructures (Pachiyappan et al., 2026). Contemporary ports involve port authorities, logistics operators, shipping companies, municipalities, regulatory bodies, and local communities, all of which generate and use data for planning, operations, and decision-making. Without accessible and interoperable data systems, the capacity of ports to coordinate responses to operational, environmental, and social challenges remains limited. In this context, ODP and ODCP can improve information exchange, transparency, and cooperation across organizational and institutional boundaries.

Despite the increasing importance of digitalization in the maritime sector, the literature provides limited systematic analysis of ODP and ODCP in port environments. This research gap is particularly relevant to sustainable mobility. Ports are major nodes within urban and interurban transport networks and directly affect traffic flows, congestion, emissions, noise, land use, and the integration of maritime and land-based transport. As interfaces between global supply chains and local mobility systems, they significantly influence the environmental and social performance of surrounding urban areas.

Against this background, the study identifies and analyses ODP and ODCP used in the maritime port sector. It maps their scope, focus, functions, and practical applications and develops a structured framework for comparing and designing such platforms. The study also reviews the literature on open data and collaborative platforms in maritime contexts, with particular attention to economic, environmental, and social sustainability. In doing so, it identifies major research gaps, implementation challenges, and opportunities for future development.

The paper is organized as follows. Section 2 presents the theoretical background. Section 3 describes the materials and methods, including the literature review and bibliometric analysis. Section 4 reports the bibliometric findings, assesses existing platforms, and introduces the proposed comparison framework. Section 5 discusses the implications for sustainable mobility and port operations, as well as the main limitations and challenges. Section 6 concludes the paper and outlines practical implications and directions for future research.

2.THEORETICAL BACKGROUND

This section presents a structured review of the literature on ODP and ODCP, with particular attention to their application in complex socio-technical systems and, more specifically, in the maritime port context. The review aims to synthesize existing research on the characteristics, challenges, and benefits associated with these platforms, highlighting how open data and collaborative approaches have been conceptualized, implemented,

and evaluated across different domains. By consolidating contributions from both general and sector-specific studies, this section establishes the theoretical foundations for the analytical framework proposed in this research.

In addition, the literature review emphasizes sustainability-related aspects and the role of data-driven platforms in supporting coordinated decision-making and stakeholder interaction (Shojaei et al., 2026). By examining methodological approaches, evaluation models, and empirical findings reported in prior studies, the review identifies key gaps in the literature, especially regarding the integration of sustainability dimensions and the limited focus on maritime port applications. This synthesis provides a coherent basis for the methodological choices adopted in this study and justifies the need for a structured analysis of ODP and ODCP tailored to the maritime sector.

2.1. OPEN DATA / OPEN DATA AND COLLABORATIVE PLATFORMS ANALYSIS

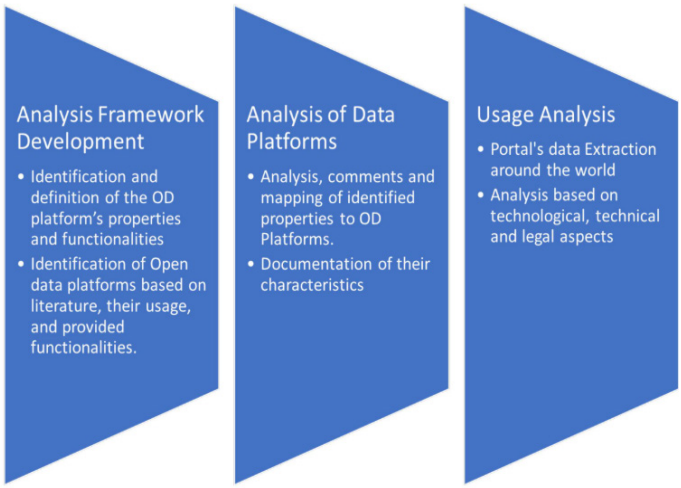
Beyond their technical architecture, ODP and ODCP should be understood as components of broader open data ecosystems shaped by governance structures, institutional arrangements, data standards, and user communities (Van Loenen et al., 2021). Their effectiveness therefore depends not only on data availability, but also on stakeholder coordination, governance quality, and the integration of sustainability principles into platform design. Value is generated primarily through the reuse, linkage, and combination of heterogeneous datasets across organizational and sectoral boundaries (Bauer & Kaltenböck, 2012). Accordingly, platforms should be assessed not only by the data they publish, but also by their capacity to support integration, reuse, and downstream applications.

Platform maturity represents a further analytical dimension. Open data platforms range from basic repositories supporting one-way data publication to advanced collaborative environments enabling real-time interaction, shared data curation, and multi-stakeholder decision-making (Alexopoulos et al., 2014). This distinction underpins the difference between ODP, which primarily facilitate data dissemination, and ODCP, which incorporate participatory and collaborative functions. Identifying a platform's position along this maturity continuum is therefore essential for systematic comparison.

Interoperability and user engagement are also critical. Interoperability refers to the capacity to exchange, integrate, and reuse data across heterogeneous systems, standards, and institutional settings (Ali et al., 2022a). Without it, open data cannot fully support coordinated decision-making or cross-sector collaboration. User orientation is equally important, as platforms that fail to address accessibility, trust, usability, and stakeholder needs tend to achieve lower levels of adoption and impact (Kassen, 2018).

Together, ecosystem embeddedness, data reuse, platform maturity, interoperability, and user engagement provide the theoretical basis for analysing maritime ODP and ODCP. These dimensions complement the structured methodology proposed by Ali et al. (2022b), presented in Figure 1, and provide a coherent framework for evaluating and comparing platforms across different application domains.

Figure 1 - A proposed methodology for the analysis of ODP



Source: (Ali et al., 2022b)

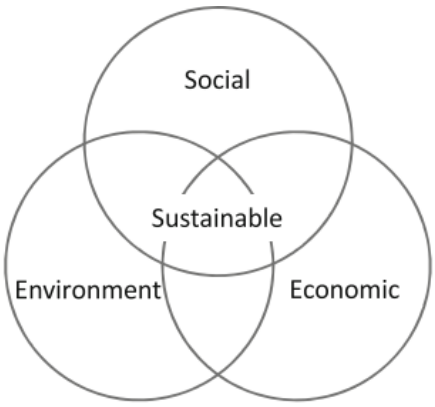
2.2. SUSTAINABILITY ANALYSIS IN ODP AND ODCP

Sustainability has become a central concern in contemporary policy, planning, and research, particularly in sectors characterized by complex socio-technical systems and substantial environmental impacts. However, sustainability considerations remain insufficiently integrated into most existing open data platforms, which are typically designed to prioritize data availability and technical interoperability rather than sustainable outcomes (Van Loenen et al., 2021).

This limitation is particularly evident in the port and maritime sector, where empirical research on the sustainability implications of ODP and ODCP remains scarce. Consequently, establishing a coherent method for evaluating sustainability within data-driven port platforms represents an important methodological challenge.

To address this gap, the study adopts the framework developed by Jiang et al. (2019) for assessing the sustainability performance of government open data platforms. The model conceptualizes sustainability through three dimensions: economic, environmental, and social (Figure 2). In the absence of a domain-specific framework for maritime open data platforms, this established multidimensional model provides an appropriate basis for analysing and comparing ODP and ODCP from a sustainability perspective.

Figure 2 - Typical representation of sustainability as three intersecting circles



Source: (Jiang et al., 2019)

2.3. BARRIERS FOR ODP AND ODCP

Previous studies have identified a wide range of barriers that must be addressed for open data platforms to fulfill their intended role as fundamental enabling tools (Ferreira et al., 2025). These barriers span multiple dimensions, including technical, organizational, and human-related challenges, and collectively constrain the effective use and impact of ODP. Issues related to data quality and standardization, legal constraints, data privacy and security, strategic business considerations, technical complexity, and user literacy have been shown to significantly limit the full potential of open data platforms (Beno et al., 2017).

Beyond these structural and technical limitations, several authors have highlighted the practical difficulties associated with implementing and the everyday use of open data platforms, often resulting in lower-than-expected levels of adoption and utilization (Folmer et al., 2019; Hyseni & Bexheti, 2022). From the perspective of end users, such difficulties lead to usability constraints, reduced confidence in the data, and challenges in incorporating platform outputs into decision-making.

Addressing these barriers represents a considerable challenge for platform developers and system designers, who must balance technological sophistication with accessibility and usability (Slobodova, 2020; Vítor et al., 2022). The literature suggests that overcoming these obstacles requires not only technical solutions but also organizational alignment, capacity building, and user-oriented design approaches. Consequently, several aspects have been identified as critical to enhancing the success and long-term viability of open data platforms, reinforcing the need for structured evaluation frameworks that account for these diverse dimensions (Ali et al., 2022b).

Millette, C. and Hosein, P. (2016) highlighted the main requirements of open data platforms to best serve the needs of the public: (a) highly available data, (b) reusable and distributive data, and (c) universally consumable. They also identified seven principles that a data platform solution must address to meet developers' and consumers' needs: completeness, primacy, timeliness, accessibility, machine-readability, non-discrimination, and non-proprietary.

2.4. BENEFITS OF ODP AND ODCP

Collaborative platforms enhance interaction, coordination, and knowledge exchange among geographically dispersed stakeholders. By supporting real-time communication and multiple content formats, including text, audio, video, and images, they enable more flexible and responsive forms of collaboration. When integrated into organizational processes, these platforms can improve productivity, facilitate feedback, and strengthen collective problem-solving (Andriessen et al., 2023).

In the maritime sector, digitally enabled collaboration has considerable potential to improve the efficiency, sustainability, and safety of port operations (Alexopoulos et al., 2014; Gupta et al., 2022). Combining open data with collaborative functionalities supports coordinated decision-making, aligns operational strategies, and increases transparency among port stakeholders.

These benefits extend beyond individual ports to cross-sectoral partnerships and international cooperation. Shared data environments enable stakeholders to exchange best practices, compare performance, and jointly address operational and sustainability challenges. Data-sharing agreements, collaborative research, and digital cooperation platforms further promote knowledge diffusion and collective learning, reinforcing the strategic value of ODP and ODCP in the maritime port sector (Gupta et al., 2022; Herrera-Cubides et al., 2023).

2.5. ODP AND ODCP AS ENABLERS OF PORT–CITY INTEGRATION AND SUSTAINABLE URBAN MOBILITY

Ports are not isolated logistics hubs. As crucial interfaces between maritime supply chains and land-based transport networks, they shape and directly impact traffic flows, congestion patterns, air quality, noise levels, land use, and the integration of multiple modes of transport within and around urban areas. Addressing sustainability in maritime transport, therefore, requires analytical tools and data infrastructures that explicitly capture this port-city link and support coordinated decision-making across organizational and institutional boundaries.

In this context, ODPs and ODCPs emerge as important facilitators of port-city integration. By facilitating access to standardized, interoperable, and real-time data among diverse stakeholders - including port authorities, municipal governments, logistics operators, transport agencies, and local communities - these platforms can support the kind of systemic and multilateral coordination that sustainable urban mobility demands (Seisenbekov et al., 2026). However, the extent to which existing platforms are designed to perform this integrative function remains underexplored in the literature.

Vaca-Recalde et al. (2024) offer a relevant perspective on this potential through their proposal for a connected and intelligent framework for vehicle automation in smart ports. Their work demonstrates how integrated data platforms in port environments can support real-time coordination between port operations and the surrounding transportation infrastructure, contributing to more efficient logistics flows. Essentially, the framework extends beyond the port perimeter, encompassing the interfaces between automated port vehicles, urban road networks, and intermodal transfer points - a design that reflects the inherently hybrid, port-city nature of modern port operations.

Menegon et al. (2023)integrated and efficient planning of coastal and marine spaces at macro-regional level. This research presents the Geoportal of the Adriatic-Ionian Region (GAIR offer a complementary perspective on Maritime Spatial Planning. The development of a geoportal for the Adriatic-Ionian region illustrates how spatially integrated data platforms can support coordinated governance in maritime and coastal environments, reconciling competing uses of marine and coastal space - including those that directly affect urban and peri-urban areas. The geoportal's emphasis on data interoperability, multi-stakeholder access, and regulatory compliance provides a concrete model of how the ODP and ODCP can operationalize the environmental and social dimensions of sustainability at the port-city interface.

From a platform design perspective, Vítor et al. (2022) demonstrate the technical feasibility of scalable smart-city data platforms that integrate real-time data streams from heterogeneous urban sources. Their architecture, designed to support real-time processing and data sharing in a smart city environment, is directly relevant to the challenge of port-city integration: ports generate continuous operational data - ship movements, gate transactions, container flows, emissions - which could, in principle, be integrated into urban mobility management systems, provided there is an adequate platform infrastructure.

The user-oriented perspective of Millette and Hosein (2016) reinforces this point. The authors emphasize that the value of open data platforms ultimately lies in their accessibility and usability for end users. Their identification of seven design principles (completeness, primacy, timeliness, accessibility, machine readability, non-discrimination, and non-proprietary access) provides a normative benchmark for evaluating maritime platforms. This is particularly relevant in the context of port-city data sharing, where diverse and technically heterogeneous user communities must be served simultaneously.

Taken together, these contributions suggest that the effectiveness of the ODP and ODCP

as instruments of port-city integration and sustainable urban mobility depends on at least three interrelated conditions: the platform's ability to integrate heterogeneous data sources into the port-city interface, including real-time operational and environmental data; the platform's design to enable access by multiple stakeholders, ensuring that the data can be used by actors with different technical skills and institutional roles; and the platform's alignment with urban mobility governance frameworks, allowing its results to contribute to decisions regarding land use planning, transportation policy, and environmental management. These conditions are not consistently met by existing platforms, as revealed by the empirical analysis presented in Sections 4.2 and 4.3, and inform the port-city integration dimension explicitly incorporated into the comparison framework proposed in Section 4.4.

3. MATERIALS AND METHODS

This study employed a multi-stage methodology combining a structured literature review, bibliometric analysis, and empirical assessment of maritime open data and collaborative platforms.

First, a literature search was conducted in the Web of Science database using two query strings: (a) ("open data platform" OR "collaborative platform*") AND maritime*, and (b) ("open data platform" OR "collaborative platform*") AND (maritime AND sustainab*). The search yielded 110 records. After restricting the sample to peer-reviewed scientific articles, 57 publications remained.

The 57 articles were then screened to identify studies explicitly addressing sustainability in maritime platforms. This process yielded 10 documents, including six published scientific articles. These six studies were examined in detail to assess how sustainability was conceptualized across the economic, environmental, and social dimensions proposed by Purvis et al. (2019), as well as to identify the main challenges and solutions discussed in the literature.

Two bibliometric analyses were subsequently conducted using VOSviewer. The first covered the full set of 57 articles on maritime ODP and ODCP, while the second focused on the sustainability-related subset. This enabled comparison of publication trends, thematic structures, and relationships among research topics.

The empirical phase examined ports included in the World Shipping Council's Top 50 Container Ports ranking (2024). The analysis identified ODP and ODCP associated with these ports, either directly or through secondary research, and assessed their data coverage, availability, quality, functionality, and usability.

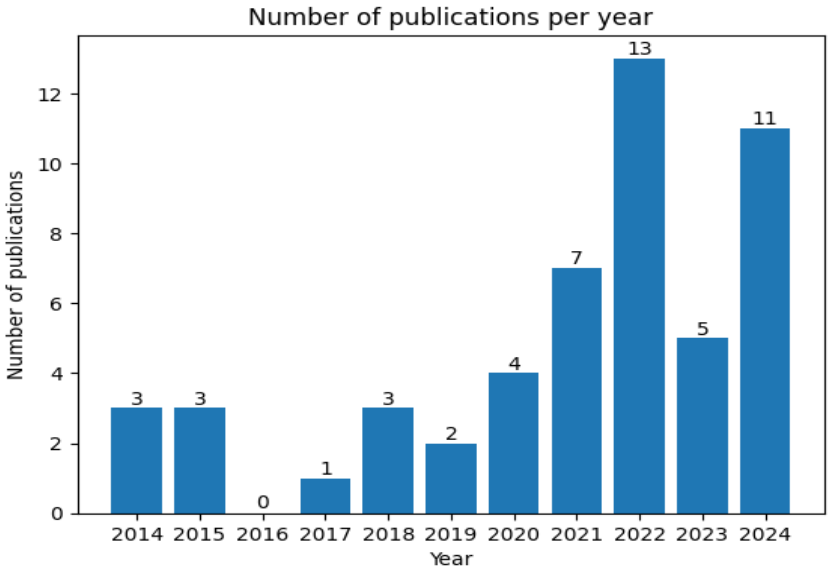
In total, 39 maritime-related platforms were identified and evaluated. The combined findings from the literature review, bibliometric analyses, and empirical assessment formed the basis for the comparative framework for maritime ODP and ODCP proposed in this study.

4. RESULTS AND DISCUSSION

4.1. BIBLIOMETRIC ANALYSIS OF ODP AND ODCP IN THE MARITIME CONTEXT

This subsection presents the results of the bibliometric analyses conducted to examine the scientific literature on ODP and ODCP in the maritime context. The analysis aims to provide an overview of research trends, publication patterns, and thematic relationships within existing literature, and to assess the extent to which sustainability-related aspects have been addressed. By visualizing the volume, distribution, and connections among published studies, the bibliometric results provide a contextual foundation for interpreting subsequent findings and for identifying research gaps in the maritime port domain.

Figure 3 - Temporal distribution of scientific publications on maritime ODP and ODCP



Source: Own elaboration using VOSviewer

Figure 3 shows that research on maritime ODP and ODCP remained limited and irregular between 2014 and 2019, with no indexed publications recorded in 2016. Publication activity increased from 2020 onward and peaked in 2022. Despite a slight decline in 2023, the high output recorded in 2024 indicates sustained and growing academic interest. These trends confirm that maritime ODP and ODCP constitute a relatively recent but expanding research field.

Figure 4 illustrates the multidisciplinary distribution of publications across research areas. Oceanography and Environmental Sciences account for a substantial share of the literature, reflecting the importance of open and interoperable data for monitoring and managing marine and environmental systems. Engineering disciplines, particularly Marine Engineering and Ocean Engineering, are also strongly represented, highlighting the technical and operational relevance of these platforms.

Contributions from Electrical and Electronic Engineering, Telecommunications, Computer Science, and Information Systems further emphasize the role of digital infrastructure, sensor networks, data management, and platform integration. However, the comparatively limited representation of social sciences and information systems suggests that research remains predominantly technical and domain-specific. This imbalance highlights the need for more interdisciplinary approaches that integrate technological, organizational, governance, and sustainability perspectives in port and maritime ecosystems.

Figure 4 - Categorization by activity areas that have published articles about maritime ODCP



Source: Own elaboration using VOSviewer

The results presented in Table 1 indicate a decentralized research landscape in which no single organization dominates scientific production on maritime ODP and ODCP. Although the University of Lisbon and Leiden University appear at the top of the table by publication count, the overall volume of articles per organization remains relatively low. This distribution suggests that research on maritime ODP and ODCP is dispersed across multiple institutions rather than concentrated in a small number of leading research centers, reflecting the field's emerging, exploratory nature.

In contrast, several organizations are represented by a single publication yet have a high number of citations. This pattern is particularly evident among research institutes, governmental bodies, and specialized organizations such as the Alfred Wegener Institute, NOAA, and various marine research centers. The high citation counts associated with these contributions suggest that, although limited in number, these studies have had a significant scientific impact, often serving as key references within the field.

The presence of both academic institutions and applied research organizations reflects the interdisciplinary and practice-oriented nature of research on maritime ODP and ODCP. Universities tend to contribute through broader conceptual or methodological studies, while research institutes, governmental agencies, and consultancy-oriented organizations often provide highly influential, domain-specific insights grounded in empirical data or operational experience. Overall, the distribution shown in Table 1 highlights a research domain characterized by institutional diversity, dispersed contributions, and a mix of exploratory academic work and high-impact applied studies, reinforcing the relevance of maritime ODP and ODCP for both research and practice.

Table 1 - Leading organizations contributing to research on maritime ODP and ODCP

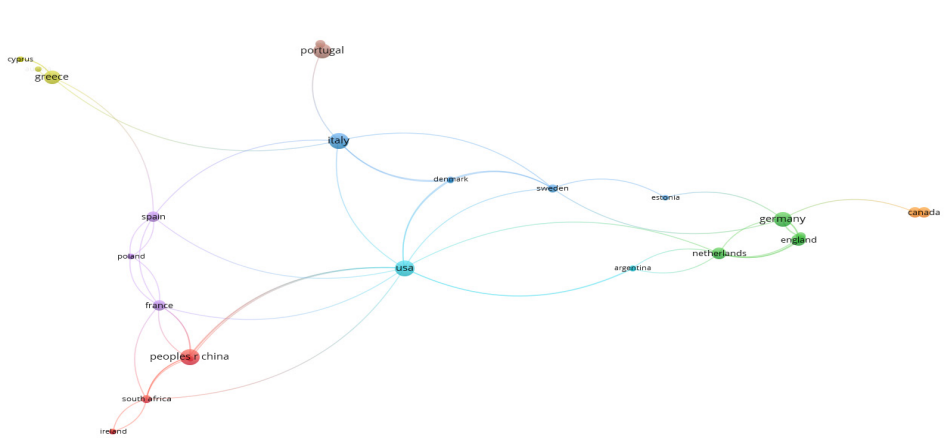
Organization	Documents	Citations	Total Link Strength
univ lisbon	3	19	7
leiden univ	3	4	4
noaa	2	13	7
alfred wegener inst	1	31	12
carl von ossietzky univ oldenburg	1	31	12
cefas lowestoft lab	1	31	12
deep seas environm solut ltd	1	31	12
ecap consultancy grp	1	31	12
oil & gas uk	1	31	12
scottish assoc marine sci	1	31	12
seascape belgium	1	31	12
univ aberdeen	1	31	12
univ edinburgh	1	31	12
univ glasgow	1	31	12
wageningen marine res	1	31	12
wageningen univ	1	31	12
cafoscari univ venice	1	5	8
earthx	1	0	8
emilia romagna geol seism & soil survey	1	5	8
hellen ctr marine res	1	5	8

Source: Own elaboration using VOSviewer

The collaboration network, shown in Figure 5, reveals an emerging, moderately fragmented pattern of international cooperation in maritime ODP and ODCP research. A small number of countries, particularly the United States and Italy, serve as central hubs connecting regional clusters, while several others remain more peripheral. Although European collaboration is relatively strong, especially in Northern and Western Europe, cross-regional and intercontinental links remain limited.

Overall, the network structure suggests significant potential to strengthen international collaboration and support a more integrated, globally oriented research landscape.

Figure 5 - Connections between countries that publish more articles related to maritime ODCP



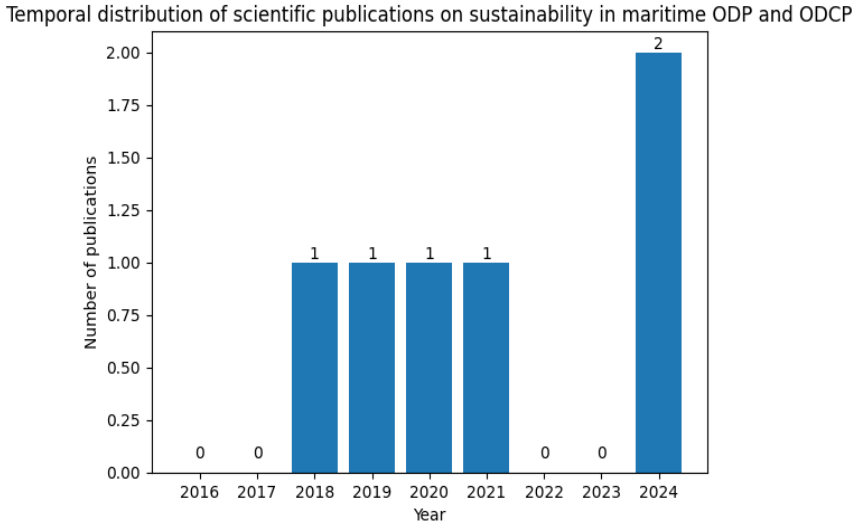
Source: Own elaboration using VOSviewer

This study also examines scientific publications that explicitly address sustainability-related aspects in the context of maritime ODP and ODCP. This analysis explores how sus-

tainability has been conceptualized and operationalized across existing studies, with particular attention to its economic, environmental, and social dimensions.

Figure 6 presents the temporal distribution of scientific publications on sustainability on maritime ODP and ODCP. The results indicate a limited and irregular scientific production on sustainability in maritime ODP and ODCP. Research in this area only emerged after 2018, remains discontinuous over time, and shows a slight increase in 2024. Moreover, the limited number of available studies limits the ability to identify robust trends or draw definitive conclusions, highlighting sustainability as an underexplored dimension in this research domain.

Figure 6 - Temporal distribution of scientific publications on sustainability on maritime ODP and ODCP



Source: Own elaboration using VOSviewer

The distribution of scientific publications by activity areas, as shown in Figure 7, highlights the disciplinary profile of research addressing sustainability in the context of maritime ODP and ODCP. Environmental Sciences and Environmental Studies emerge as the most represented areas, accounting for most of the identified publications. This predominance reflects the strong association between sustainability concerns and environmental monitoring, impact assessment, and ecosystem management, areas in which data availability and interoperability play a central role.

Figure 7 - Categorization by activity areas that have published articles about maritime ODCP linked to the sustainability theme



Source: Own elaboration using VOSviewer

Building on the sustainability assessment model proposed by Jiang et al. (2019), which conceptualizes sustainability as a multidimensional construct comprising three main dimensions - economic, environmental, and social -this study analyzed the selected articles addressing sustainability in the context of maritime ODP and ODCP according to these three dimensions. In the absence of domain-specific evaluation frameworks tailored to maritime data platforms, the adopted approach provided a consistent and widely accepted basis for structuring the analysis.

Accordingly, each article was examined to identify its primary focus and contributions within the economic, environmental, and social dimensions of sustainability. The results of this analysis are summarized in Table 2, which evidences not only the distribution of articles across the three dimensions, but also the recurrent application domains within each pillar.

These shared application domains provide insight into prevailing research priorities and illustrate how sustainability has been operationalized in existing studies on maritime ODP and ODCP.

Table 2 - Sustainability dimensions and application domains of published maritime ODP and ODCP studies

Dimension	Application Domains	Articles
Economic	Sustainable Blue Economy development	(Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024; Van Vranken et al., 2020)
	Costs reductions	(Kyvelou & Ierapetritis, 2019; Vaca-Recalde et al., 2024; Menegon et al., 2023; Murray et al., 2018; Kyvelou & Ierapetritis, 2019; Spadon et al., 2024)
	High investments needed	(Vaca-Recalde et al., 2024)
Environment	Overexploitation or degradation prevention	(Menegon et al., 2023)
	Environment risks prevention	(Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024)
	Biodiversity and habitat protection	(Menegon et al., 2023; Murray et al., 2018; Kyvelou & Ierapetritis, 2019; Spadon et al., 2024)
	Efficient use of resources	(Vaca-Recalde et al., 2024; Van Vranken et al., 2020)
	Climate impacts of changing processes	(Murray et al., 2018; Spadon et al., 2024)
Social	Stakeholder engagement	(Menegon et al., 2023; Kyvelou & Ierapetritis, 2019; Van Vranken et al., 2020; Spadon et al., 2024)
	Conflicts resolution	(Menegon et al., 2023; Kyvelou & Ierapetritis, 2019; Van Vranken et al., 2020)
	Quality of life	(Menegon et al., 2023)
	Labor impacts	(Vaca-Recalde et al., 2024; Murray et al., 2018)
	Safety and security improvements	(Vaca-Recalde et al., 2024; Spadon et al., 2024)

Source: Own elaboration

From an economic perspective, the analysed studies primarily examine efficiency gains, cost reduction, and the optimization of maritime and port operations. ODP and ODCP support data-driven decision-making, reduce duplication of effort, and improve resource allocation. Economic sustainability is also linked to innovation, competitiveness, and the development of data-enabled maritime services. The most frequently reported benefits concern lower labour costs (Vaca-Recalde et al., 2024), the avoidance of duplicated process-optimization studies (Murray et al., 2018), more efficient use of maritime resources (Kyvelou & Ierapetritis, 2019; Van Vranken et al., 2020), and reduced data-management costs (Menegon et al., 2023; Spadon et al., 2024).

Within the environmental dimension, the main application areas include environmental monitoring, risk prevention, biodiversity protection, and the efficient use of natural resources. Open and interoperable data support environmental assessment, impact analysis, regulatory compliance, and integrated environmental management. In particular, ODCP can help identify biodiversity hotspots and support the protection of natural habitats (Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024). They also facilitate the centralization and standardization of data used to detect patterns, model contaminant dispersion, and assess environmental risks (Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024).

The social dimension is mainly associated with stakeholder engagement, governance, conflict resolution, safety, and quality of life. The reviewed studies emphasize the role of ODP and ODCP in promoting transparency, enabling participatory decision-making, and strengthening collaboration among stakeholders within maritime and port ecosystems.

The social dimension mainly points to the stakeholders' engagement, both as a challenge and a benefit, lightening the need to involve the community as a whole, relieving the importance of local communities (and their cultural heritage), and transboundary cooperation (Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Spadon et al., 2024; Van Vranken et al., 2020). The potential to use the data to resolve conflicts, ensure coexistence among traditional sectors, and improve fairness in resource allocation is also enhanced (Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Van Vranken et al., 2020).

Overall, the table illustrates that sustainability-oriented research on maritime ODP and ODCP tends to associate each sustainability dimension with specific application domains, reinforcing the need for integrated approaches that address economic, environmental, and social objectives in a coordinated manner.

4.2. OPEN DATA AVAILABILITY IN THE TOP 50 CONTAINER PORTS

Following the literature review and bibliometric analyses, this subsection presents the results of a systematic assessment of open data availability among the world's leading container ports. The analysis focused on the ports included in the worldwide Top 50 Container Ports list, published by the World Shipping Council (2024). The objective was to map the current state of ODP and ODCP adoption at the port level.

For each port, the assessment followed a two-step procedure. In a first step, the official port authority website was examined directly to identify any linked or embedded open data platform. In cases where no platform was immediately visible, a second check was performed through standardized web searches combining the port name with terms such as "open data", "data portal", and "data platform", as well as a review of relevant governmental or regulatory portals associated with the port's national or regional jurisdiction.

The results (Table 3) reveal that open data provision is far from universal among the world's major container ports. Of the 50 ports analysed, 28 - corresponding to 56% of the total - were found to have some form of open data available for access or sharing. The remaining 22 ports had no identifiable platform: 18 had no platform, or none that was visible and easy to find through the procedures described above, while 4 did not have a direct, dedicated website for the port authority itself and instead provided only static information, such as sustainability reports or news. Table 3 provides a full overview of the 50 ports analysed and their corresponding data availability status.

These findings suggest that, despite the growing relevance of data-driven approaches in the maritime sector, the systematic provision of open data at the individual port level remains limited. The absence of platforms in a significant share of the Top 50 ports, which represent some of the most resource-intensive and strategically significant nodes in glob-

al supply chains, underscores a clear implementation gap between the recognized potential of ODP and ODCP and their actual deployment in port environments.

Table 3 - Open Data Availability in the Top 50 Container Ports

Port Identification	ODP/ODCP Status
Shangai, China	Not available
Singapore, Singapore	Available
Ningbo -Zhoushan, China	Not available
Shenzhen, China	Available
Guangzhou Harbor, China	Available
Busan, South Korea	Available
Qingdao, China	Available
Hong Kong, China	Available
Tianjin, China	Available
Rotterdam, The Netherlands	Available
Jebel Ali, Dubai, UAE	Available
Port Klang, Malaysia	Available
Xiamen, China	Available
Antwerp, Belgium	Available
Kaohsiung, Taiwan, China	Available
Dalian, China	Not available
Los Angeles, USA	Available
Hamburg, Germany	Available
Tanjung Pelepas, Malaysia	Not ODP, only static information
Laem Chabang, Thailand	Available but not at the port site
Keihin Ports, Japan	Not ODP, only static information
Long Beach, USA	Available
Tanjung Priok, Indonesia	Not available
New York-New Jersey, USA	Available
Colombo, Sri Lanka	Available
Ho Chi Minh City, Vietnam	Available
Suzhou, China	Not available
Piraeus, Greece	Not available
Yingkou, China	Available
Valencia, Spain	Not available
Manila, Philippines	Not available
Taicang, China	Not available
Hai Phong, Vietnam	Not available
Algeciras, Spain	Available
Jawarharlal Nehru Port (Nhava Sheva), India	Available
Bremen/Bremerhaven, Germany	Available
Tanger Med, Morocco	Available but not at the port site
Lianyungang, China	Not available
Mundra, India	Not available
Savannah, U.S.A	Available
Tokyo, Japan	Not available
Rizhao, China	Not available
Colon, Panama	Available
Santos, Brazil	Available
Salalah, Oman	Available
Dongguan, China	Not available
Guangxi Beibu, China	Not available
Cai Mep, Vietnam	Not available
Yingkou Bayuquan, China	Not available
Port Said, Egypt	Available

Source: Own elaboration

4.3. REFERENCE PLATFORMS FOR MARITIME ODP/ODCP

Complementing the port-level assessment, this subsection examines maritime-relevant ODP and ODCP operating at the sector level. Rather than focusing on platforms formally

associated with individual port authorities, the analysis identifies platforms supporting maritime operations, research, and governance across the wider data ecosystem.

A total of 39 platforms were assessed. These included sector-specific solutions for maritime and port activities, such as NXTPort, EMSA, Sea Traffic Management–PortCDM, and MarineTraffic; multi-domain platforms used by maritime stakeholders, including Eurostat, OECD iLibrary, and Esri; and thematic platforms focused on ocean observation, environmental monitoring, and transport policy, such as EMODnet, the World Ocean Database, and the ITF. This broader ecosystem approach follows Ali et al. (2022b), who emphasize that open data ecosystems in complex sectors include both dedicated and cross-sectoral platforms.

Each platform was evaluated according to its thematic focus, supported data types and formats, access conditions, collaborative functions, sustainability features, and web performance. Table 4 summarizes their main objectives, functionalities, and application areas.

The findings show that most platforms prioritize data provision and information access, particularly in maritime monitoring, safety, environmental observation, and transport performance. Environmental and oceanographic data are especially prominent, reflecting the importance of these platforms for ecosystem monitoring, environmental assessment, and regulatory compliance. By contrast, fewer platforms support operational coordination, logistics integration, or multi-stakeholder decision-making.

Collaborative functions are also unevenly developed. Although some platforms enable user interaction, data sharing, and integration with external systems, many remain focused on one-way data publication. This suggests that collaboration, despite its prominence in policy and conceptual discussions, has not yet become a central design feature of many maritime platforms.

Overall, existing maritime ODP and ODCP remain fragmented and specialized, with strong capabilities in data provision and environmental monitoring but limited support for integrated collaboration and cross-domain decision-making. These findings, together with the bibliometric and port-level results, informed the framework presented in the following subsection.

Table 4 - Maritime-related platforms focus

39 Maritime-Related Platforms	Focus or Topic
Blue Cloud	Maritime Open Platform
European Marine Observation and Data Network (EMODnet)	Maritime Data Provider
Admiralty	Marine Geospatial Data
NXTPort	Smart Data Sharing Platform
ESRI	Geospatial Data
UN Sustainable Development Goal 14	Maritime Sustainability
UNCTAD	Maritime Transport Data
Eurostat	Generic Statistical Data
U.S. Bureau of Transportation Statistics (BTS)	Governmental
Lloyd's List Intelligence	Maritime Services
Digital Transport and Logistics Observatory (DTLO)	Transport Digitalization
European Maritime Safety Agency (EMSA)	Service/Assistance Provider
World Bank Port Performance Indicators	Consulting and Reporting
Electronic Quality Shipping Information System (EQUASIS)	Maritime Safety Promotion
Global Container Database (GCO)	Container Technical Information
Greenhouse Gas Emissions from Shipping (IMO GHG Data)	Maritime Transport Regulation
World Maritime University Port Database (WMU Port Database)	Education

39 Maritime-Related Platforms	Focus or Topic
International Transport Forum (ITF)	Transport Policy Think Tank
OECDilibrary	Generic Statistical Data
EuroOcean	Ocean Promotion (ONG)
European MSP Platform	Maritime Spatial Planning
CoastObs	Maritime Data Provider
Collaborative Land-Sea Integration Platform (Coastal)	Rural-Coastal Development
EuroGOOS	Marine Data and Standards
JERICOri	Maritime Data Provider
EuroSea	Ocean Research
International Association of Ports and Harbors (IAPH)	Global Trade Association
Sea Traffic Management – PortCOM	Real-Time Maritime Data
European Commission's Port Services Regulation Database	Legal and Regulation
International Tanker Owners Pollution Federation	Maritime Technical Assistance
European Short Sea Shipping Information System (ESSSIS)	Shortsea Shipping Information
European Maritime Transport Environmental Report (EMTER)	Environmental Report
Marine Traffic	Ship Tracking
Vessel Finder	Ship Tracking
World Ocean Database (WOD)	Ocean Open Data
National Data Buoy Center (NDBC)	Meteo/Ocean Open Data
openAQ	Air Quality Open Data
Saildrone Data Explorer	Real-Time Ocean Information
Integrated Marine Observing System (IMOS Data Portal)	Australia Ocean Data

Source: Own elaboration

Considering the literature previously reviewed and based on the analysis of port websites and collaborative and open data platforms, it was concluded that the most relevant features or functions of these solutions are as follows:

- Community Engagement and Collaboration: Features like discussion forums, user feedback mechanisms, and collaborative data curation tools, such as version control systems and annotation features, enable users to collaborate directly on datasets.
- User Authentication and Authorization: Secure authentication and authorization mechanisms control access to sensitive or restricted datasets. Authentication should be integrated with partner platforms to enable seamless collaboration among organizations and stakeholders.
- Data Licensing and Usage Policies: Clear licensing and usage policies define how the data can be accessed, used, and shared, leaving no room for ambiguity.
- Governance and Sustainability: Establishing clear governance structures and sustainability plans ensures the platform's long-term viability.
- Documentation and Support: Comprehensive documentation and support services help users navigate the platform. Every interaction on the platform should be thoroughly documented. User support services enable quick responses and stakeholder satisfaction, improving the quality of the experience.

4.4. MARITIME OPEN DATA COLLABORATIVE PLATFORMS FEATURES FRAMEWORK

The main findings of this study were synthesized to identify and consolidate a comprehensive set of essential features for maritime open data and collaborative platforms. This synthesis draws on three complementary sources of evidence: (1) the systematic literature

review and bibliometric analysis reported in Section 4.1, which identified the dominant research themes, sustainability dimensions, and knowledge gaps in existing scholarship; (2) the port-level availability assessment reported in Section 4.2, which revealed the current state of ODP and ODCP deployment among the world's major container ports; and (3) the inventory and characterisation of 39 maritime-relevant reference platforms reported in Section 4.3, which provided a broad empirical basis for identifying the features and functionalities most consistently present or absent in existing solutions. By integrating these complementary perspectives, the analysis moves beyond isolated observations to provide a structured understanding of the key characteristics underpinning effective ODP and ODCP in the maritime context.

Based on this integrated analysis, the results were formalized into a structured framework (Table 5) that organizes the identified features into coherent dimensions. The proposed framework is intended to serve both as an evaluation instrument and as a practical design guide. On the one hand, it can serve as a checklist to assess and compare existing maritime platforms; on the other hand, it offers guidance to developers, port authorities, and decision-makers for the design and implementation of new ODP and ODCP, with particular attention to sustainability, interoperability, and long-term viability.

Table 5 - Framework to maritime Open Data and Collaborative Platforms (ODCP)

Key Features / Properties		
Data Properties	Periodicity	Annual
		Monthly
		Real-Time (RT)
		Near RT
	Data Formats	CSV
		JSON
		XML/XMLS
		Databases
		PDF
		Images (jpeg, png, tiff, svg, ...)
		Audio (wav, mp3, flac, ...)
		Video (mp4, avi, av1, ...)
		GIS
		Others (*specify*)
Access and Management	API	API Access
		Documentation
	Deployment	Desktop App
		Android
		iOS
		Browser
	Integration	Devices
		Platforms

Key Features / Properties		
Security and Compliance	Open data standard compliance	Government Entities
		Researchers and Developers
		None
	Authentication	No login / Open
		Single Sign-on (SSO)
		Multifactor Auth (MFA)
		Third-party Auth. (Google/JUL)
Features and Functionalities	Search/ Searchability	Search
		Categories & Sorting
		Onsite
	Data Visualization Tools	Offsite
		Third-party
		File Upload
	Data Insertion Tools	API
		Database
	Data Linkage	Linking with other platforms
Costs and Pricing	Free Access	Free Access / Open Data
	Licensing	Clear license terms
	Subscription Fees	Subscription
		Service Levels / User Types
	Purchasing	Pay per Item / Shop Cart
		Pay per Service / Feature
		Pay per API calls
	Custom	Pricing under consultation
Sustainability	Environmental management	Certifications, Terms of Service
		Environmental Compliance (regulations)
	Infrastructure and Hosting	Sustainable Cloud Providers
		Energy-Efficient Hardware
		Data Center Cooling Technologies
	Sustainable Data Practice	Data minimization strategies
		KPI for energy consumption (transaction/ query)
UI/UX Evolution	Changes over time	Interface
		Functionality
		Others (*specify*)
Community and Support	Documentation	Guides, tutorials, API docs
	Community Support	Forums, user groups, etc.
	Professional Support	Professional support services

Key Features / Properties		
Port–City Interface & Urban Mobility Integration	Multimodal Connectivity	Land-side transport data (road, rail, inland waterways)
		Intermodal transfer point data
	Operational Data Sharing	Operational data (vessel movement, gate transaction, cargo flow)
		API-compatible with urban transport systems
	Spatial & Coastal Planning Support	Port boundary and land use data
		Coastal zone geospatial data
		Maritime Spatial Planning (MSP) tools
		Multi-layer GIS analytical tools
	Regulatory Compliance Support	MSP directive compliance documentation
		Integrated coastal management reporting
	Multi-stakeholder Accessibility	Maritime sector users
		Transport agencies and local authorities
		Urban planners and researchers
		Civic/public access (non-discriminatory)
	Environmental Monitoring	Environmental data (port emissions, noise level, water quality)
		Biodiversity and habitat indicators
5-star model	Assessment of the level of openness and accessibility of data on the Web	
PageSpeed Insights	Assessment of the digital accessibility of the platform interface	

Source: Own elaboration

When analyzing Maritime ODP, various criteria were considered to assess its effectiveness and suitability. These criteria encompass different aspects of the platform's functionality, accessibility, security, and support. Key criteria considered in the assessment include:

- Data Properties: The types and formats available on the platform were evaluated, including whether it provides periodic data updates, such as annual or monthly reports, and whether the data is available in real-time or near real-time. Additionally, various supported data formats were considered, including CSV, JSON, XML, databases, images, audio, video, GIS data.
- Access & Management: Checking how users can access and manage the data, including the availability of API and documentation for developers, as well as the deployment and integration options such as desktop applications, mobile apps for Android and iOS, or browser-based access.
- Security and Compliance: Verifying the platform's adherence to open data standards and compliance with relevant regulations. Authentication methods, including single sign-on, multi-factor authentication, and third-party authentication, are also considered to ensure data security and user privacy.
- Features and Functionalities: Investigate the platform's search capabilities, data visualization tools, data insertion tools, data linkage with other platforms, and data evaluation tools to assess its usability and effectiveness in handling and presenting data.
- Costs and Pricing: Analysing the platform's pricing model, including options for free access, licensing terms, subscription fees, and purchasing options such as pay-per-item or pay-per-service (Parker & Van Alstyne, 2018).

- Sustainability: Verify specific dimensions that address each platform's environmental impact to evaluate its commitment to this theme. Information in this regard can come from certifications such as ISO, membership in sustainability organisations, transparency about how data is stored and managed, the type and amount of energy spent on these processes, or the commitment of the various suppliers.
- UI/UX Evolution: using an Internet Archive tool named Wayback Machine (Internet Archive, 2001), track changes in the platform's user interface and user experience over time to evaluate its evolution and responsiveness to user feedback and technological advancements.
- Community and Support: Considering the availability of documentation such as guides, tutorials, and API documentation, as well as the level of community support through forums and user groups. Professional support services are also considered to assess the platform's overall support infrastructure.
- Port–City Interface & Urban Mobility Integration: Assessing the extent to which the platform supports data sharing and coordination at the interface between port operations and urban mobility systems. As ports function as critical nodes in urban and interurban transport networks, their operational data have direct implications for congestion, emissions, land use, and multimodal transport integration in surrounding areas (Vaca-Recalde et al., 2024). This criterion evaluates whether the platform provides land-side transport data - covering road, rail, and inland waterways - and data on intermodal transfer points to enable coordination between maritime and urban transport flows (Vaca-Recalde et al., 2024). It also examines whether operational data such as vessel movements, gate transactions, and cargo flows are available, and whether the platform offers API-compatible outputs suitable for integration with external urban transport management systems (Vítor et al., 2022). The spatial and regulatory dimensions are assessed through the availability of geospatial data on port boundaries, coastal zones, and land use, as well as tools supporting Maritime Spatial Planning and compliance with integrated coastal management frameworks (Menegon et al., 2023). Finally, the criterion considers the platform's accessibility to a diverse range of stakeholders beyond the maritime sector - including transport agencies, urban planners, researchers, and the general public - following the open data design principles of completeness, accessibility, non-discrimination, and non-proprietary access (Millette & Hosein, 2016), as well as the availability of environmental monitoring data relevant to the port–city interface, including emissions, noise, water quality, and biodiversity indicators (Menegon et al., 2023; Vaca-Recalde et al., 2024).
- 5-star model: This criterion aims to analyse the five classification levels for the available data on a web platform based on the 5-Star Model for ODP (Tim Berners-Lee, 2010). This is a framework developed by Tim Berners-Lee, the inventor of the World Wide Web, to assess the level of openness and accessibility of data on the Web. The model aims to encourage organizations to make data available in a way that maximizes its potential for re-use and interoperability and consists of five progressively more open levels, or "stars," each representing a higher degree of openness and usability.
- Performance: To standardize the evaluation of each ODP's digital accessibility and web performance - understood as the technical quality and responsiveness of the platform's web interface - a Google tool called PageSpeed Insights was used (Google, 2010). PageSpeed Insights is a widely adopted web performance analysis tool that evaluates the loading speed, responsiveness, and quality of the user experience of web pages, returning a standardized score on a scale from 0 to 100, where higher values indicate better performance. It should be noted that this metric captures the

digital accessibility of the platform interface and is not intended to measure maritime operational performance or logistics efficiency.

Several limitations of this study should be acknowledged to properly contextualize the findings and inform their interpretation. First, the port-level analysis is restricted to the 50 ports included in the WSC Top 50 Container Ports ranking, which, while representative of the world's largest container traffic volumes, does not capture the full diversity of smaller, regional, or specialized port contexts. The findings regarding ODP and ODCP availability may therefore not be generalized beyond the major container port segment.

Second, the platform assessment relied exclusively on publicly visible and accessible information, without access to internal platform documentation, usage statistics, backend functionalities, or organizational data. Platforms that restrict access to registered or institutional users may have been partially assessed or classified as less functional than they are in practice.

Third, the study does not incorporate end-user perspectives. The assessment of platform characteristics reflects the research team's structured observation rather than the experience, perceptions, or reported satisfaction of port operators, logistics professionals, urban planners, or other platform users. User-side evaluations would likely reveal adoption barriers and usability gaps that the present methodology does not capture.

Fourth, although the platform assessment covered multiple dimensions - including data properties, access, security, functionalities, costs, sustainability features, and web performance - the per-platform results of this assessment are not individually reported in this article. The analysis informed the framework's development but was not presented as a comparative matrix, limiting the reader's ability to verify or replicate the evaluation for individual platforms.

Fifth, the sustainability-focused bibliometric subset comprised only six peer-reviewed scientific articles, which constrains the robustness of trend analyses in that dimension and reflects the early-stage nature of sustainability-oriented research in the maritime ODP and ODCP domain rather than a limitation of the search procedure.

Finally, the study adopts an exploratory and descriptive research design. While this approach is appropriate for mapping an emerging and fragmented field, it does not allow for the establishment of causal relationships between platform characteristics and sustainability or operational outcomes.

5. CONCLUSION

This study examined the role of ODP and ODCP in the maritime port sector, with particular emphasis on their contribution to sustainability. By combining a bibliometric analysis with an empirical assessment of existing platforms, the research provides an integrated overview of how open data and collaborative approaches are currently being applied in maritime contexts and how they support economic, environmental, and social objectives.

The results demonstrate that, although ODCP holds significant transformative potential, its current level of implementation and maturity varies considerably across platforms. Most of the analysed solutions remain primarily focused on data provision and operate at a relatively low level of openness and integration, limiting their ability to fully exploit the potential of open data. This fragmentation reinforces the need for structured and standardized approaches, such as the framework proposed in this study, to support both the evaluation and the design of maritime ODP and ODCP.

From a sustainability perspective, the findings confirm that ODCP can contribute meaningfully across the three pillars. Economically, these platforms support cost reductions and operational efficiency by improving data accessibility and reducing duplicate work. Environmentally, data centralization and standardization facilitate resource optimiza-

tion, environmental monitoring, and biodiversity protection. Socially, ODCP enhances stakeholders' engagement, transparency, and fairness in decision-making processes, particularly in complex port ecosystems involving multiple actors.

Importantly, these contributions extend beyond the port perimeter and are directly connected to broader challenges of sustainable urban mobility. As critical nodes in urban and interurban transport networks, ports influence traffic flows, congestion patterns, emissions, land use, and interactions between maritime and land-based transport modes. In this context, ODCP can support better coordination between port operations and urban mobility systems, enabling more integrated planning, improved intermodal connections, and data-driven strategies to mitigate the negative externalities of freight transport in urban areas.

Several challenges remain. The lack of harmonized data standards, limited integration capabilities, and low levels of user literacy continue to hinder the effective adoption and widespread diffusion of ODCP. In addition, the bibliometric analysis revealed that sustainability-oriented research in the context of maritime ODCP remains limited and discontinuous, highlighting clear opportunities for further investigation.

Several directions for future research emerge from this study. Building on the framework proposed here, future work could apply the evaluation criteria to generate individual platform assessments and present the results in structured comparative form — a matrix or scoring table that would allow direct comparison across the 39 platforms analysed and beyond. This would transform the present exploratory study into a replicable benchmarking instrument. The framework itself could also be validated and refined through expert consensus methodologies, such as the Delphi method, or through empirical application in smart port case studies, testing whether the proposed dimensions and criteria reflect the priorities of maritime practitioners and platform developers (Vaca-Recalde et al., 2024; Vítor et al., 2022).

A second line of future inquiry concerns the integration of operational key performance indicators. Extending the comparative analysis to incorporate metrics such as vessel turnaround time, fuel consumption per TEU, idle time, cargo loss rates, or emissions in port areas would allow researchers to evaluate how effectively platforms translate data availability into measurable sustainability and operational gains. The use of established sector indices - such as the World Bank Logistics Performance Index or the UNCTAD Liner Shipping Connectivity Index - as contextual benchmarks for assessing port-level platform performance would also strengthen the analytical rigor of future comparative studies (Vaca-Recalde et al., 2024).

A third direction concerns the port–city interface and sustainable urban mobility dimension, introduced in Section 2.5 and incorporated into the framework proposed in Section 4.4. Future research should empirically test this dimension by examining whether and how existing platforms provide data relevant to urban transport management, multimodal planning, and port–city governance, and by engaging municipal authorities and urban planners as user communities alongside maritime stakeholders (Menegon et al., 2023; Millette & Hosein, 2016; Vítor et al., 2022).

Finally, future studies could explore the business models, governance arrangements, and long-term funding structures that underpin successful maritime ODP and ODCP, and examine how platform design choices affect user adoption, data quality, and sustained engagement across diverse stakeholder communities. Longitudinal studies tracking platform evolution over time - for instance, through repeated application of the Wayback Machine methodology used here (Internet Archive, 2001) - would provide valuable insights into the lifecycle dynamics of maritime open data ecosystems.

Realizing the full potential of ODP and ODCP requires coordinated effort across policy-

makers, port authorities, urban planners, industry, researchers, and local communities. By fostering collaboration and shared understanding across these domains, the maritime and urban mobility sectors can enhance resilience, support sustainable development, and respond more effectively to the challenges posed by increasingly interconnected transport systems.

Funding

Content produced within the scope of the Agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53).

Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the study's design; in the collection, analyses, or interpretation of data; in the writing of the manu-script; or in the decision to publish the results.

Acknowledgments

NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project no.º 53).

NECE, Research Centre for Business Sciences, Research Centre and this work are funded by FCT – Fundação para a Ciência e a Tecnologia, IP, project UIDB/04630/2020 and DOI identifier 10.54499/UIDB/04630/2020

CIEQV - Life Quality Research Center, Financed by national funds through FCT – Foundation for Science and Technology, I.P., under the project nº UID/CED/04748/2025

REFERENCES

Alexopoulos, C., Zuiderwijk, A., & Charapabidis, Y. (2014). Designing a Second Generation of Open Data Platforms : *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 230–241. https://doi.org/10.1007/978-3-662-44426-9

Ali, M., Alexopoulos, C., & Charalabidis, Y. (2022a). Data Interoperability and the Open Data Ecosystem: Roles and Research Areas. *Book of Abstracts of the International Conference on Open Data (ICOD 2022)*, 74–80. https://zenodo.org/records/8070106/files/12_Ali.pdf?download=1

Ali, M., Alexopoulos, C., & Charalabidis, Y. (2022b). A comprehensive review of open data platforms, prevalent technologies, and functionalities. *15th International Conference on Theory and Practice of Electronic Governance*, 203–214. https://doi.org/10.1145/3560107.3560142

Andriessen, J., Citro, T., Schaberreiter, T., & Serra, L. (2023). *On the Road of Data-driven Discussion : a Comparison of Open-source Collaboration Platforms*. https://ceur-ws.org/Vol-3574/paper_4.pdf

Bauer, F., & Kaltenböck, M. (2012). *Linked Open Data: A Quick Start Guide for Decision Makers*. http://www.semantic-web.at/LOD-TheEssentials.pdf

Beno, M., Figl, K., Umbrich, J., & Polleres, A. (2017). Perception of key barriers in using and publishing open data. *EJournal of EDemocracy and Open Government*, *9*(2), 134–165. https://doi.org/10.29379/jedem.v9i2.465

Ferreira, I. A., Miranda, P., Marreiros, J., Mendes, A., & Carriço, N. (2025). Why do open data platforms fail? – A revised conceptual model with mitigation actions. *Computers and Industrial Engineering*, *203* (October 2024). https://doi.org/10.1016/j.cie.2025.111042

Folmer, E., Beek, W., Rietveld, L., Ronzhin, S., Geerling, R., & den Haan, D. (2019). Enhancing the usefulness of open governmental data with linked data viewing techniques. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2019-Janua*(February), 2912–2921. https://doi.org/10.24251/hicss.2019.352

Google. (2010). *PageSpeed Insight*. https://pagespeed.web.dev/

Gupta, S., Modgil, S., Kumar, A., Sivarajah, U., & Irani, Z. (2022). Artificial intelligence and cloud-based Collaborative Platforms for Managing Disaster, extreme weather and emergency operations. *International Journal of Production Economics*, *254*(September), 108642. https://doi.org/10.1016/j.ijpe.2022.108642

Han, C. (2018). Assessing the impacts of port supply chain integration on port performance. *Asian Journal of Shipping and Logistics*, *34*(2), 129–135. https://doi.org/10.1016/j.ajsl.2018.06.009

Herrera-Cubides, J. F., Gaona-García, P. A., Montenegro-Marin, C. E., & Sánchez-Alonso, S. (2023). The Relevance of Open Data Principles for the Web of Data. *Journal of Electrical and Computer Engineering*, *2023*, 1–17. https://doi.org/10.1155/2023/4854965

Hyseni, B., & Bexheti, L. A. (2022). Perspective of open data application in Kosovo, challenges, and advantages. In *2022 11th Mediterranean Conference on Embedded Computing, MECO 2022*. https://doi.org/10.1109/MECO55406.2022.9797194

Internet Archive. (2001). *Wayback Machine*. https://web.archive.org/

Jiang, H., Shao, Q., Liou, J. J. H., Shao, T., & Shi, X. (2019). Improving the sustainability of open government data. *Sustainability (Switzerland)*, *11*(8), 1–27. https://doi.org/10.3390/su11082388

Kassen, M. (2018). *Open data and its institutional ecosystems A comparative cross□jurisdictional analysis of open data platforms*. https://doi.org/10.1111/capa.12251

Kyvelou, S. S., & Ierapetritis, D. (2019). Discussing and analyzing "maritime cohesion" in MSP, to achieve sustainability in the marine realm. *Sustainability (Switzerland)*, *11*(12), 1–29. https://doi.org/10.3390/su11123444

Mansoursamaei, M., Moradi, M., González-Ramírez, R. G., & Lalla-Ruiz, E. (2023). Machine Learning for Promoting Environmental Sustainability in Ports. *Journal of Advanced Transportation*, *2023*. https://doi.org/10.1155/2023/2144733

Menegon, S., Fadini, A., Perini, L., Sarretta, A., Depellegrin, D., De Maio, E., Farella, G., Landini, M., Fava, C., Ferrarin, C., Ghezzo, M., Manea, E., Porporato, E. M. D., Pastres, R., Sedioli, O., Politikos, D. V., Maina, I., Kavadas, S., Matarrese, R., & Barbanti, A. (2023). A geoportal of data and tools for supporting Maritime Spatial Planning in the Adriatic-Ionian Region. *Environmental Modelling and Software*, *160*(November 2022), 105585. https://doi.org/10.1016/j.envsoft.2022.105585

Millette, C., & Hosein, P. (2016). A consumer focused open data platform. *2016 3rd MEC International Conference on Big Data and Smart City, ICBDSC 2016*, 101–106. https://doi.org/10.1109/ICBDSC.2016.7460350

Murray, F., Needham, K., Gormley, K., Rouse, S., Coolen, J. W. P., Billett, D., Dannheim, J., Birchenough, S. N. R., Hyder, K., Heard, R., Ferris, J. S., Holstein, J. M., Henry, L. A., McMeel, O., Calewaert, J. B., & Roberts, J. M. (2018). Data challenges and opportunities for environmental management of North Sea oil and gas decommissioning in an era of blue growth. *Marine Policy*, *97*(June), 130–138. https://doi.org/10.1016/j.marpol.2018.05.021

Pachiyappan, S., Neogi, A., Govindappa, C., Kasibhatla, R., Meena, A., Srinivas, S., & Nagaraja, C. (2026). Green Finance as a Mediator Between Green Banking Practices and Sustainable Behavioural Outcomes. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 189-211. https://doi.org/10.2478/eoik-2026-0032

Parker, G., & Van Alstyne, M. (2018). Innovation, openness, and platform control. *Management Science*, *64*(7), 3015–3032. https://doi.org/10.1287/mnsc.2017.2757

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, *14*(3), 681–695. https://doi.org/10.1007/s11625-018-0627-5

Seisenbekov, A., Beisenova, M., Koshetayev, D., Akhmetova, Z., & Suyunbayev, S. (2026). The Impact of Digitalization and Innovation on Postal And Courier Services in the Context of Sustainable Economic Development: Evidence from Kazakhstan. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 249-268. https://doi.org/10.2478/eoik-2026-0035

Shojaei, S. A., Pakgohar, A., & Tran, D. Y. V. (2026). Green Deliveries on A Budget: How Sustainability and Cost Shape Vietnamese E-Commerce Consumer Choices. *Economics - Innovative*

and Economic Research Journal, 14(2), 67-86. https://doi.org/10.2478/eoik-2026-0026

Slobodova, O. (2020). Motivations of civil society actors to reuse open data. Case study of discrete actors in Lyon. *Bitacora Urbano Territorial*, *30*(3), 55–70. https://doi.org/10.15446/BITACORA.V30N3.80740

Spadon, G., Kumar, J., Chen, J., Smith, M., Hilliard, C., Vela, S., Gehrmann, R., DiBacco, C., Matwin, S., & Pelot, R. (2024). *Maritime Tracking Data Analysis and Integration with AISdb*. 1–8. https://doi.org/10.1016/j.softx.2024.101952

Tim Berners-Lee. (2010). *5-Star model*. https://5stardata.info/en/

Vaca-Recalde, M. E., Marcano, M., Matute, J., Hidalgo, C., Martinez-Rodriguez, B., Bilbao-Arechabala, S., Jorge-Hernandez, F., Murgoitio, J., Perez, J., Santaella, J., & Camacho, A. (2024). Connected and intelligent framework for vehicle automation in Smart-Ports. *IEEE Access*, *May*, 120347–120361. https://doi.org/10.1109/ACCESS.2024.3434628

Van Loenen, B., Zuiderwijk, A., Vancau-Wenberghe, G., Lopez-Pellicer, F. J., Mulder, I., Alexopoulos, C., Magnussen, R., Saddiqa, M., Dulong De Rosnay, M., Crompvoets, J., Polini, A., Re, B., & Flores, C. C. (2021). Towards value-creating and sustainable open data ecosystems: A comparative case study and a research agenda. *EJournal of EDemocracy and Open Government*, *13*(2), 1–27. https://doi.org/10.29379/jedem.v13i2.644

Van Vranken, C., Vastenhoud, B. M. J., Manning, J. P., Plet-Hansen, K. S., Jakoboski, J., Goringe, P., & Martinelli, M. (2020). Fishing Gear as a Data Collection Platform: Opportunities to Fill Spatial and Temporal Gaps in Operational Sub-Surface Observation Networks. *Frontiers in Marine Science*, *7*(October). https://doi.org/10.3389/fmars.2020.485512

Vítor, G., Rito, P., Sargento, S., & Pinto, F. (2022). A scalable approach for smart city data platform: Support of real-time processing and data sharing. *Computer Networks*, *213*, 109027. https://doi.org/10.1016/j.comnet.2022.109027

Vu, V. V., Tai Le, P., Do, T. M. T., Nguyen, T. T. H., Tran, N. B. M., Paramasivam, P., Le, T. T., Le, H. C., & Chau, T. H. (2024). An insight into the Application of AI in maritime and Logistics toward Sustainable Transportation. *International Journal on Informatics Visualization*, *8*(1), 158–174. https://doi.org/10.62527/joiv.8.1.2641

World Shipping Council. (2024). *The Top 50 Container Ports*. https://www.worldshipping.org/top-50-container-ports?rq=The%20Top%2050%20Container%20Ports

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

SUSTAINABILITY AS A COMPETITIVE ADVANTAGE IN LUXURY GASTRONOMY: EVIDENCE FROM EASTERN EUROPE

Noémi Tordai (Pál)[1*], Flavia Dana Oltean[2]

Received 26.02.2026. | Send to review 19.03.2026. | Accepted 13.08.2026.

Original Article

[1] George Emil Palade University of Medicine, Pharmacy, Science and Technology of Târgu Mureş, Târgu Mureş, Romania

***Corresponding Author:**
Noémi Tordai (Pál)

Email:
pal.noemi.24@stud.umfst.ro

JEL Classification:
L83, Q56, M31,O13

Doi: 10.61432/CPNE0401153t

UDK: 338.486.1.02:316.323.6

ABSTRACT
Sustainability has gradually become a central concern within the hospitality industry, particularly in the context of luxury gastronomy. While fine dining has traditionally been associated with creativity, exclusivity, and technical excellence, increasing attention is now directed towards responsible sourcing, environmental impacts, and the relationship between restaurants and their local social and ecological environments. In Eastern Europe, this transition has a distinctive character, as many sustainability-related practices are not entirely new but are often embedded within long-established culinary traditions and local production systems. This study examines how consumers perceive sustainability in luxury gastronomy and explores how these perceptions influence authenticity, willingness to pay, behavioural loyalty, and perceived competitive advantage. The empirical analysis is based on a structured online survey comprising 179 valid responses, primarily collected from Eastern European consumers. The research applies descriptive statistics, reliability analysis, correlation analysis, and regression modelling to examine the relationships among the investigated constructs. The findings indicate that sustainability does not directly determine competitive advantage. Instead, its influence appears to operate primarily through perceived authenticity and, to a lesser extent, willingness to pay. Luxury restaurants that integrate sustainability practices in a consistent, credible, and experience-oriented manner are more likely to be perceived as authentic, which subsequently strengthens their competitive positioning. However, the results also demonstrate that sustainability practices are not equally visible to consumers and do not generate the same level of perceived value. Overall, the study suggests that sustainability can represent a strategic resource in luxury gastronomy, but only when it is meaningfully incorporated into the overall dining experience rather than treated as an isolated operational practice.

Keywords: *sustainable gastronomy, luxury restaurants, competitive advantage, consumer perception, Eastern Europe, hospitality sustainability*

1. INTRODUCTION

In recent years, sustainability has moved increasingly closer to the centre of hospitality research and practice. Although sustainability-related concerns have long existed within the sector, their strategic importance has changed considerably. The current shift reflects

not only a greater frequency of discussion but also a deeper transformation in how restaurants understand their responsibilities, operational choices, and relationship with broader social and environmental systems. This transition is closely connected to growing concerns regarding climate change and resource consumption, which increasingly influence everyday decisions within hospitality organisations (Gössling & Hal.l, 2022; Liu et al., 2023).

These developments are particularly evident in luxury gastronomy, where high-end restaurants often act as early adopters of new approaches in sourcing, culinary techniques, and operational models. Within this context, sustainability is rarely presented as an isolated practice; rather, it becomes integrated into broader narratives of quality, authenticity, and dining experience. However, the presence of sustainability initiatives alone does not guarantee consumer recognition or value creation. In many cases, the impact of such practices depends on how effectively they are communicated and perceived by customers rather than solely on how they are implemented internally (Huang et al., 2023).

Institutional recognition has further contributed to the growing visibility of sustainability within luxury gastronomy. The Michelin Guide, traditionally associated with culinary excellence, has expanded its evaluation framework through initiatives such as the Michelin Green Star, which acknowledges restaurants demonstrating commitment to sustainable practices. Such recognition can enhance restaurant visibility and influence destination perceptions. Nevertheless, the interpretation and communication of sustainability through external certification systems remain complex, as consumers may not always perceive sustainability indicators in a consistent manner (Daries et al., 2018; Huang & Hal.l, 2023; Mrkaić Ateljević, 2025).

At a broader level, gastronomy has become increasingly interconnected with tourism development (Shojaei, et al., 2026). Culinary experiences are no longer considered merely complementary elements of travel but increasingly represent primary motivations for destination choice. Consequently, restaurants contribute not only to individual consumption experiences but also to destination image formation, regional identity, and tourism competitiveness (Cankül, 2019; UNWTO, 2012). Sustainable gastronomy may generate additional economic benefits by strengthening connections with local producers, preserving regional culinary traditions, and enhancing the attractiveness of destinations seeking differentiation through authenticity and quality.

Despite this increasing attention, several research gaps remain, particularly in the Eastern European context. Existing studies frequently approach sustainability as a broad and aggregated concept, providing limited insight into which specific sustainability dimensions are most relevant from a consumer perspective and how they contribute to competitive positioning (Bonfanti et al., 2025; Liu et al., 2023). Furthermore, previous research has often examined sustainability outcomes and consumer attitudes separately, while less attention has been given to the mechanisms through which sustainability-related attributes influence perceptions of competitive advantage in luxury gastronomy. This gap is particularly important in Eastern Europe, where sustainable gastronomy is gaining visibility internationally but remains comparatively underrepresented in empirical hospitality research.

Addressing this gap, the present study adopts a more detailed approach by examining sustainability as a multidimensional construct. Rather than treating sustainability as a single general concept, the research investigates specific attributes including transparency, waste reduction, local sourcing, support for local producers, perceived authenticity, and trust in ecological certifications. The objective is to understand how these dimensions influence consumer evaluations of sustainability-oriented luxury dining experiences and how they contribute to perceived competitive advantage.

The study makes several contributions. First, it extends existing research by conceptualising sustainability as a multidimensional phenomenon rather than a single aggregated construct. Second, it provides empirical evidence from Eastern Europe, a region that remains relatively underexplored in hospitality and gastronomy studies despite its increasing international visibility. Third, it develops and empirically examines a framework connecting sustainability perceptions with authenticity, willingness to pay, behavioural loyalty, and perceived competitive advantage. Beyond the restaurant context, the study contributes to broader discussions on destination competitiveness by highlighting how sustainable luxury gastronomy can support tourism attractiveness, regional identity, and local economic development. More broadly, the research reflects an ongoing transformation in which sustainability increasingly influences how quality, authenticity, and competitiveness are defined within luxury gastronomy.

The remainder of the paper is structured as follows. The next section reviews the relevant literature and develops the conceptual framework and research hypotheses. The methodology section then presents the research design, data collection procedures, and analytical approach. The following section reports the empirical findings, while the discussion interprets the results in relation to existing literature. Finally, the paper concludes by outlining the main contributions, limitations, and directions for future research.

2. LITERATURE REVIEW

The relationship between sustainability and competitive advantage has attracted increasing attention within hospitality research, particularly in the context of luxury gastronomy. Earlier approaches often framed sustainability primarily as a matter of ethical responsibility, regulatory compliance, or operational efficiency. More recent perspectives, however, suggest that sustainability may also function as a strategic resource, influencing restaurant positioning, consumer perceptions, and long-term competitiveness (Gössling & Hal.l, 2022; Liu et al., 2023). Nevertheless, the relationship between sustainability and competitive advantage is not automatic. Although sustainability initiatives are generally associated with positive outcomes, their strategic value depends largely on how they are interpreted, communicated, and experienced by consumers.

A central mechanism through which sustainability may contribute to competitive advantage is **perceived authenticity**. In luxury gastronomy, value creation extends beyond technical quality and product excellence; it also depends on the coherence, meaning, and credibility of the overall dining experience. Sustainability practices can strengthen authenticity when they are integrated into the restaurant's identity, philosophy, and operational approach (Cabrita et al., 2026). When consumers perceive these practices as genuine and consistent, they may enhance trust, emotional connection, and loyalty towards the restaurant. Conversely, sustainability initiatives perceived as symbolic, superficial, or disconnected from the restaurant's core identity may have limited influence or even generate scepticism among consumers (Filimonau & Krivcova, 2017; Liu et al., 2023). Therefore, sustainability is unlikely to influence competitive advantage directly, but rather through intermediate perceptual mechanisms such as authenticity.

Closely connected to authenticity is the relationship between sustainability and consumer behavioural responses, particularly willingness to pay and loyalty. Consumers increasingly express favourable attitudes towards environmentally and socially responsible practices; however, the extent to which these attitudes translate into actual purchasing behaviour remains debated. Existing research suggests that sustainability can justify premium pricing when practices are visible, credible, and aligned with consumer expectations. Nevertheless, studies also identify a gap between stated environmental preferences and real consumption decisions, particularly within luxury contexts where consumers evaluate multi-

ple dimensions of value simultaneously (Filimonau et al., 2017; Bonfanti et al., 2025). This distinction highlights the importance of examining not only consumer attitudes but also the mechanisms through which sustainability influences economic outcomes.

Another relevant aspect concerns the visibility and interpretability of sustainability practices. From the consumer perspective, not all sustainability initiatives are equally accessible or meaningful. Operational practices such as energy efficiency, waste reduction, and resource optimisation may generate substantial environmental benefits but often remain invisible during the dining experience. In contrast, practices such as local sourcing, seasonal menus, and producer relationships are more easily communicated and incorporated into restaurant narratives. Research indicates that visible and easily interpretable sustainability attributes tend to have a stronger influence on consumer perceptions, creating a potential gap between actual sustainability performance and perceived sustainability value (Huang et al., 2023; Rosário et al., 2023).

Within this context, locality represents a particularly important dimension of sustainable luxury gastronomy. The use of local and seasonal ingredients is frequently associated with environmental responsibility, but it also carries cultural and symbolic meanings. Restaurants that emphasise local sourcing often position themselves as representatives of regional identity, strengthening connections between gastronomy, place, and community. This relationship can enhance perceived authenticity and contribute to differentiation within competitive markets. However, the strategic value of locality depends on how effectively these connections are communicated and understood by consumers (Huang & Hal.l, 2023; Demir & Bertan, 2025).

Institutional recognition represents another factor shaping sustainability perceptions in luxury gastronomy. The Michelin Guide, as one of the most influential global evaluation systems in the restaurant sector, performs an important signalling function by shaping expectations regarding quality, innovation, and excellence. The introduction of the Michelin Green Star expanded this role by explicitly recognising sustainability-oriented practices. Such certifications may strengthen consumer trust and provide external validation of restaurant sustainability efforts. However, their effectiveness depends on consumer awareness and interpretation, as recognition systems may reinforce existing perceptions among informed consumers while remaining less meaningful to others (Daries et al., 2018; Marquez Garat, 2022).

The relationship between gastronomy and tourism further expands the relevance of sustainability within luxury restaurants. Culinary experiences increasingly influence destination attractiveness, tourist satisfaction, and place identity. As a result, restaurants are evaluated not only as individual businesses but also as contributors to broader destination competitiveness. Sustainable gastronomy therefore operates at multiple levels, influencing firm-level differentiation while simultaneously supporting regional tourism development and destination image formation (Cankül, 2019; UNWTO, 2012; Sang & Anh, 2026).

Despite the growing body of research, several important gaps remain. First, much of the existing literature continues to conceptualise sustainability as a broad and aggregated construct, providing limited understanding of which specific sustainability attributes generate the strongest influence on consumer perceptions and competitive outcomes. Second, empirical evidence from Eastern Europe remains relatively limited, despite the region's growing presence in international gastronomy and tourism markets. This geographical gap restricts understanding of how sustainability is interpreted in contexts where traditional culinary practices, local identity, and emerging luxury markets intersect.

Addressing these limitations, the present study adopts a more differentiated approach by examining sustainability as a multidimensional construct rather than a single concept.

Specifically, it investigates consumer perceptions of transparency, waste reduction, local sourcing, support for local producers, perceived authenticity, and trust in ecological certifications. By analysing how these dimensions influence authenticity, willingness to pay, behavioural loyalty, and perceived competitive advantage, the study aims to provide a more nuanced understanding of the strategic role of sustainability in luxury gastronomy.

3. CONCEPTUAL FRAMEWORK AND HYPOTHESES

The increasing integration of sustainability into hospitality has generated growing academic interest, particularly within the context of luxury gastronomy. Earlier research primarily focused on the operational implementation of sustainable practices, including resource efficiency, responsible sourcing, and environmental management. More recent studies, however, have increasingly shifted attention toward the consumer perspective and the ways in which sustainability-related actions are interpreted and valued by customers (Liu et al., 2023; Gössling & Hal.l, 2022). This transition reflects a broader understanding that sustainability is not only a matter of organisational practice but also a component of market positioning. The strategic relevance of sustainability depends not only on what restaurants implement, but also on how these actions are perceived, communicated, and incorporated into the overall dining experience.

Within luxury gastronomy, sustainability is rarely perceived by consumers as a clearly defined set of operational measures. Instead, it is often interpreted through visible signals such as local sourcing, responsible procurement, environmental awareness, and connections with regional communities. These elements may communicate values related to quality, care, and responsibility, but their interpretation is not always uniform. When sustainability practices are effectively communicated, they may strengthen the relationship between the restaurant and its local context, reinforcing the sense of place and contributing to a more meaningful dining experience. However, less visible practices may remain unnoticed by consumers, creating a potential gap between actual sustainability performance and perceived sustainability value (Huang & Hal.l, 2023).

In this context, authenticity represents an important mechanism through which sustainability may influence consumer perceptions. Luxury gastronomy extends beyond the functional consumption of food and incorporates symbolic, emotional, and experiential dimensions. Creativity, prestige, identity, and narrative coherence contribute to how consumers evaluate high-end dining experiences. When sustainability practices are perceived as consistent with the restaurant's identity and values, they may enhance perceptions of authenticity and credibility. Nevertheless, the relationship between sustainability perceptions and consumer behaviour remains complex, as expressed preferences do not always translate directly into actual consumption decisions (Filimonau & Krivcova, 2017).

Willingness to pay represents another relevant dimension in understanding the economic implications of sustainability in luxury gastronomy. Previous research suggests that sustainability-oriented practices may positively influence evaluations of service quality, brand image, and overall experience value. However, these effects depend on the extent to which sustainability is considered meaningful and credible by consumers. In luxury contexts, where prices already contain symbolic and experiential components, sustainability may contribute to the justification of premium prices by reinforcing perceptions of exclusivity, responsibility, and value. Nevertheless, such effects are not automatic and depend on how successfully sustainability is integrated into the broader restaurant experience (Biloslavo & Janković, 2025; Liu et al., 2023).

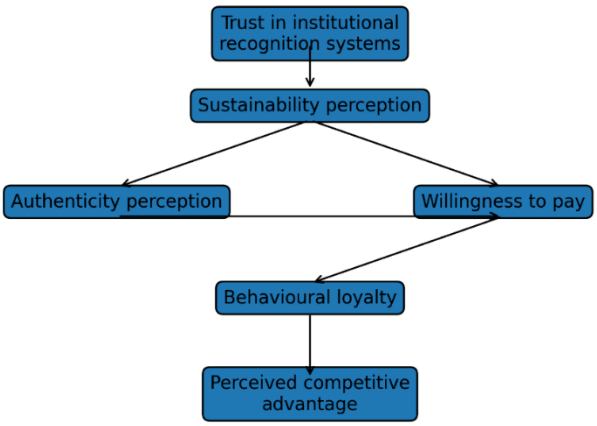
Institutional recognition also contributes to the formation of sustainability perceptions. The Michelin Guide represents one of the most influential quality-assessment systems in global

gastronomy, shaping both consumer expectations and restaurant visibility. Through initiatives such as sustainability-related distinctions, institutional recognition can provide external validation of environmental and social practices. Such recognition may strengthen trust and credibility among consumers; however, its influence depends on how these signals are interpreted by different audiences and whether sustainability certifications are perceived as meaningful indicators of genuine commitment (Daries et al., 2018; UNWTO, 2012).

Taken together, these dimensions suggest that perceived competitive advantage in luxury gastronomy does not emerge from sustainability alone. Rather, it results from the interaction between sustainability perceptions, authenticity, consumer value evaluation, and the broader dining experience. Restaurants that successfully integrate these elements into a coherent identity may develop stronger differentiation, enhanced customer relationships, and greater market distinctiveness. However, the relationship between sustainability and competitiveness is likely to vary depending on contextual factors, consumer expectations, and the credibility of sustainability communication.

Based on these considerations, the present study develops a conceptual framework in which perceived sustainability is expected to influence authenticity, willingness to pay, and behavioural loyalty. These dimensions are subsequently considered as potential mechanisms contributing to perceived competitive advantage. Rather than assuming direct and uniform effects, the framework recognises that sustainability creates strategic value through a series of interconnected consumer perceptions and evaluations.

Figure 1. Conceptual framework of sustainability perception and competitive advantage in luxury gastronomy



Source: Author`s calculation

The figure illustrates the proposed relationships between sustainability perception, authenticity perception, willingness to pay, behavioural loyalty, and perceived competitive advantage in luxury gastronomy.

Sustainability practices are increasingly associated with perceptions of authenticity within hospitality and gastronomy. Consumers often interpret local sourcing, environmental responsibility, and support for local communities as signals of genuineness, transparency, and commitment to place. Previous studies suggest that sustainability-related initiatives can strengthen the perceived credibility of restaurants and enhance the authenticity of the dining experience (Huang & Hal.l, 2023; Liu et al., 2023). When sustainability is embedded within the identity and values of a restaurant rather than communicated merely as a marketing strategy, consumers are more likely to perceive the experience as authentic.

H_1: Perceived sustainability practices positively influence the perceived authenticity of luxury gastronomy experiences.

The relationship between sustainability and willingness to pay has received increasing attention in consumer behaviour research. Sustainable practices may create additional value for consumers by reducing ethical concerns and increasing confidence in the quality, responsibility, and credibility of products and services. Several studies indicate that consumers are willing to accept price premiums when sustainability initiatives are perceived as genuine, transparent, and meaningful (Bonfanti et al., 2025; Filimonau et al., 2017). This relationship is particularly relevant in luxury gastronomy, where consumers often associate higher prices with superior quality, exclusivity, and distinctive experiences.

H_2: Perceived sustainability practices positively influence consumers' willingness to pay for luxury gastronomy experiences.

Authenticity may also represent an important factor influencing consumers' willingness to pay. Experiences perceived as authentic are often evaluated as more valuable because they provide emotional, cultural, and symbolic benefits beyond the functional aspects of consumption. Previous research indicates that authenticity contributes positively to perceived value and may justify higher levels of expenditure among consumers seeking unique and meaningful experiences (Filimonau & Krivcova, 2017; Huang et al., 2023).

H_3: Perceived authenticity positively influences consumers' willingness to pay.

Willingness to pay is frequently associated with behavioural outcomes, including revisit intentions and recommendations. Consumers who perceive strong value in a service and demonstrate acceptance of premium prices are generally more likely to develop favourable behavioural intentions and stronger relationships with the establishment. Previous studies have identified positive relationships between perceived value, customer satisfaction, and behavioural loyalty within hospitality contexts (Bonfanti et al., 2025; Liu et al., 2023).

H_4: Consumers' willingness to pay positively influences behavioural loyalty, including revisit and recommendation intentions.

Competitive advantage in luxury gastronomy is shaped by multiple interconnected factors rather than by a single attribute. Sustainability may contribute to differentiation by strengthening reputation, increasing consumer trust, and supporting unique value propositions. At the same time, behavioural loyalty may reinforce competitive positioning through repeat visits, positive word-of-mouth, and long-term customer relationships. Existing literature suggests that both sustainability perceptions and customer loyalty can contribute to stronger competitive positioning within hospitality markets (Gössling & Hal.l, 2022; Marquez Garat, 2022).

H_5: Perceived sustainability practices and behavioural loyalty positively influence the perceived competitive advantage of luxury gastronomy establishments.

These hypotheses provide the foundation for the empirical model examined in this study. The conceptual framework assumes that sustainability practices influence competitive advantage both directly and indirectly through mediating mechanisms such as perceived authenticity and willingness to pay. By analysing these relationships, the study aims to provide a deeper understanding of how sustainability is transformed into competitive positioning within the luxury gastronomy sector.

The next section presents the research design and methodology used to test the proposed hypotheses.

4.METHODOLOGY

4.1. RESEARCH DESIGN

This study adopts a quantitative research design to examine how consumers perceive sustainability practices in luxury gastronomy and how these perceptions relate to authenticity, willingness to pay, behavioural loyalty, and perceived competitive advantage. Quantitative methods are particularly suitable for analysing relationships between variables and evaluating perception-based constructs in a structured and comparable manner (Hair et al., 2019; Liu et al., 2023). The approach is especially appropriate in a cross-country setting, where consistent measurement is required across different national contexts. The study focuses on consumers from Eastern Europe, a region that is becoming increasingly visible in the international gastronomic landscape but remains relatively underexplored in empirical hospitality research.

4.2. SAMPLE AND DATA COLLECTION

Data were collected through a structured online questionnaire distributed primarily via digital platforms and social media channels. This method enabled access to respondents from multiple countries within a relatively short period while maintaining consistency in data collection procedures (Bryman, 2016).

A total of 179 valid responses were retained for analysis. Participants originated from several Eastern European countries, with the largest proportions coming from Romania, Slovenia, Bulgaria, and Hungary. Although the sample is not perfectly balanced across countries, it reflects the regional focus of the study and provides a suitable basis for exploring consumer perceptions in emerging gastronomic markets.

The sample size was considered adequate for the statistical techniques employed in the study. According to Hair et al. (2019), multiple regression analysis can be reliably conducted with substantially smaller samples than the one obtained in the present research. Therefore, the final sample of 179 respondents provides sufficient statistical power for the proposed analyses and hypothesis testing.

4.3. QUESTIONNAIRE DEVELOPMENT

The questionnaire was designed to capture the main constructs included in the conceptual framework: sustainability perception, authenticity perception, willingness to pay, behavioural loyalty, and perceived competitive advantage. Measurement items were adapted from established studies in hospitality, sustainability, and consumer behaviour research.

Items related to sustainability perception were derived from previous studies examining environmental responsibility, local sourcing, and ethical food production. Measures of authenticity and willingness to pay were adapted from research focusing on consumer evaluations of luxury gastronomy experiences. To ensure contextual relevance, all items were slightly modified to reflect the characteristics of fine-dining restaurants in Eastern Europe while preserving conceptual consistency with previous studies.

The questionnaire consisted of several sections corresponding to the major constructs investigated. Respondents first evaluated sustainability-related practices, followed by items measuring authenticity perception, willingness to pay, behavioural loyalty, and perceived competitive advantage.

4.4. MEASUREMENT OF VARIABLES

All constructs were measured using multiple-item scales. Sustainability perception included statements related to environmental responsibility, local sourcing, and sustainable operational practices. Authenticity perception captured the extent to which respondents

associated sustainability with genuine culinary traditions and local identity. Willingness to pay reflected respondents' acceptance of potential price premiums for sustainability-oriented dining experiences. Behavioural loyalty was measured through revisit and recommendation intentions, while perceived competitive advantage referred to the extent to which sustainability contributes to differentiation and long-term positioning.

All items were evaluated using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Likert scales are widely used in perception-based research because they allow attitudes and evaluations to be measured in a structured and comparable manner across respondents (Hair et al., 2019).

4.5. DATA ANALYSIS TECHNIQUES

The empirical analysis was conducted in several stages. First, descriptive statistics were calculated to provide an overview of the sample and identify general response patterns. Measures of central tendency and dispersion were reported for all constructs.

Second, reliability analysis was performed using Cronbach's alpha coefficients to evaluate the internal consistency of the measurement scales. Values above the commonly accepted threshold of 0.70 were considered satisfactory (Hair et al., 2019).

Third, Pearson correlation analysis was conducted to examine the relationships among the principal constructs included in the conceptual framework. Correlation coefficients provided an initial assessment of the strength and direction of the associations between variables.

Finally, multiple regression analysis was employed to test the proposed relationships and evaluate the extent to which sustainability-related perceptions influence consumer behaviour and perceived competitive advantage. Regression analysis allows the identification of statistically significant effects while accounting for the simultaneous influence of multiple variables.

Several diagnostic procedures were conducted to assess model robustness. Multicollinearity was examined using Variance Inflation Factor (VIF) values, all of which remained below the commonly accepted threshold of 5, indicating no significant multicollinearity concerns. In addition, the assumptions of linear regression were evaluated. Residuals were approximately normally distributed, and no substantial violations of homoscedasticity were detected.

To reduce the potential influence of common method bias, respondents were assured of anonymity and confidentiality throughout the data collection process. Furthermore, Harman's single-factor test was performed. The results indicated that no single factor accounted for most of the variance, suggesting that common method bias is unlikely to significantly affect the findings.

Taken together, these procedures provide a coherent analytical framework for examining the relationships proposed in the conceptual model and offer a robust basis for evaluating the role of sustainability as a source of competitive advantage in luxury gastronomy.

5. RESULTS

5.1. SAMPLE CHARACTERISTICS

This section presents the empirical findings of the quantitative analysis. The analysis is conducted in several stages. First, the characteristics of the sample are described. Second, descriptive statistics for the main constructs are presented. Third, reliability analysis is performed to evaluate the internal consistency of the measurement scales. Fourth, correlation analysis is conducted to examine the relationships among the main variables.

Finally, regression analysis is applied to test the hypotheses developed within the conceptual framework.

The empirical analysis is based on 179 valid responses collected through an online questionnaire. The respondents originate primarily from Central and Eastern European countries. The largest groups of participants come from Romania, Slovenia, Bulgaria, and Hungary, while additional responses were obtained from other European countries. This geographical distribution reflects the regional focus of the study and provides insights into consumer perceptions of sustainability within emerging gastronomic markets.

Table 1. Sample distribution by country

Country	Number of respondents	Percentage
Romania	59	32.96%
Slovenia	32	17.88%
Bulgaria	29	16.20%
Hungary	25	13.97%
Other countries	34	18.99%
Total	179	100%

Source: Author`s calculation

Table 1 presents the geographical distribution of respondents participating in the survey. The largest share of respondents originates from Romania (32.96%), followed by Slovenia (17.88%), Bulgaria (16.20%), and Hungary (13.97%). The remaining respondents (18.99%) represent other European countries.

To provide a more comprehensive description of the sample, additional demographic characteristics are presented in Table 2. Respondents represent diverse age groups and educational backgrounds, allowing the analysis to capture a broad range of consumer perspectives regarding sustainability and luxury gastronomy.

Table 2. Demographic characteristics of respondents

Variable	Category	N	%
Age	Under 25	80	44.69
	25–34	24	13.41
	35–44	26	14.53
	45–54	34	18.99
	55+	15	8.38
Education	Secondary	68	37.99
	Bachelor	46	25.70
	Master	39	21.79
	Doctoral	26	14.53

Source: Author`s calculation

The sample is relatively young, with respondents under the age of 25 representing the largest group (44.69%). In terms of education, secondary education represents the largest category (37.99%), followed by bachelor (25.70%), master (21.79%), and doctoral degree holders (14.53%). This distribution suggests a diverse sample with varying educational backgrounds and consumption perspectives.

Table 3. Mean values of the main constructs by country

Construct	Romania	Slovenia	Bulgaria	Hungary
Sustainability perception	3.59	3.86	3.47	3.57
Authenticity perception	3.78	3.91	3.93	3.61
Willingness to pay	3.45	3.67	3.69	3.56
Behavioural loyalty	3.77	3.86	4.13	3.63
Perceived competitive advantage	3.67	3.86	4.05	3.83

Source: Author's calculation

Table 3 presents the mean values of the main constructs across the four countries with the highest representation in the sample. The results indicate some variation between countries. Respondents from Slovenia report the highest level of sustainability perception (M = 3.86), while Bulgarian respondents demonstrate the highest levels of behavioural loyalty (M = 4.13) and perceived competitive advantage (M = 4.05). Authenticity perception is also particularly pronounced among respondents from Bulgaria (M = 3.93) and Slovenia (M = 3.91). Although the observed differences are relatively moderate, the findings suggest that sustainability-related perceptions represent an important dimension across all examined national contexts. This supports the broader relevance of sustainability-oriented strategies within the luxury gastronomy sector in Eastern Europe.

Descriptive statistics were calculated to examine the central tendencies and variability of the main variables included in the conceptual model. These variables correspond to the core constructs analysed in the study: sustainability perception, authenticity perception, willingness to pay, behavioural loyalty, and perceived competitive advantage.

The descriptive results indicate generally positive consumer evaluations of sustainability practices in luxury gastronomy. Respondents tend to associate sustainable restaurant practices with higher levels of authenticity, responsible management, and overall quality of the dining experience. Furthermore, willingness to pay for sustainable gastronomy experiences demonstrates moderate to relatively high mean values, suggesting that consumers show a certain degree of openness toward paying premium prices for restaurants perceived as environmentally and socially responsible.

Table 4 presents the descriptive statistics of the main constructs included in the analysis.

Table 4. Descriptive statistics of main variables

Variable	Mean	Standard deviation
Sustainability perception	3.62	0.96
Authenticity perception	3.81	0.89
Willingness to pay	3.55	0.92
Behavioural loyalty	3.81	0.93
Perceived competitive advantage	3.79	0.85

Source: Author`s calculation

Authenticity perception (M = 3.81) and behavioural loyalty (M = 3.81) display the highest mean values among the constructs, suggesting that respondents particularly associate sustainability-oriented practices with credibility and consistent behavioural intentions.

5.2. RELIABILITY ANALYSIS

Reliability analysis was conducted to evaluate the internal consistency of the measurement scales used in the questionnaire. Cronbach's alpha coefficients were calculated for

each multi-item construct included in the study. Cronbach's alpha values above the commonly accepted threshold of 0.70 indicate satisfactory internal consistency of the measurement scales.

The results point to good to very good internal consistency across all constructs, suggesting that the questionnaire items consistently capture the underlying concepts they were designed to measure.

Table 5 presents the Cronbach's alpha coefficients for the main constructs.

Table 5. Reliability analysis

Construct	Number of items	Cronbach alpha
Sustainability perception	4	0.85
Authenticity perception	4	0.83
Willingness to pay	4	0.82
Behavioural loyalty	3	0.80
Competitive advantage perception	4	0.80

Source: Author`s calculation

All constructs show good internal consistency, with Cronbach's alpha values ranging between 0.80 and 0.85, indicating strong reliability of the measurement scales.

5.4. Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships between the main constructs included in the conceptual model. The results indicate several positive and statistically significant correlations between the variables. Sustainability perception is positively associated with both authenticity perception and willingness to pay. In addition, behavioural loyalty shows positive correlations with authenticity perception and willingness to pay. These findings are consistent with theoretical expectations suggesting that sustainability-related perceptions are closely linked to authenticity and value-related evaluations in luxury gastronomy.

Table 6 presents the correlation matrix for the main variables.

Table 6. Correlation matrix

Variable	1	2	3	4	5
1 Sustainability perception	1				
2 Authenticity perception	0.65	1			
3 Willingness to pay	0.68	0.74	1		
4 Behavioural loyalty	0.58	0.68	0.64	1	
5 Competitive advantage perception	0.56	0.75	0.71	0.71	1

Source: Author`s calculation

Sustainability perception shows strong positive correlations with authenticity perception ($r = 0.65$) and willingness to pay ($r = 0.68$). Authenticity perception also demonstrates a strong relationship with perceived competitive advantage ($r = 0.75$), indicating that authenticity plays a central role in shaping how consumers evaluate the positioning of luxury gastronomy establishments. No excessively high correlations were observed ($r < 0.80$), suggesting that multicollinearity is unlikely to be a concern.

5.3. REGRESSION ANALYSIS

Regression analysis was conducted to test the hypotheses proposed in the conceptual framework. The model examines the extent to which sustainability perception, authen-

ticity perception, willingness to pay, and behavioural loyalty influence the perceived competitive advantage of luxury gastronomy establishments. These findings suggest that sustainability-related perceptions contribute to competitive positioning in luxury gastronomy primarily through indirect mechanisms operating via consumer attitudes and behavioural intentions.

Table 7. Regression analysis results (Dependent variable: Perceived competitive advantage)

Independent variable	Coefficient	Standard error	p-value
Sustainability perception	-0.05	0.056	0.376
Authenticity perception	0.34	0.069	<0.001
Willingness to pay	0.26	0.067	<0.001
Behavioural loyalty	0.30	0.057	<0.001
Constant	0.62	0.178	0.001

Source: Author`s calculation

The regression results demonstrate that authenticity perception, willingness to pay, and behavioural loyalty represent significant positive determinants of perceived competitive advantage. Among all analysed variables, authenticity perception has the largest effect ($\beta = 0.34$, $p < 0.001$), emphasising the importance of genuine and credible experiences in influencing consumer evaluations within luxury gastronomy. Conversely, sustainability perception does not achieve statistical significance as a direct predictor of competitive advantage ($p = 0.376$). This indicates that sustainability may contribute to competitiveness mainly through other consumer-based mechanisms, particularly by strengthening authenticity perceptions and increasing willingness to pay.

The estimated model accounts for a considerable share of the variation in perceived competitive advantage ($R^2 = 0.668$; Adjusted $R^2 = 0.660$), demonstrating a high level of explanatory capacity. The overall regression equation is statistically significant ($F = 87.46$, $p < 0.001$), confirming that the included predictors collectively provide a meaningful explanation of how consumers evaluate competitive positioning in luxury gastronomy.

The strong explanatory performance of the model may also be related to the theoretical closeness among the examined constructs. Since authenticity, willingness to pay, behavioural loyalty, and competitive advantage represent interconnected aspects of consumer experience and perceived value, their relationships may contribute to the relatively high level of explained variance.

The diagnostic procedures described in the methodology section confirm the reliability of the regression specification. The obtained VIF values remained within acceptable limits, indicating that the model does not suffer from problematic multicollinearity among the independent variables.

Overall, the findings suggest that sustainability does not generate competitive advantage primarily through a direct relationship. Instead, its strategic relevance appears to emerge through indirect effects, as sustainable practices enhance perceptions of authenticity, support consumers' willingness to pay, and contribute to stronger behavioural loyalty, which ultimately reinforces the competitive position of luxury gastronomy establishments.

5.4. HYPOTHESIS TESTING

Table 8. Hypothesis testing results

Hypothesis	Relationship	Result
H_1	Sustainability perception → Authenticity perception	Supported
H_2	Sustainability perception → Willingness to pay	Supported
H_3	Authenticity perception → Willingness to pay	Supported
H_4	Willingness to pay → Behavioural loyalty	Supported
H_5	Sustainability perception and behavioural loyalty → Competitive advantage	Partially supported

Source: Author`s calculation

The hypothesis testing results provide overall support for the proposed conceptual framework. The correlation analysis identifies positive and statistically significant associations among the key constructs, offering empirical support for hypotheses H_1-H_4. However, these relationships should be interpreted carefully, as the cross-sectional design of the study limits the ability to establish definitive causal effects.

The findings indicate that sustainability perception is positively associated with both authenticity perception and willingness to pay, supporting H_1 and H_2. This suggests that consumers are more likely to perceive luxury gastronomy establishments as authentic when sustainability practices are present and meaningfully communicated. Furthermore, sustainability-oriented practices appear to enhance consumers' acceptance of premium prices by increasing the perceived value of the overall dining experience. These results reinforce the view that sustainability contributes to value creation not only through environmental responsibility but also through consumer interpretation and emotional evaluation.

The results also confirm H_3, demonstrating a significant positive relationship between authenticity perception and willingness to pay. Consumers who perceive sustainable gastronomy experiences as genuine and credible show a greater tendency to accept higher prices. This finding highlight authenticity as an important pathway through which sustainability-related attributes can generate additional value within luxury gastronomy.

Similarly, the evidence supports H_4, as willingness to pay is positively related to behavioural loyalty. Respondents who demonstrate a stronger readiness to pay for sustainability-oriented gastronomic experiences are also more likely to express intentions to revisit and recommend such establishments. This indicates that perceived value may contribute to the development of stronger and more lasting customer relationships.

The findings provide partial support for H_5. Although behavioural loyalty has a significant positive effect on perceived competitive advantage, sustainability perception does not demonstrate a statistically significant direct impact within the regression model. This suggests that sustainability enhances competitive positioning primarily through indirect pathways, particularly by strengthening authenticity, increasing willingness to pay, and encouraging behavioural loyalty. Therefore, sustainability appears to create strategic value when it is successfully transformed into a meaningful consumer experience rather than being presented as an independent attribute.

5.5. ROBUSTNESS CHECKS

To further assess the stability and reliability of the results, several robustness checks were performed. Multicollinearity was examined using Variance Inflation Factor (VIF) values. All VIF values remained below the commonly accepted threshold of 5, indicating that multicollinearity was not a concern in the regression models. Residual diagnostics were also conducted to verify the assumptions of linear regression. The residuals were approx-

imately normally distributed, and no substantial deviations from homoscedasticity were observed. In addition, Harman's single-factor test was performed to assess the potential influence of common method bias. The results indicated that no single factor accounted for the majority of the explained variance, suggesting that common method bias is unlikely to significantly affect the findings. Taken together, these diagnostic procedures support the robustness and stability of the empirical results.

5.6. CROSS-COUNTRY COMPARISON OF KEY CONSTRUCTS

Table 9. Mean values of the principal constructs by country

Country	Sustainability	Authenticity	WTP	Loyalty	Competitive Advantage
Romania	3.59	3.78	3.45	3.77	3.67
Slovenia	3.86	3.91	3.67	3.86	3.86
Bulgaria	3.47	3.93	3.69	4.13	4.05
Hungary	3.57	3.61	3.56	3.63	3.83
Other countries	3.61	3.83	3.48	3.69	3.60

Source: Author`s calculation

To address potential cross-country differences, the principal constructs were also examined by country. The results indicate moderate variation across national groups. Respondents from Slovenia reported the highest sustainability perception (M = 3.86), while Bulgarian respondents recorded the highest levels of perceived competitive advantage (M = 4.05) and behavioural loyalty (M = 4.13). Romanian respondents showed relatively balanced evaluations across all constructs, whereas Hungarian respondents reported slightly lower authenticity perceptions (M = 3.61). Overall, the observed differences suggest that sustainability-related perceptions are broadly consistent across Eastern European markets, although certain variations exist regarding loyalty and competitive advantage.

6.DISCUSSION

The objective of this study was to examine how sustainability perceptions relate to authenticity, willingness to pay, and perceived competitive advantage within the context of luxury gastronomy in Eastern Europe. The findings reveal a relationship structure that is complex rather than strictly linear, which reflects the multidimensional nature of sustainability as a concept interpreted by consumers. Sustainability is not evaluated identically by all individuals; for some consumers, it represents an additional attribute, while for others it forms an integral part of the overall dining experience. Nevertheless, the results indicate that sustainability has become an increasingly relevant element in the evaluation of luxury gastronomy experiences.

One of the most significant findings relates to the connection between sustainability perception and authenticity. When restaurants are perceived as environmentally responsible or strongly connected with local producers and communities, consumers tend not to interpret these practices merely as operational choices. Instead, such initiatives are associated with credibility, commitment, and a stronger sense of place. This finding corresponds with Huang et al. (2025), who highlight the relationship between sustainability practices, local sourcing, and authenticity communication among Michelin Green Star restaurants. Similar conclusions have been reported in research examining sustainable practices in fine-dining contexts, where sustainability-related attributes contribute to the broader meaning and perceived value of the gastronomic experience (Liu et al., 2023). The present study extends these observations by demonstrating that similar patterns are evident among luxury gastronomy consumers in Eastern Europe. However, the strength

of this relationship differs among individuals, suggesting that authenticity remains influenced by personal interpretation and previous experiences.

A similar pattern can be observed regarding willingness to pay. Consumers who associate restaurants with sustainable practices appear more prepared to accept premium pricing; however, this relationship is not automatic. Sustainability contributes to price acceptance mainly when it is perceived as an authentic and meaningful component of the overall experience. Practices such as local and seasonal sourcing, responsible procurement, and support for regional producers may increase perceived value, but their influence depends largely on the extent to which they are effectively communicated and recognised by consumers. These findings are consistent with previous studies indicating that value perceptions in fine-dining environments influence consumers' willingness to pay higher prices (Liu et al., 2023). Therefore, sustainability appears capable of supporting premium positioning when consumers perceive it as a genuine source of value rather than simply a promotional element.

Authenticity appears to represent a key mechanism within this relationship. The findings indicate that sustainability becomes more influential when it strengthens perceptions of authenticity rather than being evaluated as an independent characteristic. When sustainability initiatives are considered credible and integrated into the restaurant's identity, consumers are more likely to engage emotionally with the experience and assign greater value to it. This supports the argument that authenticity functions as an important pathway through which sustainability affects consumer evaluations. At the same time, the conceptual closeness between sustainability and authenticity may explain why these constructs are challenging to fully distinguish empirically. Consumers often recognise sustainability through visible expressions of authenticity, including relationships with local producers, preservation of culinary traditions, and transparency in sourcing practices.

The relationship between sustainability and competitive advantage appears to be more nuanced. Although sustainability perception demonstrates positive associations with authenticity and willingness to pay, the regression results indicate that it does not have a statistically significant direct effect on perceived competitive advantage. This finding suggests that sustainability alone may not automatically create competitive benefits. Instead, its contribution appears to emerge through consumer-recognised mechanisms, particularly authenticity, perceived value, and behavioural loyalty. This interpretation aligns with previous research indicating that sustainability generates competitive outcomes primarily through enhanced customer experiences and stronger stakeholder relationships rather than through immediate market effects (Bonfanti et al., 2025; Marquez Garat, 2022). In this sense, sustainability represents an enabling factor for competitiveness, but its strategic value depends on whether consumers perceive and appreciate the benefits it creates.

These findings are particularly relevant for the Central and Eastern European context. The region possesses several characteristics that naturally correspond with sustainability-oriented gastronomy, including strong culinary heritage, extensive use of regional ingredients, and established relationships between restaurants and local suppliers. In many cases, sustainability does not represent a completely new practice, but rather a process of recognising, structuring, and communicating existing traditions and approaches. This interpretation is consistent with research on Michelin Green Star restaurants, which identifies local sourcing, regional food systems, and community engagement as important components of sustainable gastronomy (Huang et al., 2025). The results suggest that restaurants can strengthen their competitive positioning not only by adopting sustainable practices but also by making these practices visible, understandable, and relevant to consumers.

From a tourism perspective, the implications extend beyond individual restaurants. Gastronomy increasingly contributes to destination attractiveness and influences how places are experienced, differentiated, and remembered by visitors. The findings suggest that sustainability contributes to destination competitiveness indirectly through authenticity, perceived value, and behavioural loyalty. Sustainability-oriented luxury restaurants may therefore enhance not only their own market position but also the attractiveness of destinations by strengthening local identity, supporting regional food systems, and contributing to broader tourism development. This interpretation corresponds with previous research emphasising the growing role of gastronomy in destination competitiveness and tourism development (Cankül, 2019; UNWTO, 2012). Consequently, sustainable luxury gastronomy may represent not only a strategy for restaurant differentiation but also a broader instrument for regional branding, local economic development, and strengthening tourism ecosystems.

6.1. IMPLICATIONS FOR TOURISM DEVELOPMENT

The implications of these findings extend beyond the individual restaurant level. Luxury gastronomy is becoming an increasingly important element of destination attractiveness and tourism competitiveness, especially for regions aiming to differentiate themselves through authenticity, quality, and unique experiences. Sustainable gastronomy can contribute to local economic development by strengthening connections with regional suppliers, supporting small-scale producers, and encouraging higher-value tourism demand. Therefore, sustainability has the potential to enhance not only the competitive position of individual restaurants but also the broader economic performance of tourism destinations. This aspect is particularly relevant for Eastern European regions, where traditional culinary practices and local production systems remain important components of cultural identity. In such contexts, sustainable gastronomy can serve as a mechanism for generating economic value while simultaneously preserving regional heritage.

Overall, the findings indicate that sustainability in luxury gastronomy should not be viewed solely as an environmental responsibility, but rather as a strategic dimension of competitiveness. Its influence emerges through its ability to shape consumer perceptions, reinforce authenticity, and support long-term market positioning. However, the strategic value of sustainability depends on the way it is incorporated into the overall dining experience and communicated to consumers. When sustainability practices are coherent, credible, and visible, they can enhance both perceived value and competitive advantage. Conversely, when these elements are insufficiently integrated or poorly communicated, the contribution of sustainability to competitiveness becomes considerably weaker.

7. LIMITATIONS AND FUTURE RESEARCH

Although the study provides valuable insights into consumer perceptions of sustainability within luxury gastronomy, several limitations need to be considered. Some limitations are inherent to perception-based empirical research, while others arise from the specific scope and design of the present study.

First, the research is based on self-reported survey responses. Consequently, the findings reflect consumers' declared attitudes and perceptions rather than their actual purchasing behaviour. Previous studies have demonstrated that positive sustainability attitudes do not always translate into corresponding consumption choices, highlighting the persistence of the attitude, behaviour gap in sustainability research. Future investigations could address this limitation by combining survey data with behavioural evidence, such as reservation patterns, online review analysis, purchasing records, or observations of

consumer decisions in real restaurant environments, providing a more complete picture of sustainability-related behaviour (Daries et al., 2018).

Second, the empirical analysis is geographically concentrated mainly on Central and Eastern Europe. This focus reflects the purpose of the study, as the region remains relatively underexplored in luxury gastronomy research despite its growing relevance. However, perceptions of sustainability may differ depending on cultural values, economic conditions, and institutional contexts. Future research including Western European and international samples would enable cross-regional comparisons and help establish whether the observed relationships are specific to the Eastern European context or applicable more broadly (Gössling & Hal.l, 2022; Liu et al., 2023).

A further limitation relates to the consumer-oriented perspective adopted in the study. The analysis examines how sustainability is perceived by customers, rather than how sustainability practices are implemented within restaurants. Sustainable gastronomy involves complex operational decisions related to costs, supplier networks, resource management, and organisational strategies, many of which remain invisible to consumers. Future studies could therefore incorporate qualitative approaches, including interviews with restaurant owners, chefs, managers, suppliers, and other relevant stakeholders, to provide deeper insight into the practical challenges and strategic opportunities associated with sustainable luxury gastronomy (Liu et al., 2023).

The cross-sectional design of the research also represents an important limitation. Consumer expectations, sustainability awareness, and perceptions of value are continuously evolving, particularly within a rapidly changing hospitality environment. Since the current study captures consumer perceptions at a single point in time, it cannot fully explain how these relationships develop or change over longer periods. Longitudinal research would therefore provide valuable evidence regarding the evolution of sustainability perceptions and their influence on consumer behaviour and competitive positioning.

The findings also suggest several directions for future research. One important area concerns the relationship between sustainability practices and institutional recognition systems within gastronomy. The growing relevance of the Michelin Green Star provides an opportunity to examine how sustainability certifications influence consumer trust, restaurant reputation, destination image, and long-term competitiveness. Comparative research between Michelin Green Star establishments and non-certified restaurants could further clarify the strategic value of sustainability recognition.

Another promising research direction relates to the interaction between local sourcing, regional identity, and destination development. In many Eastern European contexts, traditional ingredients, local producers, and small-scale food systems represent important elements of gastronomic identity. Future studies could examine how these resources contribute to sustainable innovation, destination branding, and regional competitiveness, particularly in emerging gastronomic destinations seeking stronger international recognition (Gössling & Hal.l, 2022; Liu et al., 2023).

Future research could also explore the economic consequences of sustainability-oriented strategies in greater detail. While this study focuses primarily on consumer perceptions, additional research could investigate financial outcomes associated with sustainability practices, including profitability, operational efficiency, organisational resilience, and return on sustainability investments. Such approaches would contribute to a broader understanding of sustainability as a strategic capability within luxury gastronomy.

Despite these limitations, the study provides empirical evidence that sustainability can represent an important strategic resource in luxury gastronomy. The findings indicate that its contribution to competitiveness emerges primarily through authenticity, willing-

ness to pay, and behavioural loyalty rather than through a direct relationship alone. By integrating these dimensions into a single analytical framework, the study contributes to the broader discussion on sustainability, consumer value creation, and destination competitiveness in luxury gastronomy, while also identifying important directions for future academic and managerial research.

8. CONCLUSIONS

This study investigated the relationships among sustainability perception, authenticity, willingness to pay, behavioural loyalty, and perceived competitive advantage within the context of luxury gastronomy in Eastern Europe. The results demonstrate that sustainability represents an important factor in shaping consumer evaluations, although its contribution does not appear to be primarily direct. Rather than functioning as an independent source of competitive advantage, sustainability influences outcomes through interconnected processes involving authenticity, perceived value creation, and consumer attachment. A key finding of the research is the strong relationship between sustainability perception and authenticity. Consumers who perceive restaurants as environmentally responsible and engaged with local producers are more likely to evaluate these establishments as genuine, trustworthy, and closely connected to their context. Furthermore, sustainability perception demonstrates positive relationships with willingness to pay and behavioural loyalty, indicating that sustainable practices can strengthen consumer involvement and long-term engagement. However, the regression results reveal that sustainability does not have a statistically significant direct effect on perceived competitive advantage. Instead, its strategic contribution appears to emerge indirectly through authenticity, willingness to pay, and loyalty-related mechanisms. From a theoretical standpoint, the study contributes to hospitality and gastronomy research by approaching sustainability as a multidimensional phenomenon rather than a single, unified construct. The findings show that sustainability-related attributes influence consumer perceptions through a combination of interconnected pathways and emphasise the central role of authenticity as a mechanism connecting sustainability practices with competitive outcomes. From an empirical perspective, the study expands existing evidence by analysing responses from 179 consumers across several Eastern European countries, a region that remains relatively limited in international research on luxury gastronomy and sustainable hospitality. The findings provide additional insight into how consumers in emerging gastronomic markets understand sustainability and how these perceptions translate into behavioural intentions and evaluations of competitive positioning. From a managerial perspective, the results indicate that the implementation of sustainability practices alone may not be sufficient; their effective communication and integration into the overall dining experience are equally important. Sustainability generates value when consumers perceive clear connections between responsible practices, authenticity, local identity, and gastronomic quality. Therefore, restaurant managers should consider sustainability not merely as an operational requirement but as an element of strategic experience design. The findings also have implications for tourism stakeholders, as sustainable gastronomy can contribute to destination attractiveness, regional identity formation, stronger local production networks, and wider economic benefits within tourism ecosystems. Overall, the study demonstrates that sustainability can represent a strategic resource for luxury gastronomy, but its effectiveness depends on the extent to which it is meaningfully incorporated, communicated, and recognised by consumers. By linking sustainability perception with authenticity, willingness to pay, behavioural loyalty, and perceived competitive advantage, this research contributes to a deeper understanding of how sustainability can support both restaurant competitiveness and broader tourism development.

REFERENCE LIST

Biloslavo, R., & Janković, N. (2025). Sustainable practices in hospitality: A case study of a Slovenian Michelin Green Star restaurant. Sustainability, 17(10), 4271. https://doi.org/10.3390/su17104271

Bonfanti, A., Bagnato, G., & Vigolo, V. (2025). The contribution of sustainable practices to the creation of memorable customer experience: Empirical evidence from Michelin Green Star restaurants. International Journal of Hospitality Management, 126, 104110. https://doi.org/10.1016/j.ijhm.2025.104110

Bryman, A. (2016). *Social research methods* (5th ed.). Oxford University Press. Available at: https://global.oup.com/ukhe/product/brymans-social.-research-methods-9780198796053

Cabrita, M. do R., Castro, M., Mendes, A., Pinho, T., & Sabino, M. R. (2026). Open Sustainable Innovation in Port Ecosystems: A Literature Review. *ECONOMICS - Innovative and Economic Research Journal*, *14*(1), 27-49. https://doi.org/10.2478/eoik-2026-0002

Cankül, D. (2019). Gastronomy tourism and destination competitiveness. In *Proceedings of the International Gastronomy Tourism Congress* (pp. 100–109). İzmir, Turkey. https://www.researchgate.net/publication/330162546_Gastronomy_Tourism_and_Destination_Competitiveness

Daries, N., Cristobal-Fransi, E., Ferrer-Rosell, B., & Mariné-Roig, E. (2018). Maturity and development of high-quality restaurant websites: A comparison of Michelin-starred restaurants in France, Italy and Spain. International Journal of Hospitality Management, 73, 125–137. https://doi.org/10.1016/j.ijhm.2018.02.007

Demir, Y., & Bertan, S. (2025). Spatial distribution of sustainable gastronomy criteria in Michelin Green Star restaurants. Journal of Multidisciplinary Academic Tourism, 10(3), 287–295. https://doi.org/10.31822/jomat.2025-10-3-287

Filimonau, V., & Krivcova, M. (2017). Restaurant menu design and more responsible consumer food choice: An exploratory study of managerial perceptions. *Journal of Cleaner Production, 143*, 516–527. https://doi.org/10.1016/j.jclepro.2016.12.080

Gössling, S., & Hall, C. M. (2022). The sustainable chef: The environment in culinary arts, restaurants, and hospitality. Routledge. https://doi.org/10.4324/9781315187488-1

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning. https://www.cengage.com/c/ebook-multivariate-data-anal.ysis-8e-hair-babin-anderson/9781473756557/

Huang, Y., & Hall, C. M. (2023). Locality in the promoted sustainability practices of Michelin-starred restaurants. Sustainability, 15(4), 3672. https://doi.org/10.3390/su15043672

Huang, Y., Hall, C. M., & Chen, N. C. (2025). The sustainability characteristics of Michelin Green Star restaurants. Journal of Foodservice Business Research, 28(2), 219–244. https://doi.org/10.1080/15378020.2023.2235258

Liu, S.-F., Li, Z.-X., & Zhang, Y. (2023). Sustainable operation of fine-dining restaurants: Antecedents and consequences of customers' self-image congruity at a Cantonese Michelin-starred restaurant based on the value-attitude-behavior model. Sustainability, 15(3), 2421. https://doi.org/10.3390/su15032421

Marquez Garat, J. (2022). *Gastronomy and sustainability: A study of the role of the Michelin Green Star sustainability award in food system transformation* (Master's thesis, Norwegian University of Life Sciences). https://hdl.handle.net/11250/3041645

Michelin Guide. (2023). New stars and awards 2023. Retrieved from https://guide.michelin.com/en/article/michelin-guide-ceremony/new-stars---awards---michelin-guide-germany-2023

Mrkaić Ateljević, A. (2025). Bibliometric analysis as a basis for research on sustainability in tourism in Bosnia and Herzegovina. *Collection of Papers New Economy*, 3(1), 57-70. https://doi.org/10.61432/CPNE0301057a

Rosário, A. T., Lopes, P. R., & Rosário, F. S. (2023). The digital marketing for sustainable development. *Preprints*. https://doi.org/10.20944/preprints202307.0330.v1

Sang, T. M., & Anh, N. Q. (2026). Internal Control Systems and Technological Capabilities as Drivers of Bank Risk Management for Advancing Sustainable Development Goal 16. *ECONOMICS - Innovative and Economic Research Journal*, *14*(1), 235-252. https://doi.org/10.2478/eoik-2026-0012

Shojaei, S. A., Pakgohar, A., & Tran, D. Y. V. (2026). Green Deliveries on a Budget: How Sustainability and Cost Shape Vietnamese E-Commerce Consumer Choices. *ECONOMICS - Innovative and Economic Research Journal*, *14*(2), 67-86. https://doi.org/10.2478/eoik-2026-0026

UNWTO. (2012). *Global report on food tourism*. World Tourism Organization. https://doi.org/10.18111/9789284414819

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

INSTITUTIONAL AND ECONOMIC FRAMEWORKS FOR ESTABLISHING A GREEN ENERGY ZONE IN AZERBAIJAN: EVIDENCE, CHALLENGES, AND DEVELOPMENT PROSPECTS

Mahabbat Mammadov[1], Turkan Hasanova[1], Oksana Krivoruchko[2], Ruhangiz Aliyeva[1], Gunel Imamquluyeva[1*]

Received 13.02.2026. | Sent to review 28.03.2026. | Accepted 20.08.2026.

Original Article

CC BY NC ND

[1] Azerbaijan University of Architecture and Construction, Baku, Azerbaijan

[2] The Kharkiv National Automobile and Highway University, Ukraine

***Corresponding Author:**
Gunel Imamquluyeva

Email:
gunel.imamquliyeva@azmiu.edu.az

JEL Classification:
Q42, Q48, O13

Doi: 10.61432/CPNE0401175m

UDK: 712.252:316.356.2(4-672EU)

ABSTRACT

This study examines how artificial intelligence, IT infrastructure, and cybersecurity shape digital inequality during labour market transformation in the European Union. Using an integrated analytical framework and panel data analysis, it responds to a research gap in which these dimensions have largely been assessed separately. Findings indicate that artificial intelligence can widen digital inequality when adequate institutional and technological support is lacking. In contrast, advanced IT infrastructure and strong cybersecurity may reduce such disparities by improving access to digital resources, supporting participation in the digital economy, and strengthening trust in digital systems. Further evidence shows that the influence of artificial intelligence on digital inequality varies according to infrastructural capacity and cybersecurity preparedness. This confirms the relevance of broader structural and institutional conditions in determining the outcomes of digital transformation. A key contribution of this study is its integration of technological, infrastructural, and institutional factors within a unified framework. It also emphasizes cybersecurity as a significant component of digital inequality and provides empirical evidence from the European Union context. Policy implications suggest that AI-driven development should be supported by investment in connectivity, digital skills, and cyber resilience. Coordinated policy measures are necessary to foster innovation while advancing digital inclusion and institutional capacity. Limitations arise from the use of aggregated country-level data and proxy indicators for artificial intelligence and cybersecurity. Future research should consider more detailed datasets, sector-specific differences, and the long-term effects of digital transformation on labour markets. Overall, the study demonstrates that the link between artificial intelligence and digital inequality is multidimensional and context-dependent. Inclusive digital transformation requires technological advancement together with robust infrastructure, cybersecurity, and effective public policy.

Keywords: *artificial intelligence, digital inequality, IT infrastructure, cybersecurity, labour market transformation, European Union, digital inclusion*

1. INTRODUCTION

Climate change and increasing anthropogenic pressure on the environment have made energy efficiency and renewable energy development strategic priorities at both global

and national levels. In Azerbaijan, these priorities are reflected in state programs, development strategies, and regulatory frameworks that promote the transition to a green economy. Current initiatives focus on reducing the environmental impacts of the fuel and energy sector through measures such as the remediation of oil-contaminated land, land reclamation, and carbon emission reduction. This study also compares Azerbaijan's approach with international practices and examines the growing contribution of renewable energy, particularly solar and wind power, to the global energy transition. Azerbaijan possesses substantial renewable energy resources and is among the regional leaders in this field. The country's technical offshore wind potential is estimated at approximately 157 GW, providing significant opportunities for large-scale renewable energy development. Solar and wind energy account for the largest share of this potential. In addition, the establishment of a Green Energy Zone in the liberated territories has become a strategic national objective aimed at creating a sustainable and environmentally friendly energy system. This initiative prioritizes the expansion of solar, wind, and hydropower generation, the implementation of energy efficiency measures, the adoption of smart technologies, and the development of electric transport.

2. LITERATURE REVIEW

The transition to green energy and the development of sustainable energy systems have become central themes in energy economics and environmental policy. The literature consistently recognizes renewable energy as a key driver of carbon emission reduction, energy security, and sustainable economic growth. International organizations, including the International Renewable Energy Agency (IRENA), identify renewable energy integration as essential for global decarbonization and the transition to low-carbon energy systems. Recent studies emphasize the economic and environmental benefits of renewable energy deployment. Zhang et al. (2026) argue that renewable energy technologies can simultaneously address growing energy demand, reduce CO_2 emissions, and promote green innovation through effective policy frameworks. In resource-dependent economies, particularly oil-exporting countries, green energy development is also viewed as an opportunity for economic diversification. Gasimli et al. (2024a, 2024b, 2025) demonstrate that strategic investments and institutional reforms could enable Azerbaijan to diversify its economy and strengthen its position as a future exporter of green energy.

Several studies examine Azerbaijan's policy and institutional framework for renewable energy development. Hajizadeh (2023) highlights the importance of aligning national energy security objectives with sustainability goals, emphasizing investment frameworks and institutional readiness. Similarly, Bayramov (2021) and Guliyev (2024) note that although strategic policies and regulatory instruments have been introduced, implementation challenges and regulatory inconsistencies continue to constrain progress.

Empirical evidence also supports the positive economic effects of renewable energy. Aliyev et al. (2024) identify a long-term positive relationship between renewable energy consumption and economic growth in Azerbaijan, while Gulaliyev et al. (2020) demonstrate the country's substantial solar energy potential and its contribution to emission reduction and regional development. Landoni and Muradzada (2026) further argue that governance quality, regulatory stability, and institutional capacity remain critical determinants of a successful energy transition in hydrocarbon-dependent economies.

Additional research by Shahbazov (2024) and Humbatova (2024) examines the relationship between economic growth, environmental sustainability, and renewable energy development, concluding that policy effectiveness depends on the successful implementation of integrated green energy strategies. Earlier work by Mammadov and Aliyev (2013) provides the theoretical foundation for energy planning and program-target management

in Azerbaijan, complementing national strategic documents such as the *Azerbaijan 2030* development strategy.

Despite the expanding literature, an important research gap remains. Existing studies primarily address macroeconomic impacts, policy frameworks, or individual sectors, whereas limited attention has been given to the integrated institutional and economic conditions required for establishing a coherent Green Energy Zone in Azerbaijan. This study addresses this gap by examining the policy coherence, institutional readiness, and economic feasibility of green energy zone development within a unified analytical framework.

3.DATA AND METHODOLOGY

This study applies a qualitative and comparative research design to examine the development of green energy initiatives in Azerbaijan. It is based on the program-target approach, which enables the assessment of state policies, strategic frameworks, and institutional mechanisms aimed at promoting environmental sustainability and establishing a Green Energy Zone.

The empirical foundation of the research consists of official state programs, strategic development documents, and policy reports adopted in Azerbaijan. These include national energy and environmental programs, socio-economic development strategies, and long-term policy frameworks such as *Azerbaijan 2030: National Priorities for Socio-Economic Development*. These sources provide the basis for evaluating the evolution, priorities, and institutional support of green energy policy.

The methodological framework combines comparative analysis, content analysis, and the program-target method. Comparative analysis is used to examine policy continuity across different periods, while content analysis identifies key priorities, policy tools, and implementation mechanisms in official documents. The program-target method assesses how strategic objectives are transformed into practical measures and programs.

Elements of historical analysis are also included to trace the development of program-based planning, its theoretical foundations, and its application in different national contexts. This approach helps clarify how international experience in program-based management can be adapted to Azerbaijan.

Overall, the selected methods provide a comprehensive basis for assessing the coherence and effectiveness of green energy policies and their contribution to sustainable development.

4.RESULTUS AND DISCUSSIONS

Environmental protection has become a strategic priority in Azerbaijan, with the fuel and energy sector playing a central role in addressing ecological challenges such as the remediation of oil-contaminated land, drainage of polluted water bodies, and land reclamation on the Absheron Peninsula (Aliyev et al., 2024). Globally, annual losses of oil and petroleum products are estimated at approximately 45 million tons, with an additional 8 million tons lost during transportation, highlighting the environmental costs associated with conventional energy production (Mammadov & Aliyev, 2013).

Following its accession to the Kyoto Protocol, Azerbaijan strengthened its environmental policies through state programs and national development strategies that promoted renewable energy and emission reduction. As a result, national carbon dioxide emissions declined from approximately 60 million tons to 37 million tons after 2010. A major contribution was made by the *Comprehensive Action Plan for Improving the Environmental Situation in the Republic of Azerbaijan for 2006–2010*, which focused on addressing ecological problems in Baku and the Absheron Peninsula (CoM, 2006).

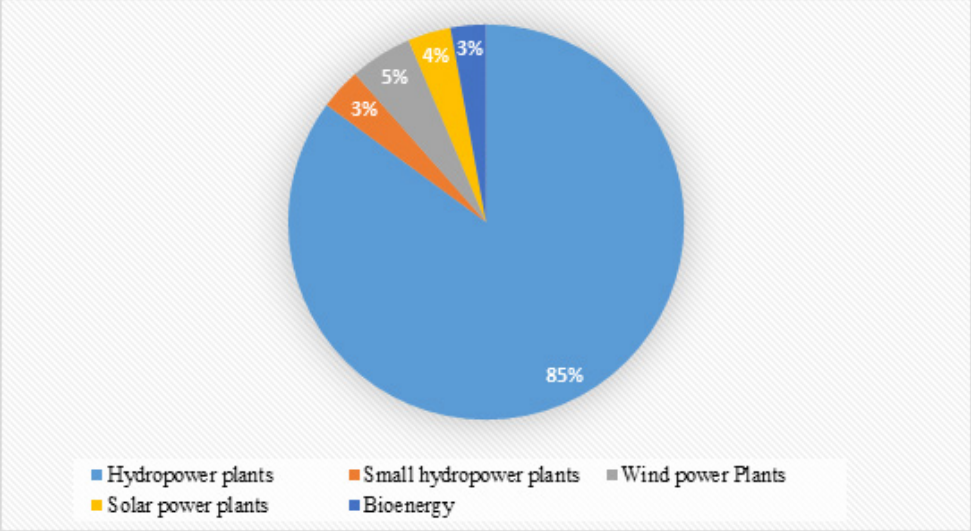
The Absheron Peninsula remains the country's most environmentally vulnerable region, accommodating around 40% of the population and 70% of industrial activity. Consequently, sustainable environmental management and renewable energy development have become national priorities. Since the adoption of the State Program on the Use of Alternative and Renewable Energy Sources in 2004 (SPRES, 2004), Azerbaijan has expanded its commitment to green energy in response to rising energy demand, environmental degradation, and the depletion of fossil fuel resources.

Azerbaijan possesses substantial renewable energy potential, creating favorable conditions for investment and the implementation of large-scale green energy projects. Global trends further reinforce this transition. According to IRENA (2026), renewable energy accounted for 29.9% of global electricity generation in 2023. Between 2012 and 2023, electricity generation from renewable sources grew at an average annual rate of 5.9%, considerably exceeding the 1.3% growth recorded for conventional energy sources. In 2023 alone, renewable electricity generation increased by 5.6%, compared with 1.2% for traditional energy, demonstrating the accelerating role of renewables in the global energy mix (MoE, 2026).

Comparative analysis shows that solar and wind energy have experienced the fastest growth since 2010. In 2023, these technologies generated 13.2% of global electricity and recorded a 15.7% increase compared with the previous year. The structure of renewable energy has also changed substantially over the past two decades, with wind and solar power accounting for 44% of renewable electricity generation in 2023, compared with only 1.1% in 2000.

Despite these global trends, Azerbaijan's renewable electricity generation remains dominated by hydropower, which accounts for approximately 85% of total renewable output. Wind energy contributes 5%, solar energy 4%, while bioenergy and small hydropower each account for 3%. The following section presents the structure of electricity generation from renewable energy sources in Azerbaijan.

Figure 1. Renewable energy plants in Azerbaijan (in %)

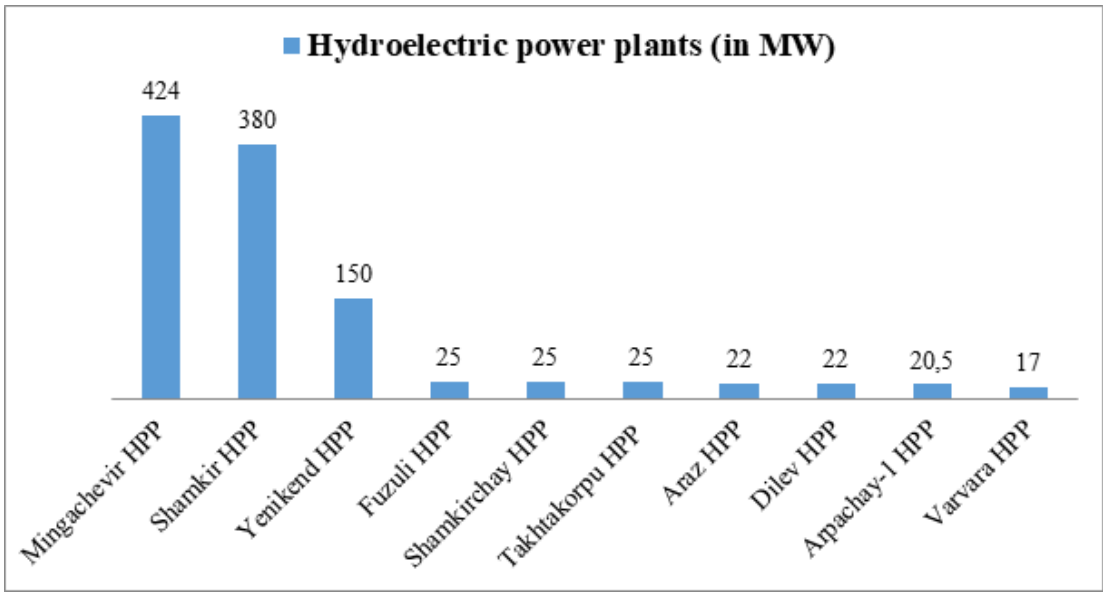


Source: Compiled by the authors based on data from AREA (2026)

Research on Azerbaijan's renewable energy potential indicates that the country has an estimated capacity of 27.5 thousand MW. Solar energy represents the largest share, with 23.0 thousand MW, followed by wind energy at 3.0 thousand MW, mountain rivers at 520 MW, and bioenergy at 380 MW. At present, renewable energy accounts for 17.3% of Azerbaijan's total energy production (MoE, 2026). Progress in this sector is also reflected

in electricity generation from hydropower plants. In 2021, total installed capacity from renewable energy plants reached 1,110.5 MW, mainly generated by major hydropower facilities such as Mingachevir HPP, Shamkir HPP, Yenikend HPP, Fuzuli HPP, Shamkirchay HPP, Takhtakorpu HPP, Araz HPP, Dilev HPP, Arpachay-1 HPP, and Varvara HPP. The dynamics of these indicators are presented in Figure 2.

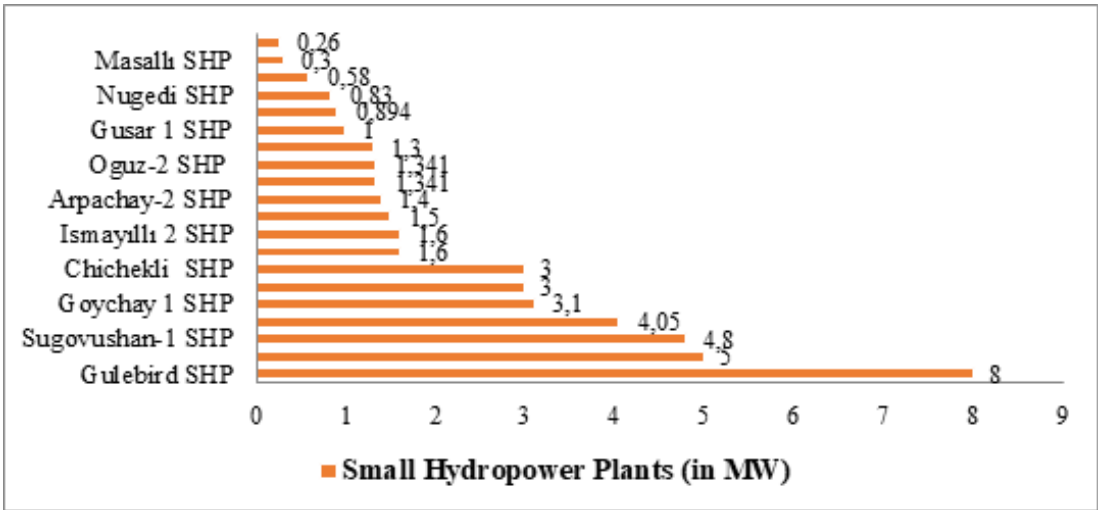
Figure 2. Hydroelectric Power Plants



Source: Compiled by the authors based on data from AREA (2026)

In Azerbaijan, small hydroelectric power plants produced a total of 44.3 MW per year (SSC, 2026), including the following plants in residential areas: Gulebird SHPP – 8.0 MW; Vaykhir SHPP – 5.0 MW; Suqovushan-1 SHPP – 4.8 MW; Mughan SHPP – 4.05 MW; Goychay-1 SHPP – 3.1 MW; Suqovushan-2 SHPP – 3.0 MW; Chichekli SHPP – 3.0 MW; Ismayilli-1 SHPP – 1.6 MW; Ismayilli-2 SHPP – 1.6 MW; Balakan SHPP – 1.5 MW; Arpachay-2 SHPP – 1.4 MW; Oguz-1 SHPP – 1.341 MW; Oguz-2 SHPP – 1.341 MW; Shaki SHPP – 1.3 MW; Qusar-1 SHPP – 1.0 MW; Oguz-3 SHPP – 0.894 MW; Nugedi SHPP – 0.83 MW; Shaki SHPP – 0.58 MW; Masalli SHPP – 0.3 MW; and Astara K368 SHPP – 0.26 MW.

Figure 3. Small Hydroelectric Power Plants (in MW)

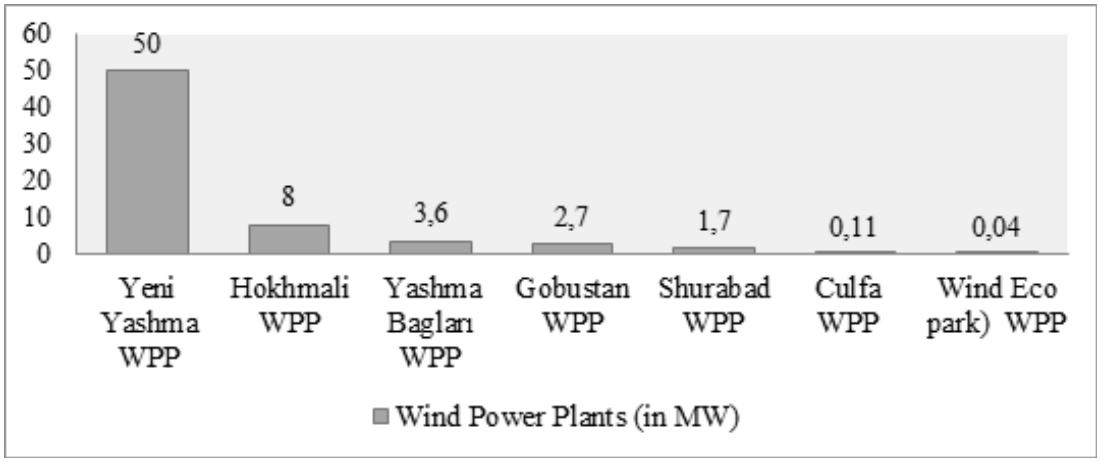


Source: Compiled by the authors based on data from AREA (2026)

Among non-hydropower renewable sources in Azerbaijan, wind energy ranks second in terms of production volume. In 2023, wind energy generation increased by 9.8%, while in 2022 it accounted for 13.9% of renewable energy production.

Total electricity generation from wind power plants reached 66.1 MW. The largest contribution came from the Yeni Yashma Wind Power Plant, followed by Hokhmali, Yashma Bagları, Qobustan, Shurabad, Culfa, and the Wind Eco-Park facilities.

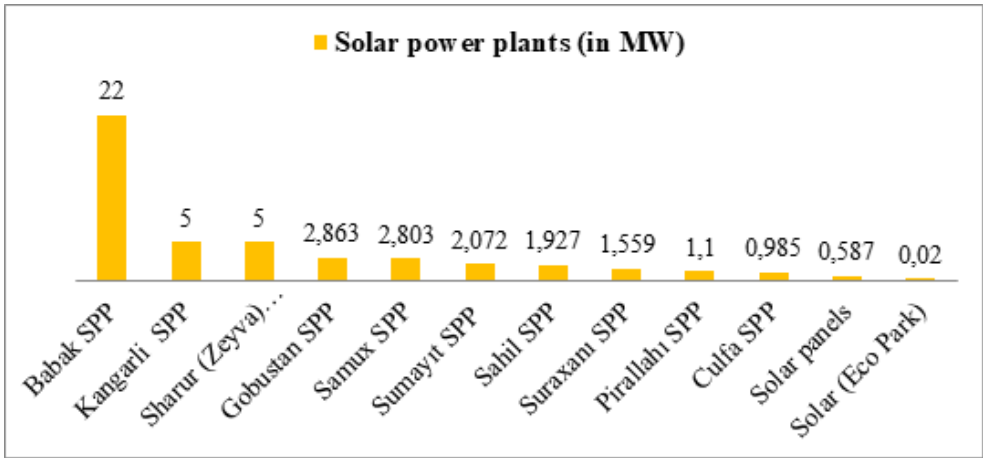
Figure 4. Wind Power Plants (MW)



Source: Compiled by the authors based on data from AREA (2026)

In recent years, the fastest-growing sector of the renewable energy industry in Azerbaijan has been solar energy production. Compared to the previous year, energy production in this sector increased by 25.2%, marking the highest level of energy output observed since 2018.

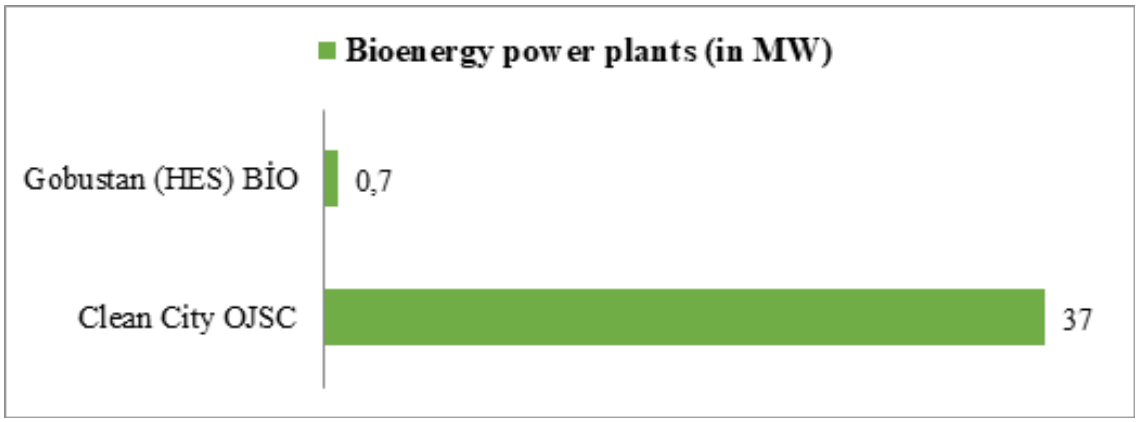
Figure 5. Solar power plants (MW)



Source: Compiled by the authors based on data from AREA (2026)

Figure 5 shows that the total capacity of solar power plants in Azerbaijan is 45.9 MW. The largest contributions come from the Babek, Kengerli, and Sharur Solar Power Plants, followed by smaller facilities in Gobustan, Samukh, Sumgait, Sahil, Surakhani, Pirallahi, Culfa, and Eco-Park. Bioenergy production in Azerbaijan remains more limited, with a total capacity of 37.7 MW. Most of this capacity is generated by “Clean City” JSC, while the Gobustan bioenergy facility accounts for a smaller share.

Figure 6. Bioenergy (in MW)



Source: Compiled by the authors based on data from AREA (2026)

In addition to hydropower, wind, solar, and bioenergy, Azerbaijan has an estimated geothermal energy potential of 98 MW and approximately 1 MW of marine energy capacity. Expanding the share of renewable energy in the national energy mix requires continued attraction of both domestic and foreign investment, alongside the adoption of international best practices.

Azerbaijan's renewable energy policy has evolved through a series of state programs and strategic initiatives. The *State Program on the Use of Alternative and Renewable Energy Sources* (SPRES, 2004) established the institutional foundation for the sector by promoting the use of renewable resources, improving the efficiency of hydrocarbon consumption, and encouraging environmentally sustainable energy production. Subsequent policy documents, including the *State Strategy on the Use of Renewable Energy Sources for 2012–2020*, strengthened this framework through legislative reforms, tariff and subsidy mechanisms, technological innovation, and support for private investment. Public-private partnership mechanisms, reinforced by regulations adopted in 2024, have further enhanced investment opportunities in the renewable energy sector.

The development of a Green Energy Zone in Azerbaijan's liberated territories represents one of the country's principal strategic priorities. Following the 2020 Patriotic War, the government adopted a dedicated decree to promote renewable energy development in these areas and commissioned the preparation of a comprehensive concept with the support of the Japanese consulting company TEPSCO. The initiative aims to utilize the region's considerable renewable energy resources, introduce energy-efficient and low-carbon technologies, and establish a sustainable energy system supported by demand forecasting and modern planning approaches.

Implementation measures include the expansion of renewable electricity generation, improvements in energy efficiency, deployment of electric vehicles, installation of rooftop solar systems, use of solar-powered public lighting, application of smart energy management technologies, and energy recovery from waste. At the UN Climate Change Conference (COP26) in 2021, Azerbaijan announced its commitment to reduce greenhouse gas emissions by 40% by 2050 and to establish a net-zero emissions zone in the liberated territories.

Preliminary assessments indicate that the districts of Qubadli, Zangilan, Jabrayil, and Fuzuli possess more than 7,200 MW of technical solar energy potential, while Lachin and Kalbajar have approximately 2,000 MW of wind energy potential. The Tartar and Hakari rivers also provide significant opportunities for hydropower development. To support these objectives, several hydropower plants have already been restored and commissioned in Lachin, Kalbajar, and Sugovushan, while construction continues on the Khudaferin and Giz Galasi hydropower projects on the Araz River. Additional investments include a planned 100 MW wind farm in the Lachin–Kalbajar region and a 240 MW solar

power project in the Zangilan–Jabrayil area implemented through cooperation between the Ministry of Energy and BP.

5. CONCLUSION

This study examined the institutional and economic foundations for establishing a Green Energy Zone in Azerbaijan by analyzing the country's renewable energy potential, policy framework, and implementation mechanisms. The findings indicate that Azerbaijan has established a comprehensive strategic and institutional basis for renewable energy development through state programs, national strategies, and regulatory reforms. Although notable progress has been achieved in expanding renewable energy capacity, particularly in hydropower, wind, solar, and bioenergy, the energy system remains dominated by hydropower, while the potential of other renewable sources is not yet fully utilized. The analysis further shows that institutional challenges, including limited interagency coordination, regulatory inconsistencies, and delays in project implementation, continue to constrain the pace of the energy transition. Strengthening governance structures, improving regulatory effectiveness, and expanding public–private partnerships will be essential for accelerating renewable energy development. From an economic perspective, Azerbaijan possesses considerable untapped renewable energy resources that can support energy diversification, attract investment, and promote sustainable economic growth. The Green Energy Zone initiative in the liberated territories represents a strategic opportunity to modernize regional energy infrastructure and align national energy policy with global sustainability objectives. This study contributes to the literature by integrating institutional, economic, and spatial dimensions within a unified analytical framework. Unlike previous studies that primarily examined individual sectors or policy measures, it provides a comprehensive assessment of the factors shaping green energy zone development in Azerbaijan. Overall, the findings suggest that Azerbaijan has established a solid foundation for the transition to a green energy system. Nevertheless, fully realizing the country's renewable energy potential will require continued institutional reforms, greater investment, wider adoption of advanced technologies, and effective policy implementation. Future research should focus on quantitative evaluations of investment efficiency, cost–benefit analyses of renewable energy projects, and comparative studies of energy transition in other resource-rich economies.

REFERENCES

Aliyev, S., Hasanov, R., Aghayeva, K., Gasimov, J. and Ahmadova, S. (2024). The Relationship between Renewable Energy Consumption and Economic Growth: Insights from Iceland and Azerbaijan. *International Journal of Energy Economics and Policy* 14(5), pp. 229–235, https://doi.org/10.32479/ijeep.16490

AREA. (2025). Azerbaijan Renewable Energy Agency under the Ministry of Energy of the Republic of Azerbaijan(AREA). *Potential of RE*. [Online:] https://area.gov.az/en/page/yasil-texnologiyalar/boem-potensiali

AREA. (2026). Azerbaijan Renewable Energy Agency under the Ministry of Energy of the Republic of Azerbaijan (AREA). RE statistic in Azerbaijan. [Online:] https://area.gov.az/az/page/layiheler/berpa-olunan-enerji-stansiyalari/boem

Azerbaijan 2030. (2021). *Azerbaijan 2030: National priorities for socio-economic development*. https://president.az/az/articles/view/50474

Bayramov, A. (2021). Azerbaijan's renewable energy policy: Opportunities, drivers and challenges. *Caucasus Analytical Digest*, 120, 2–7. https://doi.org/10.3929/ethz-b-000476772

CoM. (2005). The Cabinet of Ministers of the Republic of Azerbaijan (CoM). (2005, February 14). State Program for the development of the *fuel and energy complex of the Republic of Azerbaijan for 2005–2015*. [Online:] https://e-qanun.az/framework/7402

CoM. (2006). The Cabinet of Ministers of the Republic of Azerbaijan (CoM). (2006, September 28). *Comprehensive action plan for improving the environmental situation in the Republic of Azerbaijan for 2006–2010*. [Online:] https://e-qanun.az/framework/12395

CoM. (2022). The Cabinet of Ministers of the Republic of Azerbaijan (CoM). Action Plan for the creation of a "green energy" zone in the liberated territories of the Republic of Azerbaijan in 2022-2026. [Online:] https://nk.gov.az/az/senedler/serencamlar/%E2%80%9Cazarbaycan-respublikasinin-isgaldan-azad-edilmis-arazilarinda-2022-2026-ci-illarda-%E2%80%9Cyasil-enerji%E2%80%9D-z-6209

DoP. (2021). Decree of the President of the Republic of Azerbaijan on measures to establish a "green energy" zone in the territories of the Republic of Azerbaijan liberated from occupation. https://e-qanun.az/framework/47397

Ganiyev, K., Alizada, S., Asgarov, A., Gasimli, M., & Gasimzade, N. (2024). Safety management in the construction industry: Bibliometric analysis. *Problems and Perspectives in Management,* 22(3), 198–213. http://dx.doi.org/10.21511/ppm.22(3).2024.16

Gasimli, V., Huseyn, R. & Suleymanov, A. (2025). Repositioning oil exporters for the Green Energy Transition: the case of Azerbaijan. *Polityka Energetyczna – Energy Policy Journal,* 28(4), 181–200. https://doi.org/10.33223/epj/209658

Gasimli, V., Huseyn, R., & Huseynov, R. (2024a). Economy-wide and environmental benefits of green energy development in oil-rich countries: Evidence from Azerbaijan. *Economic Annals,* 69(241), 41–64. https://www.ceeol.com/search/article-detail?id=1324071

Gasimli, V., Huseyn, R., & Huseynov, R. (2024b). What advantages arise from the shift towards sustainable energy sources in resource-rich economies? Empirical insights from Azerbaijan. *International Journal of Energy Economics and Policy,* 14(1), 12–20. https://doi.org/10.32479/ijeep.15016

Gulaliyev, M., Mustafayev, E., & Mehdiyeva, G. (2020). Assessment of solar energy potential and its ecological-economic efficiency: Azerbaijan case. *Sustainability,* 12(3), 1–11. https://doi.org/10.3390/su12031116

Guliyev, F. (2024). Renewable energy targets and policies in traditional oil-producing countries: A comparison of Azerbaijan and Kazakhstan. *Journal of Eurasian Studies,* 15(1), 110–124 https://doi.org/10.1177/18793665231177720

Hajizadeh, E. (2023). Imperatives of Green Energy Strategy in Azerbaijan. *Journal of Energy and Power Engineering*, 17(1), 27–37. https://doi.org/10.17265/1934-8975/2023.01.004

Humbatova, S. I., Hajiyeva, N., Fodor, M. G., Sood, K., & Grima, S. (2024). The Impact of Economic Growth on the Ecological Environment and Renewable Energy Production: Evidence from Azerbaijan and Hungary. Journal of Risk and Financial Management, 17(7), 275. https://doi.org/10.3390/jrfm17070275

IRENA. (2026). Statistics Data, International Renewable Energy Agency. [Online:] [Accessed: 2026-03-11] https://www.irena.org/Data

Landoni, M., & Muradzada, N. (2026). Renewable Dependence as an Institutional Transition Risk in Hydrocarbon Economies: Insights from Azerbaijan. *Economies*, *14*(1), 14. https://doi.org/10.3390/economies14010014

Mammadov, M., & Aliyev, N. (2013). *Economic programming in the development and management of the fuel and energy complex*. Baku.

Mammadov, M., Mammadova, F., Alizada, S., Hasanova, T. & Alekperov, S. (2025). Comprehensive analysis and evaluation of Azerbaijan's National Energy Complex: current status and future prospects. *Polityka Energetyczna – Energy Policy Journal*, 28(4), 109–124. https://doi.org/10.33223/epj/208463

Mammadov, M., Mammadova, F., Kariuk, A., & Mammadov, E. (2022). Economic reforms and development strategies as providing sustainable development. In Lecture Notes in Civil Engineering, Vol. 181, 669–676. Springer. https://link.springer.com/chapter/10.1007/978-3-030-85043-2_63

Mammadova, F., Fetahova, N., Mammadov, S., Gasimov, R., & Aliyev, S. (2024). Governmental management of social housing as an element of state social policy: Bibliometric analysis. *Problems and Perspectives in Management*, *22*(2). http://dx.doi.org/10.21511/ppm.22(2).2024.39

Mammadova, G., Mammadov, N., Taplamacioglu, C., Akbarova, S. (2025). Conceptual Strategy for Technological Transition to Renewable Energy. In: Zabulonov, Y., Peer, I., Zheleznyak, M. (eds) Liquid Radioactive Waste Treatment: Ukrainian Context. LWRT 2023. Lecture Notes in Civil Engineering, vol 712. Springer, Cham. https://doi.org/10.1007/978-3-031-95663-8_17

MoE. (2026). Ministry of Energy of the Republic of Azerbaijan. (n.d.). *Reports*. [Online:] https://minenergy.gov.az/az/hesabatlar

Shahbazov, P. 2024. Green era in Azerbaijani energy. Azerbaijan official newspaper, 229 (9684). [Online:] https://www.azerbaijan-news.az [Accessed: 2026-01-18] (in Azerbaijani).

SPRES. (2004). State program on the use of renewable energy sources in the Republic of Azerbaijan. Baku. [Online:] https://e-qanun.az/framework/5796

SPSEDR. (2019). *State Program on socio-economic development of the regions of the Republic of Azerbaijan for 2019–2023*. https://e-qanun.az/framework/41320

SSC. (2026). State Statistical Committee of the Republic of Azerbaijan (SSC). Energy. [Online:] https://stat.gov.az/source/balance_fuel/?lang=en [Accessed: 2026-01-30].

Zhang, L., Xiang, R., Yang, Q. (2026). Exploring the role of technological innovation and renewable energy in environmental sustainability across Asian economies. Scientific Reports, 16, 14010 (2026). https://doi.org/10.1038/s41598-026-41128-8

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

OPEN INNOVATION AS A COORDINATION MECHANISM IN PORT ECOSYSTEMS: A COMPARATIVE ANALYSIS OF EUROPEAN SEAPORTS

Maria Rosilene Sabino[1,2*], Marcela Castro[1,3,4], Ana Mendes[1,2], Tiago Pinho[1,2]

Received 11.03.2026. | Send to review 27.03.2026. | Accepted 13.08.2026.

Original Article

[1] Instituto Politécnico de Setúbal, Escola Superior de Ciências Empresariais, Campus do IPS - Setúbal, Portugal

[2] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Caparica, Portugal

[3] LASI - Laboratório Associado de Sistemas Inteligentes, Guimarães, Portugal.

[4] NECE - Research Centre for Business Sciences, Department of Management and Economics, Faculty of Human and Social Sciences, Universidade da Beira Interior, Covilhã, Portugal

***Corresponding Author:**
Maria Rosilene Sabino

Email:
maria.sabino@esce.ips.pt

JEL Classification:
E24, J44, O33

Doi: 10.61432/CPNE04011858

UDK: 699.887(4):316.422-027.511

ABSTRACT
European seaports are undergoing transformative changes driven by digitalisation, sustainability demands, and increased interdependence in maritime logistics. As multi-actor systems within global supply networks, ports require innovative strategies to coordinate diverse stakeholders, knowledge flows, and institutional frameworks. This paper investigates how Open Innovation serves as a coordination mechanism in European port ecosystems and examines the influence of different governance configurations on sustainability-oriented value creation. Using a semi-structured literature review and qualitative comparative analysis, four case studies—Rotterdam, Valencia, Barcelona, and Motril-Granada—are examined alongside small and medium-sized Baltic ports. The findings reveal that Open Innovation varies based on port scale, ecosystem maturity, governance capacity, institutional mediation, digital readiness, and strategic focus. Rotterdam illustrates a distributed innovation ecosystem; Valencia represents an institutional model; Barcelona exemplifies smart-port and business-model innovation; Motril-Granada highlights a Blue Economy approach; and Baltic ports emphasise capacity building. While Open Innovation promotes stakeholder alignment and shared agenda-setting, challenges such as fragmented governance and varying resource capacities constrain its overall impact. This paper contributes to research on port innovation and maritime logistics by proposing a conceptual framework that views Open Innovation as a key coordination mechanism for sustainable port transformation.

Keywords: *Open Innovation, Port Ecosystem, Maritime Ports, Port Governance, business model innovation*

1. INTRODUCTION

European seaports are undergoing a profound transformation. Traditionally understood as sea–land interfaces and logistics nodes, ports have increasingly become complex ecosystems in which port authorities, terminal operators, shipping companies, logistics providers, technology firms, public agencies, research institutions, and local communities interact to generate economic, environmental, and social value. This transformation has been accelerated by digitalisation, sustainability pressures, changing supply chain requirements and the need to coordinate increasingly interdependent maritime logistics systems.

In this context, innovation has become a strategic condition for port competitiveness and sustainable development. However, innovation in ports is not merely a technological issue (Seisenbekov et al., 2026). Port-related innovation often involves regulatory, organisational, managerial, cultural and technological dimensions, requiring coordinated action among multiple actors. Vanelslander et al. (2019) show that port-related innovation is multidimensional, and that collaborative innovation or co-innovation is likely to become increasingly important for maritime and port-related innovation. Similarly, Acciaro and Sys (2020) argue that maritime innovation initiatives are often uncoordinated, unfocused and poorly managed, which may prevent them from delivering expected strategic outcomes. These insights suggest that the central challenge is not only how ports innovate, but how innovation is coordinated across fragmented ecosystems.

Open Innovation offers a relevant lens for addressing this challenge. Since Chesbrough's seminal contribution, Open Innovation has been understood as a model in which firms and organisations use purposive inflows and outflows of knowledge to accelerate innovation and expand the use of internal and external ideas (Chesbrough, 2003; Chesbrough & Bogers, 2014). In port ecosystems, however, Open Innovation cannot be reduced to the adoption of external ideas by individual organisations. Ports operate as multi-actor systems embedded in wider transport networks, urban regions and global supply chains. Therefore, Open Innovation in this context must be understood as an ecosystem-level process involving knowledge sharing, stakeholder alignment, institutional intermediation, digital integration and collaborative value creation.

This perspective is particularly relevant because ports display many characteristics of network industries. Their performance depends on interoperability, standards, information flows, hinterland connections and coordination among actors that may simultaneously cooperate and compete. Roumboutsos et al. (2022) show that innovation uptake in ports is closely related to network-industry characteristics, and that co-opetition, imitation and Open Innovation can support innovation diffusion, especially when standards and interoperability are required. This reinforces the need to analyse Open Innovation not only as a managerial practice, but as a coordination mechanism that enables ports to organise interdependencies across actors, technologies and institutional arrangements.

At the same time, sustainability has become a central driver of port transformation. Ports are increasingly expected to contribute to decarbonisation, circular economy, Blue Economy strategies, clean energy transitions, reduced environmental impacts and improved port–city relations. Sustainable value creation in ports requires a broader relational perspective that goes beyond conventional supply chain efficiency and incorporates multiple stakeholders, including civil society, policymakers, financial actors, employees, and local communities. De Martino (2021) argues that sustainable port development requires collaboration and stakeholder interaction across both the supply chain and the institutional environment. This means that Open Innovation in ports must be assessed not only in terms of operational efficiency, but also in relation to sustainability-oriented value creation.

Despite growing attention to smart ports, Port 4.0, digital platforms, environmental innovation and port innovation ecosystems, the literature remains fragmented. Existing studies provide valuable evidence on specific cases, technologies, or governance arrangements, but there remains limited understanding of how Open Innovation is operationalised across different types of European port ecosystems. In particular, less attention has been given to how different governance configurations — such as distributed innovation ecosystems, institutional intermediaries, smart-port strategies, territorial Blue Economy approaches and capacity-building initiatives in smaller ports — shape the coordination role of Open Innovation.

This paper addresses this gap by examining Open Innovation as a coordination mechanism in European port ecosystems. The guiding research question is: How is Open Innovation operationalised as a coordination mechanism across different European port ecosystem configurations?

The objective of the paper is to analyse how different port ecosystems organise Open Innovation and how these configurations support coordination, sustainability-oriented value creation and innovation performance. To achieve this objective, the study adopts a semi-structured literature review combined with a qualitative cross-case comparative synthesis. The analysis focuses on four port-specific cases — Rotterdam, Valencia, Barcelona and Motril-Granada — complemented by an aggregated comparative category of small and medium-sized Baltic ports. These cases are not treated as statistically representative units but as analytically distinct configurations that allow for comparison across different conditions of scale, governance capacity, institutional intermediation, digital readiness, and sustainability orientation.

The paper makes three contributions. First, it contributes to Open Innovation and port innovation literature by conceptualising Open Innovation as an ecosystem-level coordination mechanism rather than merely a set of collaborative practices or external knowledge flows. Second, it develops a comparative interpretation of different Open Innovation configurations in European port ecosystems, showing how scale, governance capacity, institutional support, digital infrastructure and strategic orientation shape innovation pathways. It proposes a conceptual framework that links enabling conditions, Open Innovation mechanisms, coordination functions, contextual constraints and sustainability-oriented value creation. In doing so, the paper provides a basis for future empirical research on how Open Innovation can support sustainable transformation in port systems.

The remainder of the paper is organised as follows. Section 2 develops a theoretical background, discussing Open Innovation, Sustainable Open Innovation, port innovation ecosystems, network coordination, sustainable value creation and governance. Section 3 presents the methodological approach. Section 4 provides comparative case synthesis and proposes a conceptual framework. Section 5 discusses the main findings, theoretical and practical implications, limitations and future research directions. Section 6 concludes the paper.

2. THEORETICAL BACKGROUND

2.1. OPEN INNOVATION AND SUSTAINABLE OPEN INNOVATION

Open Innovation has become one of the most influential perspectives in innovation management. Initially developed to explain how firms can purposively use internal and external knowledge flows to accelerate innovation, the concept challenged the closed innovation model by arguing that valuable knowledge is widely distributed and that organisations should combine internal capabilities with external ideas, technologies and market pathways (Chesbrough, 2003; Dahlander & Gann, 2010; West et al., 2006). In this sense, innovation is no longer conceived as an exclusively internal process, but as the outcome of interactions between organisations and their external environments.

The literature commonly distinguishes between inbound, outbound, and coupled Open Innovation. Inbound Open Innovation refers to the use of external ideas, knowledge and technologies within the organisation, whereas outbound Open Innovation concerns the external exploitation of internally developed knowledge. Coupled Open Innovation combines both directions through collaborative arrangements, partnerships, joint development projects and knowledge-sharing processes (Enkel et al., 2009, 2011; Lichtenthaler, 2011). More recent contributions have expanded Open Innovation beyond the firm level, emphasising inter-organisational networks, ecosystems and policy settings as relevant

levels of analysis (Bogers et al., 2018; West & Bogers, 2017). For port ecosystems, this coupled, ecosystem-level dimension is particularly relevant, since innovation often emerges from interactions among port authorities, terminal operators, logistics firms, technology providers, universities, research centres, start-ups and public institutions.

However, applying Open Innovation to complex, mature sectors require caution. Open Innovation should not be reduced to the presence of start-ups, incubators or informal collaboration. In mature industries, innovation may depend not only on weak ties that provide access to novel knowledge, but also on strong ties that enable trust, repeated interaction and the exchange of complex knowledge. Kazemargi et al. (2022) show that firms in mature industries can combine strong and weak supply ties to enhance both exploration and exploitation, thereby challenging the assumption that exploratory Open Innovation depends only on weak external relationships. This insight is particularly relevant for ports, where long-standing relationships, regulatory constraints and operational interdependencies shape the conditions under which openness can generate value.

More recently, the relationship between Open Innovation and sustainability has attracted growing attention. Sustainability challenges are systemic, multi-level and difficult to address through isolated organisational action. As a result, Open Innovation has increasingly been viewed as a potential mechanism for mobilising distributed knowledge and coordinating stakeholders around environmental and societal goals. Kimpimäki et al. (2022) argue that research on Sustainable Open Innovation remains fragmented, but that a multi-level understanding is needed to connect individual, organisational, city and regional levels of innovation. This is highly relevant to port ecosystems, which are simultaneously logistics infrastructures, business networks, urban interfaces, regional development assets and environmental pressure points.

Sustainable Open Innovation, therefore, extends the logic of openness by explicitly linking knowledge flows to sustainability-oriented outcomes (Adams et al., 2016). It implies that collaborative innovation should not only improve competitiveness or operational efficiency, but also contribute to environmental performance, social value and long-term resilience. Lippolis et al. (2023), for example, show that Open Innovation can act as a catalyst for sustainability when it is supported by open leadership, stakeholder engagement, organisational permeability and a strategic approach to corporate social responsibility. In port ecosystems, this means that Open Innovation must be assessed not only by the number of partnerships or technologies adopted, but also by its capacity to support sustainable transformation across the wider ecosystem.

This perspective is aligned with the broader literature on sustainability-oriented innovation and open eco-innovation, which emphasises that innovation should contribute not only to economic performance, but also to environmental and social value, while recognising the challenges of creating and capturing value in multi-actor sustainability-oriented networks (Adams et al., 2016; Garcia et al., 2019; Hermann & Wigger, 2017; Costa & Matias, 2020).

Building on these foundations, this paper conceptualises Open Innovation as an ecosystem-level coordination mechanism. Beyond a firm-centred perspective, Open Innovation is understood here as the process through which purposive knowledge flows, collaborative arrangements and boundary-spanning interactions are used to align heterogeneous actors, resources, standards, digital infrastructures and sustainability objectives across a port ecosystem (Adner, 2017; Bogers et al., 2018; West & Bogers, 2017; Ha et al., 2026). In port contexts, this coordination role is particularly critical because the adoption of innovation depends heavily on interoperability, co-opetition, standardisation, and multi-actor governance arrangements (Roumboutsos et al., 2022; Tijan et al., 2021; Vanelslander et al., 2019).

This definition also clarifies the boundary between related concepts. Open Innovation dif-

fers from general collaboration because it is specifically oriented towards innovation-related knowledge mobilisation and the purposeful use of knowledge flows (Chesbrough, 2003; Dahlander & Gann, 2010; Enkel et al., 2009). It differs from port governance in that it does not primarily concern formal authority structures, institutional mandates, or the allocation of decision rights, although it is shaped by them (de Langen et al., 2020; Zhang et al., 2019; Alsharaideh et al., 2026). Finally, it differs from value creation in that coordination is treated here as the alignment process itself, whereas value creation refers to the operational, environmental, social, and territorial outcomes generated by that alignment (De Martino, 2021; Tsvetkova & Hellström, 2022).

2.2. PORT INNOVATION ECOSYSTEMS AND NETWORK COORDINATION

Ports are no longer merely physical interfaces between sea and land. They have become complex innovation ecosystems embedded in global supply chains, regional economies and urban systems. A port ecosystem includes port authorities, terminal operators, shipping lines, logistics service providers, hinterland transport actors, customs authorities, technology firms, research institutions, regulators, municipalities and local communities. These actors are linked through flows of cargo, information, capital, knowledge and regulation. As such, port innovation is rarely the result of isolated action by a single organisation; it depends on the coordination of multiple actors with different interests, capabilities and incentives.

The literature on port innovation shows that innovation in this sector is multidimensional. Vanelslander et al. (2019) propose a typology of port-related innovation and show that innovation initiatives in the port sector often combine technological, organisational, managerial and cultural dimensions. Their analysis of 75 port-related innovation initiatives also indicates that collaborative innovation remains limited, but that co-innovation is likely to become increasingly important for the future of maritime and port-related innovation. This suggests that the key issue is not simply whether ports innovate, but how innovation is organised and coordinated across the port ecosystem.

Coordination is especially important because ports display characteristics of network industries. Their value depends on interoperability, compatibility, information exchange, hinterland connectivity, standards and the ability to synchronise operations across multiple actors. Roumboutsos et al. (2022) argue that ports, as nodes in wider transport networks, need to be analysed in relation to network-industry characteristics. Their study of Electronic Data Interchange and all-weather terminal cases shows that innovation uptake is shaped by co-opetition, imitation, Open Innovation and standardisation. This is particularly relevant for digital innovation, where isolated technological solutions may fail to generate systemic value if they are not interoperable or adopted by the wider port community.

From this perspective, Open Innovation in ports is not merely a voluntary managerial choice. It is structurally linked to the interdependent nature of port operations. Digital platforms, Port Community Systems, smart-port applications, blockchain, Internet of Things technologies and real-time data exchange require collective adoption, trust, data-sharing protocols and institutional arrangements. Without coordination, digitalisation may increase fragmentation rather than reduce it. Conversely, when supported by collaborative governance and shared standards, digital infrastructures can enhance information flows, reduce operational uncertainty and improve the synchronisation of maritime logistics chains.

The ecosystem perspective also helps to distinguish different configurations of port innovation. Mendes Constante et al. (2023), in their comparative analysis of Rotterdam and Valencia, show that port innovation ecosystems may differ substantially in their structure and governance. Rotterdam is characterised by a more distributed and connected ecosys-

tem, while Valencia presents a more centralised model in which Fundación Valenciaport plays a strong intermediary role. This distinction is important because it shows that Open Innovation does not have a single organisational form. It may be distributed across multiple actors, mediated by an institutional intermediary, driven by the port authority, organised through public–private partnerships, or embedded in territorial development strategies.

Business model innovation is another important dimension of port ecosystem transformation. Henríquez et al. (2022) analyse the Port of Barcelona and show how Industry 4.0 technologies can drive innovation in seaport business models through technology-push and market-pull mechanisms. Their study connects the smart-port and Port 4.0 concepts with data-driven services, stakeholder integration, strategic connectivity and new value creation. This reinforces the idea that digital innovation in ports should not be treated solely as technological adoption but as a reconfiguration of how ports create, deliver, and capture value. Recent evidence from maritime container shipping also highlights that digital transformation depends on dynamic capabilities rather than on technology deployment alone (Wohlleber et al., 2024).

At the same time, not all port ecosystems possess the same resources or maturity. Small and medium-sized ports often face limitations in digital readiness, human capital, financial resources, and absorptive capacity. Evidence from small and medium-sized Baltic ports shows that digital transformation in such contexts depends on capacity-building, organisational learning and cross-border cooperation. This makes it necessary to analyse Open Innovation in relation to port scale, ecosystem maturity and institutional capacity. Smaller ports may not replicate the innovation models of large hubs such as Rotterdam or Barcelona, but they may develop more adaptive and context-sensitive forms of collaborative innovation.

In summary, port innovation ecosystems require coordination mechanisms that align actors, technologies, and institutions. Open Innovation can perform this role by enabling knowledge sharing, collaborative experimentation, institutional intermediation, standardisation, and collective value creation. However, its effectiveness depends on the governance configuration of each port ecosystem and on the capacities available to transform openness into coordinated action.

2.3. SUSTAINABLE VALUE CREATION AND GOVERNANCE IN PORT ECOSYSTEMS

Sustainability has become a central dimension of contemporary port development. Ports are increasingly expected to reduce environmental externalities, contribute to decarbonisation, support circular economy strategies, improve port–city relations and participate in broader Blue Economy and energy-transition agendas. These expectations extend the role of ports beyond cargo handling and operational efficiency, requiring attention to the economic, environmental, social and territorial consequences of port activity.

The literature on sustainable value creation provides a useful basis for analysing this transformation. Conventional approaches to value creation tend to focus on cost, service quality, flexibility, delivery reliability, operational performance and customer satisfaction. By contrast, sustainability-oriented approaches expand the analysis to consider with whom and for whom value is created, how different stakeholders participate, and how economic, social, and ecological outcomes are distributed. De Martino (2021) conceptualises sustainable value creation in ports through a relational perspective, distinguishing between the supply chain level and the institutional environment level. This distinction is relevant because port sustainability depends not only on port operators and customers but also on policymakers, local communities, financial actors, civil society, and other institutional stakeholders.

Port governance is closely connected to this debate, as it shapes the institutional conditions under which sustainable value creation occurs. Governance concerns the allocation of authority, responsibilities, decision rights and coordination mechanisms among public and private actors. In a comprehensive review of 118 studies, Zhang et al. (2019) examine how and why ports are governed, identifying devolution and re-centralisation as major institutional tools and highlighting the importance of linking governance arrangements to strategic port objectives. This perspective is particularly useful for the present study as Open Innovation in ports depends on how institutional settings enable or constrain collaboration among heterogeneous actors.

Climate change has further expanded the scope of port governance. Ports are increasingly involved in mitigation and adaptation agendas, requiring coordination across wider supply chains. Monios et al. (2024) propose an updated conception of port governance under climate change, structured around four stakeholder groups: public policy, commercial actors, indirect actors and international shipping governance. Their analysis stresses that future port governance requires integrated mechanisms to share uncertain, unevenly distributed climate costs and benefits. For open innovation, this is critical because climate-oriented transformation demands collective investment, shared risk, cross-sector knowledge and long-term coordination.

Blue Economy strategies and ecosystem-level initiatives illustrate this territorial value-creation logic. The Motril-Granada case, for instance, demonstrates how port strategy can be structured around connectivity, clean energy, waste management and community relations, showing how sustainability-oriented innovation can be embedded in local development within smaller port contexts (Seisdedos & Carrasco, 2020). This confirms that innovation relies on actors that remain organisationally autonomous yet operationally interdependent—a finding consistent with maritime-cluster research on value co-creation and Open Innovation (Rupo et al., 2018).

Taken together, these contributions demonstrate that sustainable value creation in port ecosystems requires alignment across governance arrangements, stakeholder relationships, institutional conditions and ecosystem-level coordination. For this review, these elements provide the theoretical foundation for understanding Open Innovation not simply as inter-firm collaboration, but as a governance-shaped process oriented toward sustainable value creation. Accordingly, the comparative synthesis developed in this paper evaluates how different port ecosystems configure Open Innovation across institutional intermediation, stakeholder engagement, digital transformation, sustainability orientation and coordination capacity.

3.METHODOLOGICAL APPROACH

This study adopts a semi-structured literature review combined with a qualitative cross-case comparative synthesis. This methodological design is appropriate because the research question addresses a conceptually broad and interdisciplinary topic: the role of Open Innovation as a coordination mechanism in European port ecosystems. The topic lies at the intersection of innovation management, maritime logistics, port governance, digital transformation, sustainability transitions and regional development. As a result, the relevant evidence is dispersed across different research traditions, including conceptual studies, case studies, comparative analyses, review articles and sector-specific contributions.

Literature reviews are particularly useful for mapping, organising and critically interpreting fragmented bodies of knowledge, especially when a field is interdisciplinary or conceptually emerging (Snyder, 2019; Tranfield et al., 2003). Unlike narrowly systematic reviews, semi-structured and integrative reviews allow researchers to combine trans-

parency in search and selection procedures with interpretative flexibility in synthesising heterogeneous evidence (Grant & Booth, 2009; Torraco, 2005; Wong et al., 2013). This approach is therefore suitable for analysing Open Innovation in port ecosystems, where the evidence combines theoretical contributions, qualitative case studies, review articles and sector-specific analyses.

The literature on Open Innovation in port ecosystems is predominantly qualitative, conceptual, and case-based, combining diverse theoretical perspectives, case-study designs, and context-specific evidence. For this reason, statistical aggregation would not be appropriate. Instead, the study develops an interpretative synthesis of secondary evidence to identify how Open Innovation is configured across different port contexts and how it contributes to coordination, sustainability-oriented value creation, and ecosystem-level innovation. This approach is consistent with qualitative synthesis, which seeks to integrate findings from heterogeneous studies while preserving contextual meaning (Chenail, 2016; Snyder, 2019; Thomas & Harden, 2008).

The methodological design involved four stages: (1) literature identification and selection; (2) case selection; (3) development of analytical dimensions; and (4) qualitative cross-case synthesis. The process is summarised in Table 1.

Table 1. Research design

Element	Specification
Review type	Semi-structured literature review with qualitative cross-case comparative synthesis
Methodological rationale	Appropriate for interdisciplinary and heterogeneous bodies of literature combining conceptual, qualitative, review-based and case-study evidence
Main databases	Scopus and Web of Science
Supplementary search	Google Scholar and backward/forward reference checking
Search period	2014–2026
Final search date	20 March 2026
Language	English
Search fields	Title, abstract and keywords
Main document type	Peer-reviewed journal articles
Supplementary evidence	Academically grounded case-based studies and selected institutional sources when used in the reviewed literature
Search string	(“open innovation” OR “collaborative innovation” OR “innovation ecosystem” OR “co-creation”) AND (“sustainability” OR “sustainable development” OR “green port” OR “circular economy” OR “blue economy”) AND (“maritime port” OR “seaport” OR “port ecosystem” OR “port authority”)
Inclusion criteria	Studies addressing Open Innovation, collaborative innovation, innovation ecosystems, port governance, smart ports, digitalisation, Blue Economy, sustainability or value creation in maritime or port contexts
Exclusion criteria	Studies unrelated to maritime ports; purely technical studies without governance or innovation implications; inaccessible full texts; studies lacking sufficient relevance to the research question
Screening procedure	Title and abstract screening; full-text eligibility assessment; final selection according to conceptual, methodological and case-based relevance
Evidence organisation	Core theoretical literature; port innovation and governance literature; selected port-specific case studies; complementary evidence on small and medium-sized ports
Main cases	Rotterdam, Valencia, Barcelona and Motril-Granada
Aggregated comparative category	Small and medium-sized Baltic ports
Analytical dimensions	Open Innovation mechanisms; governance model; digital infrastructure; sustainability orientation; coordination mechanism; value creation; barriers and limitations
Synthesis method	Qualitative cross-case comparative synthesis
Type of generalisation	Analytical rather than statistical generalisation

Source: Authors’ elaboration

3.1. LITERATURE IDENTIFICATION AND SELECTION

The evidence base was constructed through a semi-structured selection of academic studies addressing Open Innovation, collaborative innovation, innovation ecosystems, port innovation, maritime logistics, port governance, digital transformation, smart ports, Blue Economy and sustainable value creation. The selection prioritised peer-reviewed journal articles and academically grounded case studies that provided conceptual, methodological or empirical relevance to the research question.

The literature search was conducted in Scopus and Web of Science. These databases were selected because they provide broad coverage of peer-reviewed research in innovation management, transport studies, maritime logistics, sustainability and governance. Google Scholar was used only as a supplementary tool to identify additional relevant works and to support backwards and forward reference checking. Such supplementary search strategies are commonly used in review studies to improve coverage when relevant evidence is dispersed across disciplines or when terminology varies across research traditions (Booth et al., 2016; Snyder, 2019).

The following Boolean string was applied to title, abstract, and keywords:

("open innovation" OR "collaborative innovation" OR "innovation ecosystem" OR "co-creation") AND ("sustainability" OR "sustainable development" OR "green port" OR "circular economy") AND ("maritime port" OR "seaport" OR "port ecosystem" OR "port authority")

The search covered the period from 2014 to 2026. This time window was selected because the last decade has seen intensified scholarly attention to digitalisation, sustainability transitions, smart ports, Blue Economy strategies and ecosystem-based innovation in maritime logistics. The final search was conducted on 20 March 2026.

The selection process followed three screening stages. First, titles and abstracts were screened to remove studies unrelated to ports, maritime logistics or innovation ecosystems. Second, full texts were assessed to determine whether each study contributed substantively to the research question. Third, the remaining studies were organised according to their conceptual and empirical relevance to comparative synthesis. This staged screening logic is consistent with review methodologies that require explicit selection and exclusion criteria to improve transparency and replicability (Booth et al., 2016; Tranfield et al., 2003).

Studies were included when they met at least one of the following criteria:

- they addressed Open Innovation, collaborative innovation, innovation ecosystems, co-creation or knowledge-sharing in port, maritime or logistics contexts;
- they examined port governance, smart ports, port digitalisation, Blue Economy, sustainability or value creation in ways relevant to innovation coordination;
- they provided case-based evidence on one of the selected port ecosystems or on comparable European port contexts;
- they contributed to the development of one or more analytical dimensions used in cross-case synthesis.

Studies were excluded when they were unrelated to maritime ports, focused exclusively on technical engineering performance without governance or innovation implications, lacked sufficient conceptual relevance to Open Innovation or port ecosystem coordination, or did not provide enough information to support analytical comparison.

The final evidence base was organised into four categories. The first category included core theoretical contributions on Open Innovation, Sustainable Open Innovation and innovation ecosystems. The second included studies on port innovation, port governance, smart ports and maritime innovation typologies. The third included case-based studies of Rotterdam, Valencia, Barcelona and Motril-Granada. The fourth included complemen-

tary evidence on small and medium-sized ports, with particular attention to Baltic ports, absorptive capacity, capacity-building and digital maturity.

The review process was semi-structured rather than fully systematic. This choice reflects the interdisciplinary and heterogeneous nature of the literature. The objective was not to exhaustively quantify all publications on Open Innovation and ports, but to identify and interpret the most relevant conceptual and case-based evidence for understanding Open Innovation as a coordination mechanism in port ecosystems. This positioning follows integrative review logic, in which the aim is to generate conceptual clarification and theoretical synthesis across diverse literature rather than to aggregate homogeneous empirical effects (Snyder, 2019; Torraco, 2005).

3.2. CASE SELECTION RATIONALE

The comparative synthesis focuses on four port-specific cases — Rotterdam, Valencia, Barcelona and Motril-Granada — complemented by an aggregated comparative category of small and medium-sized Baltic ports. The cases were selected through theoretical and purposive sampling rather than statistical sampling. The objective was to maximise analytical variation across different Open Innovation configurations and to compare how openness is organised under different conditions of scale, institutional maturity, digital infrastructure and sustainability orientation. Theoretical and purposive case selection is appropriate when cases are chosen for their capacity to illuminate theoretical constructs, reveal contrasts and support analytical generalisation (Eisenhardt, 1989; Flyvbjerg, 2006; Stake, 1995; Yin, 2018).

Rotterdam was selected because it represents a large European hub with a distributed and experimental innovation ecosystem. The literature associates Rotterdam with start-up facilitation, port-city innovation, serious games, digital logistics experimentation, collaborative learning and ecosystem orchestration. It is therefore useful for analysing Open Innovation in a mature, diversified and highly connected port ecosystem.

Valencia was selected because it exemplifies an institutionally mediated innovation ecosystem. In the literature, the role of Fundación Valenciaport is particularly relevant, as it operates as an intermediary organisation connecting the port authority, firms, universities, research actors and public institutions. Valencia therefore provides evidence of how Open Innovation can be structured through institutional intermediation, applied research and knowledge transfer.

Barcelona was selected because it represents a smart-port and business-model innovation pathway. Studies on the Port of Barcelona connect Industry 4.0 technologies, Port 4.0 strategies, strategic connectivity, smart-port capabilities and business model innovation. Barcelona is therefore relevant for analysing how digital technologies and long-term strategic planning shape Open Innovation and value creation in port ecosystems.

Motril-Granada was selected as a contrasting smaller-port case. Its relevance lies in how Open Innovation is connected to the Blue Economy, territorial development, sustainability, port-community engagement, and local research collaboration. Motril-Granada provides an analytically useful contrast with larger, more institutionally mature innovation ecosystems.

Small and medium-sized Baltic ports were included as an aggregated comparative category rather than as individual port-specific cases. This category provides complementary evidence on resource-constrained port ecosystems, especially regarding digital maturity, absorptive capacity, human capital, organisational learning and cross-border capacity-building. Its inclusion helps avoid treating Motril-Granada as the only representation of smaller-port contexts and strengthens the analysis of capacity-building constraints in small and medium-sized port ecosystems.

The selected cases are not symmetrical empirical units with identical evidential depth. Rotterdam, Valencia and Barcelona are more extensively documented in the literature, whereas Motril-Granada and the Baltic ports provide more specific or aggregated evidence. This asymmetry is acknowledged as a methodological limitation. However, it is also analytically useful because the study does not aim to rank ports or compare equivalent performance indicators. Instead, it compares different configurations through which Open Innovation is discussed and operationalised in European port ecosystems. This approach is consistent with comparative case synthesis, in which analytical value derives from theoretically meaningful contrasts rather than statistical representativeness (Eisenhardt & Graebner, 2007; Yin, 2018).

The case selection logic is summarised in Table 2. The cases were selected to represent analytically distinct Open Innovation configurations rather than to be statistically representative of port categories.

Table 2. Case selection rationale

Case / comparative category	Type of evidence	Open Innovation configuration	Analytical relevance
Rotterdam	Port-specific case	Distributed and experimental innovation ecosystem	Represents a large and mature European hub where Open Innovation is associated with start-up facilitation, port-city innovation, collaborative experimentation and digital logistics
Valencia	Port-specific case	Institutional-intermediated innovation ecosystem	Illustrates how an intermediary organisation can support knowledge transfer, applied research, stakeholder engagement and innovation orchestration
Barcelona	Port-specific case	Smart-port and business-model innovation ecosystem	Shows how digital technologies, strategic connectivity and Port 4.0-oriented initiatives can shape innovation pathways and value creation
Motril-Granada	Port-specific case	Blue Economy and territorial innovation ecosystem	Provides a contrasting smaller-port case where Open Innovation is linked to sustainability, territorial development, local research collaboration and port-community engagement
Small and medium-sized Baltic ports	Aggregated comparative category	Capacity-building and resource-constrained innovation ecosystems	Provides complementary evidence on digital maturity, absorptive capacity, human capital, organisational learning and resource constraints in smaller port ecosystems

Source: Authors' elaboration

3.3. ANALYTICAL STRATEGY AND COMPARATIVE DIMENSIONS

The selected studies were analysed through qualitative cross-case comparative synthesis. Cross-case analysis is useful when the objective is to identify patterns, similarities and differences across cases while retaining sensitivity to contextual specificities (Miles et al., 2014; Yin, 2018). In case-based research, comparison can support theory development by

allowing constructs to be examined across contrasting empirical settings (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). In this study, the method was used to compare how Open Innovation is operationalised across different European port ecosystem configurations and to examine its relationship to coordination and sustainability-oriented value creation.

The analytical procedure followed an abductive logic. The theoretical background informed the initial analytical dimensions, while the case-based literature refined them in the context of port ecosystems. Abductive reasoning is appropriate when research seeks to refine conceptual understanding by moving iteratively between theory and empirical material, rather than testing predefined hypotheses or developing theory from a blank slate (Dubois & Gadde, 2002; Timmermans & Tavory, 2012).

To address the study's conceptual focus, the analysis was structured around seven dimensions: Open Innovation mechanisms, governance model, digital infrastructure, sustainability orientation, coordination mechanism, value creation, and barriers and limitations.

The first dimension, Open Innovation mechanisms, refers to the specific practices through which knowledge, ideas, technologies and resources circulate across organisational boundaries. These may include start-up programmes, research partnerships, institutional intermediaries, collaborative projects, open data initiatives, digital platforms, public–private partnerships and Blue Economy projects.

The second dimension, governance model, captures the institutional arrangements through which innovation is organised. This includes distributed governance, intermediary-led models, port-authority-led strategies, smart-port governance and territorial/community-oriented governance.

The third dimension, digital infrastructure, refers to the technologies and data systems that support innovation and coordination. These include Port Community Systems, smart-port platforms, Internet of Things technologies, blockchain, data-sharing systems, digital twins and real-time information exchange.

The fourth dimension, sustainability orientation, captures how innovation is linked to environmental, social and territorial objectives. This includes decarbonisation, clean energy, circular economy, Blue Economy, green-port strategies, port-city integration and local development.

The fifth dimension, coordination mechanism, refers to the processes through which Open Innovation helps align actors, resources, technologies and objectives. These mechanisms include standardisation, co-opetition, institutional intermediation, stakeholder alignment, collaborative learning, knowledge transfer, interoperability, and shared agenda-setting.

The sixth dimension, value creation, captures the types of outcomes associated with Open Innovation. These may include operational efficiency, innovation performance, knowledge creation, stakeholder value, environmental improvement, territorial development and ecosystem resilience.

The seventh dimension, barriers and limitations, captures factors that constrain the effectiveness of Open Innovation. These include fragmented governance, limited standardisation, institutional inertia, weak absorptive capacity, resource constraints, uneven digital maturity, limited evaluation frameworks and stakeholder misalignment.

These dimensions served as interpretative lenses for organising comparative synthesis and differentiating evidence from the reviewed literature and the authors' analytical interpretation. This distinction is important because the study relies on secondary sources and does not claim to produce primary empirical findings. In qualitative synthesis, such interpretative categories help organise heterogeneous evidence while preserving contextual meaning and avoiding unsupported statistical inference (Snyder, 2019; Thomas &

Harden, 2008; Torraco, 2005).

The analytical dimensions used for the cross-case synthesis are presented in Table 3. These dimensions were used as interpretative lenses rather than as rigid quantitative coding categories.

Table 3. Analytical dimensions for the cross-case synthesis

Analytical dimension	Definition	Focus of comparison	Key supporting literature
Open Innovation mechanisms	Practices through which knowledge, ideas, technologies and resources circulate across organisational boundaries	Start-up programmes; research partnerships; institutional intermediaries; open data; digital platforms; public–private projects	Chesbrough (2003); Chesbrough & Bogers (2014); Enkel et al. (2009); Dahlander & Gann (2010)
Governance model	Institutional arrangements through which innovation is organised and coordinated	Distributed governance; intermediary-led governance; port-authority-led strategy; territorial or community-oriented governance	de Langen et al. (2020); Zhang et al. (2019); Tijan et al. (2021); Vanelslander et al. (2019)
Digital infrastructure	Technologies and data systems that support innovation, coordination and information exchange	Port Community Systems; smart-port platforms; IoT; blockchain; digital twins; real-time information exchange	Carlan et al. (2016); Costa & Matias (2020); Tijan et al. (2021); Cavalli et al. (2021); Roumboutsos et al. (2022)
Sustainability orientation	The extent to which innovation is connected to environmental, social and territorial objectives	Decarbonisation; clean energy; circular economy; Blue Economy; green-port strategies; port-city integration	Adams et al. (2016); Garcia et al. (2019); Costa & Matias (2020); De Martino (2021); Monios et al. (2024)
Coordination mechanism	Processes through which actors, resources, standards, technologies and objectives are aligned	Standardisation; interoperability; co-opetition; stakeholder alignment; collaborative learning; shared agenda setting	Adner (2017); Roumboutsos et al. (2022); Roukouni et al. (2020); Vanelslander et al. (2019)
Value creation	Outcomes generated or expected from Open Innovation processes	Operational efficiency; knowledge creation; environmental improvement; stakeholder value; territorial development; ecosystem resilience	De Martino (2021); Tsvetkova & Hellström (2022); Rupo et al. (2018); Jansen & Hein (2023)
Barriers and limitations	Factors that constrain the effectiveness or scalability of Open Innovation	Governance fragmentation; limited resources; weak absorptive capacity; institutional inertia; uneven digital maturity; lack of evaluation frameworks	Kazemargi et al. (2022); Meyer et al. (2021, 2023, 2024); Wohlleber et al. (2024); Acciaro & Sys (2020)

Source: Authors' elaboration

3.4. METHODOLOGICAL SCOPE AND LIMITATIONS

The methodological approach has several limitations. First, the study relies on secondary evidence rather than primary empirical data. It does not include interviews, direct observation or original fieldwork. As a result, the analysis depends on the availability, depth and methodological quality of existing studies. This limitation is explicitly acknowledged and addressed by positioning the paper as a review-based comparative synthesis rather than an empirical case study.

Second, the selected cases differ in scale, institutional maturity, geographical context and evidential depth. Rotterdam, Valencia and Barcelona are more extensively documented in the literature, whereas Motril-Granada and the Baltic ports provide more specific or aggregated evidence. This limits direct comparability, but it is consistent with the study's objective of identifying different configurations of Open Innovation rather than comparing equivalent empirical units.

Third, the aggregated category of small and medium-sized Baltic ports is not directly equivalent to the four port-specific cases. It is included as complementary evidence to strengthen the analysis of resource-constrained and capacity-building-oriented port ecosystems. The category should therefore be interpreted as a comparative analytical category, not as a single case equivalent to Rotterdam, Valencia, Barcelona or Motril-Granada.

Fourth, the study does not measure the direct performance effects of Open Innovation. Claims regarding coordination, value creation, and sustainability are drawn from the reviewed literature and the comparative synthesis. Therefore, the findings should be understood as analytical generalisations rather than statistical generalisations. This form of generalisation is appropriate in case-based and review-based research when findings are used to refine concepts, identify mechanisms or generate propositions for future research rather than infer population-level regularities (Yin, 2018).

Finally, the conceptual framework emerging from the study should be treated as a basis for future empirical testing. It identifies how Open Innovation may function as a coordination mechanism across different port ecosystem configurations, but further research using interviews, surveys, longitudinal case studies, or mixed methods would be required to empirically validate and refine the framework.

4. OVERVIEW OF THE COMPARATIVE CASES

The comparative synthesis examines four port-specific cases — Rotterdam, Valencia, Barcelona and Motril-Granada — together with an aggregated comparative category of small and medium-sized Baltic ports. These cases represent different configurations of Open Innovation in European port ecosystems, rather than a statistically representative sample of European ports. The purpose of the comparison is to identify how Open Innovation mechanisms are organised across different port contexts and how they relate to governance arrangements, digital infrastructures, sustainability orientation and coordination capacity.

The evidence base suggests that Open Innovation in port ecosystems is strongly shaped by contextual conditions. Large hub ports, such as Rotterdam and Barcelona, tend to have more diversified innovation ecosystems, greater access to technological infrastructures and stronger connections with start-ups, research actors and global logistics networks. Valencia offers a distinctive configuration in which institutional intermediation plays a central role. Motril-Granada provides a smaller-port case in which innovation is linked to Blue Economy, territorial development and sustainability-oriented port-community engagement. The Baltic small and medium-sized ports provide complementary evidence on capacity-building challenges, digital maturity and resource constraints in smaller port ecosystems.

The cases are therefore treated as analytically distinct configurations. Rotterdam is examined as a distributed and experimental innovation ecosystem; Valencia as an institutional-intermediated model; Barcelona as a smart-port and business-model innovation pathway; Motril-Granada as a Blue Economy and territorial innovation configuration; and the Baltic small and medium-sized ports as a capacity-building and resource-constrained category.

4.1. OPEN INNOVATION CONFIGURATIONS ACROSS PORT ECOSYSTEMS

Rotterdam is frequently presented in the literature as one of the most mature European examples of a port innovation ecosystem. The port's innovation configuration is associated with a distributed set of actors, including the Port of Rotterdam, the municipality, research organisations, start-up accelerators, knowledge platforms and private companies. Mendes Constante et al. (2023) describe Rotterdam's innovation ecosystem as "distributed and connected", contrasting it with Valencia's more centralised configuration.

A central feature of Rotterdam is the combination of experimentation, research cooperation and entrepreneurship. The literature identifies several ecosystem components in Rotterdam, including training infrastructure, talent recruitment, research facilities, test environments, support for start-ups and scale-ups, venture capital, innovation-oriented regulations and meeting spaces for entrepreneurs. Mendes Constante et al. (2023) also note the role of initiatives such as the Port Innovation Barometer, World Port Hackathon and SmartPort Summit in fostering an innovation-oriented culture. Start-up facilitation and port-city innovation ecosystems have also been discussed as mechanisms for connecting entrepreneurial activity with port development, as illustrated by comparative work on Montreal and Rotterdam (Witte et al., 2018).

Rotterdam also provides evidence of collaborative learning mechanisms. Studies on serious games and sustainable logistics innovation show how experimental tools can be used to reveal stakeholder tensions, support learning and explore adoption barriers in complex logistics systems (Roukouni et al., 2020). In this respect, Rotterdam illustrates a form of Open Innovation in which experimentation and ecosystem interactions are used to address uncertainty and interdependence.

From a coordination perspective, Rotterdam's configuration suggests that Open Innovation may operate through multiple distributed channels rather than through a single institutional intermediary. The strength of this model lies in the density of its ecosystem and in the availability of specialised actors, platforms and experimentation spaces. At the same time, distributed ecosystems may also require strong alignment mechanisms to prevent fragmentation and to ensure that innovation initiatives address shared port-system challenges rather than isolated organisational interests

4.2. VALENCIA: INSTITUTIONAL-INTERMEDIATED INNOVATION ECOSYSTEM

Valencia represents a contrasting configuration. While Rotterdam is characterised as distributed and connected, Valencia's port innovation ecosystem is more centralised and strongly mediated by Fundación Valenciaport. Mendes Constante et al. (2023) describe Fundación Valenciaport as a private, non-profit entity created in 2004 by the Port Authority of Valencia together with port cluster companies, associations, universities, the city, the region and other institutions in the port community. Its creation is presented as a deliberate effort to promote an innovation culture in Valencia's port cluster.

The role of Fundación Valenciaport is central to Valencia's Open Innovation configuration. It supports applied research, innovation projects, training, internationalisation and cooperation within the port-logistics community. The evidence indicates that developing the innovation ecosystem is a key action in the port cluster's innovation plan, highlighting

the importance of institutions in leading port clusters, aligning the port community, and establishing a common agenda on human capital, research, and innovation.

This model is analytically relevant because it illustrates how Open Innovation can be organised through institutional intermediation. In Valencia, the intermediary institution serves as a bridge among the port authority, firms, research organisations, universities, and other ecosystem actors. This reduces coordination complexity by providing a focal structure for knowledge transfer, project development and collaborative learning.

However, the literature also points to possible limitations. Mendes Constante et al. (2023) identify cultural constraints, including a limited culture of innovation, a short-term orientation, and a need for stronger collaboration. These limitations suggest that institutional intermediation can support Open Innovation but does not automatically eliminate barriers related to organisational culture, long-term commitment or stakeholder alignment.

4.3. BARCELONA: SMART-PORT AND BUSINESS-MODEL INNOVATION PATHWAY

Barcelona represents a configuration in which Open Innovation is closely associated with smart-port development, digital technologies and business model innovation. Examining the Port of Barcelona, Henríquez et al. (2022) analyse how Industry 4.0 technologies drive business model innovation, linking the evolution of seaports—from simple sea–land interfaces to value-adding entities in global supply chains—with concepts such as fifth-generation ports, smart ports and Port 4.0.

The Barcelona case is particularly useful for analysing the relationship between technology adoption and value creation. Henríquez et al. (2022) argue that Industry 4.0 technologies affect seaport business models through technology-push and market-pull mechanisms, reshaping how value is created, distributed and captured. In this sense, Barcelona's strategy cannot be reduced to technological adoption alone; it represents a comprehensive reconfiguration of the port's role, services, stakeholder relationships and value proposition. This perspective aligns with studies on the Port of Barcelona's Vision 2040, which conceptualise the port of the future through long-term strategic transformation and business model innovation (Garrido Salsas et al., 2022).

Furthermore, Barcelona provides key insights for the smart-port dimension of the comparative synthesis. In this context, smartness extends beyond automation to encompass enhanced Port Community Systems, real-time data interchange, digitally enabled synchronisation, port-city integration and sustainability goals (Henríquez et al., 2022).

From an Open Innovation perspective, Barcelona illustrates how digital infrastructures and smart-port strategies can create conditions for stronger stakeholder integration. However, this pathway also depends on the port's ability to align technology adoption with governance, market needs and business model transformation. The case therefore helps clarify that digital transformation becomes relevant to Open Innovation only when it enables new forms of coordination, value creation, and ecosystem interaction.

4.4. MOTRIL-GRANADA: BLUE ECONOMY AND TERRITORIAL INNOVATION CONFIGURATION

Motril-Granada provides a smaller-port case in which innovation is connected to Blue Economy, sustainability and territorial development. Seisdedos & Carrasco (2020) describe the Port of Motril-Granada's Blue Economy strategy as structured around four areas: connections, innovation, sustainability, and Motril itself and its surroundings. The article also states that the port encourages Open Innovation by integrating the private sector with research institutions, technological centres and universities.

The case differs from Rotterdam, Valencia and Barcelona because it is not primarily presented as a large-scale smart-port ecosystem or as a highly institutionalised innovation system. Its relevance lies in the way innovation is embedded in the port's local and territorial development agenda. The evidence indicates that the port seeks to strengthen traditional, emerging, and innovative sectors connected to the Blue Economy, while aligning its activities with European Blue Economy policies.

Motril-Granada also demonstrates sustainability-oriented initiatives. The article identifies activities related to marine and coastal ecosystems, renewable energy, climate change mitigation, energy efficiency and zero-waste processes. It also refers to specific initiatives such as shore connection, biodiversity protection, port reception facilities for waste and cargo residues, and the positioning of the port as a "Blue Port".

In analytical terms, Motril-Granada is best understood as a contrasting case rather than as a direct equivalent to larger ports. It allows the comparison to include a smaller-port configuration in which Open Innovation is linked to local development, port-community involvement, and sustainability-oriented positioning. The case should therefore be interpreted with caution: it illustrates a territorial and Blue Economy-oriented innovation pathway, but it does not provide the same level of evidence on digital maturity, ecosystem density, or institutionalised innovation governance as Rotterdam, Valencia, or Barcelona.

4.5. SMALL AND MEDIUM-SIZED BALTIC PORTS: CAPACITY-BUILDING AND RESOURCE-CONSTRAINED INNOVATION ECOSYSTEMS

The small and medium-sized Baltic ports are included as an aggregated comparative category. This category does not represent a single port-specific case but provides complementary evidence on the conditions under which smaller and medium-sized ports engage with digital transformation and innovation.

Meyer et al. (2021) show that small and medium-sized ports in the Baltic Sea Region are important regional nodes and gateways of economic and social interaction but are also exposed to specific vulnerabilities. They are often located outside major economic centres, only partly included in the TEN-T network, and characterised by lower freight volumes, limited specialisation, outdated infrastructure, a lack of investment, and a demand for new business models.

The evidence also indicates a tension between agility and capacity constraints. Small and medium-sized ports may be more flexible in adapting to new market challenges, but they are constrained by limited human capital and key employee skills. Meyer et al. (2021) therefore propose a cross-border capacity-building framework to support digital transformation in small and medium-sized port ecosystems, drawing on concepts such as absorptive capacity, organisational learning, transformation, resource-based view, dynamic capabilities, Open Innovation and service design.

This aggregated category strengthens the comparative synthesis in two ways. First, it prevents the analysis of smaller ports from relying only on Motril-Granada. Second, it highlights that Open Innovation in smaller and medium-sized ports may depend less on mature innovation infrastructures and more on capacity-building, training, knowledge transfer, and cross-border cooperation. In this sense, the Baltic ports category contributes to understanding how resource-constrained ecosystems may develop innovation capabilities through shared learning and regional collaboration.

4.6. CROSS-CASE SYNTHESIS

The cross-case synthesis indicates that Open Innovation is not operationalised through a single model across European port ecosystems. Instead, the reviewed cases reveal five an-

alytically distinct configurations: distributed experimentation in Rotterdam, institutional intermediation in Valencia, smart-port and business-model innovation in Barcelona, Blue Economy and territorial innovation in Motril-Granada, and capacity-building in small and medium-sized Baltic ports. These configurations were derived from the case-based evidence discussed in Sections 4.1–4.5, including studies on Rotterdam's experimental and ecosystem-oriented innovation practices, Valencia's intermediary-led innovation model, Barcelona's smart-port and business-model innovation pathway, Motril-Granada's Blue Economy strategy, and capacity-building dynamics in small and medium-sized Baltic ports (González-Cancelas et al., 2020; Meyer et al., 2023, 2024; Seisdedos & Carrasco, 2020; Suárez-Gargallo & Zaragoza-Sáez, 2023; Vanelslander et al., 2019).

The comparison should therefore be interpreted as an analytical synthesis of different Open Innovation configurations, rather than as a ranking of port performance. The cases are not symmetrical empirical units with identical evidential depth. Rotterdam, Valencia and Barcelona are more extensively documented in the literature, whereas Motril-Granada and the Baltic ports provide more focused or aggregated evidence. However, this asymmetry is analytically useful because it allows the synthesis to compare how Open Innovation operates under different ecosystem conditions.

A first cross-case pattern concerns the relationship between port scale and innovation configuration. Rotterdam illustrates how large, mature hub ports may support Open Innovation through distributed experimentation, start-up engagement, research platforms, hackathons, serious games, and multiple innovation spaces (Mendes Constante et al., 2023; Roukouni et al., 2020). Valencia shows a different model, in which the innovation ecosystem is more strongly mediated by Fundación Valenciaport, which acts as an institutional intermediary connecting firms, port authorities, universities, research actors and public institutions (Mendes Constante et al., 2023). Barcelona, in turn, illustrates a smart-port pathway in which digital technologies and Port 4.0 strategies are linked to business model innovation. By contrast, Motril-Granada and the Baltic ports suggest that smaller and medium-sized ports may rely less on dense innovation infrastructures and more on territorial collaboration, Blue Economy positioning, skills development and capacity-building. This comparison suggests that the configuration of Open Innovation is shaped by the resources, institutional structures and strategic priorities available within each port ecosystem (Vanelslander et al., 2019; Suárez-Gargallo & Zaragoza-Sáez, 2023; Seisdedos & Carrasco, 2020; Meyer et al., 2023, 2024).

A second pattern concerns the distinction between governance model and coordination mechanism. Governance refers to the institutional arrangements through which innovation is organised, while coordination refers to the process through which actors, resources, standards, technologies and objectives are aligned. Rotterdam's distributed governance requires coordination through ecosystem interaction, experimentation and collaborative learning. Valencia's intermediary-led governance supports coordination through knowledge transfer, project development and institutional intermediation. Barcelona's smart-port governance depends on coordination between technological adoption, business model transformation and stakeholder integration. Motril-Granada's territorial governance requires coordination between port development, local actors, research institutions and Blue Economy objectives. In the Baltic ports, coordination is mainly expressed through cross-border learning, absorptive capacity, and human capital development. Thus, the comparison clarifies that governance provides the institutional setting, whereas coordination concerns the alignment mechanisms through which Open Innovation becomes operational. This distinction is consistent with the ecosystem view of innovation, which emphasises actor interdependence and alignment, and with port

governance literature, which highlights the role of institutional arrangements, decision rights and public–private coordination in port development (Adner, 2017; de Langen et al., 2020; Zhang et al., 2019).

A third cross-case pattern concerns the role of digital infrastructure. In Rotterdam and Barcelona, digitalisation appears as a more central element of the innovation configuration. Rotterdam connects digital logistics, experimentation and ecosystem interaction, while Barcelona links Industry 4.0 technologies, Port Community Systems, strategic connectivity and business model innovation. In Valencia, digitalisation is relevant but is mediated through institutional support, applied research and innovation projects. In Motril-Granada, the dominant logic is not primarily about digital transformation but about the Blue Economy and territorial sustainability. In the Baltic ports, digitalisation appears mainly as a capacity-building challenge, constrained by limited resources, skills gaps and uneven digital maturity. This comparison suggests that digital infrastructure does not automatically produce Open Innovation. Its coordination value depends on whether digital tools are embedded in governance arrangements, stakeholder relationships and shared innovation objectives (Tijan et al., 2021; Roumboutsos et al., 2022; Vanelslander et al., 2019).

A fourth pattern concerns sustainability-oriented value creation. Across cases, sustainability is not a single or uniform outcome. In Rotterdam, sustainability is associated with the energy transition, experimentation in sustainable logistics, and an innovation culture. In Valencia, it is connected to human capital, knowledge transfer and port-logistics innovation. In Barcelona, it is linked to smart-port integration, strategic connectivity and the reconfiguration of value creation through digital technologies. In Motril-Granada, sustainability is expressed through Blue Economy, territorial development, port-community engagement and environmental positioning. In the Baltic ports, sustainability is connected to regional resilience, digital readiness, organisational learning and competitiveness in resource-constrained contexts. The synthesis therefore suggests that sustainable value creation in port ecosystems is multidimensional, including operational, environmental, social, territorial and ecosystem-level outcomes (De Martino, 2021; Monios et al., 2024; Tsvetkova & Hellström, 2022).

A fifth pattern concerns the conditions under which Open Innovation supports coordination. The cases indicate that openness alone is insufficient. Open Innovation becomes a coordination mechanism only when knowledge flows, partnerships, digital infrastructures and collaborative projects are connected to shared objectives and institutionalised interaction. In Rotterdam, the challenge is to align multiple distributed initiatives. In Valencia, the challenge is to expand innovation culture and avoid over-reliance on a central intermediary. In Barcelona, the challenge is to ensure that technology adoption is connected to business model transformation and stakeholder integration. In Motril-Granada, the challenge is to translate Blue Economy positioning into a sustained capacity for innovation. In the Baltic ports, the challenge is to overcome limited human capital, resource constraints and uneven digital maturity. These differences show that Open Innovation may enable coordination, but only under specific governance and capacity conditions (Meyer et al., 2023, 2024).

Finally, the synthesis reveals recurrent barriers across the cases. These include fragmented governance, limited innovation culture, weak standardisation, uneven absorptive capacity, resource constraints, limited human capital and difficulties in scaling innovation beyond individual projects. These barriers are important because they prevent Open Innovation from being treated as an inherently positive or self-executing process. Rather, the evidence suggests that Open Innovation requires deliberate coordination structures, institutional capacity, stakeholder alignment and evaluation mechanisms capable of

translating openness into collective action and sustainable value creation (Chesbrough, 2003; Adner, 2017; de Langen et al., 2020; Tijan et al., 2021).

Comparative synthesis is summarised in Table 4.

Table 4. Comparative synthesis of Open Innovation configurations in European port ecosystems

Case/category	OI configuration	Governance model	Main OI mechanisms	Coordination mechanism	Sustainability-oriented value creation	Main limitations
Rotterdam	Distributed and experimental innovation ecosystem	Distributed ecosystem governance	Start-ups, research platforms, hackathons, serious games, experimentation spaces	Ecosystem interaction, collaborative learning and experimentation	Energy transition, digital logistics, sustainable logistics experimentation and innovation culture	Risk of fragmentation; need to align multiple initiatives and actors
Valencia	Institutional-intermediated innovation ecosystem	Intermediary-led governance	Fundación Valenciaport, applied research, training, innovation projects and OpenTop	Institutional intermediation, knowledge transfer and port-community alignment	Human capital development, logistics innovation and sustainable port-logistics development	Limited innovation culture; short-term orientation; need for broader collaboration
Barcelona	Smart-port and business-model innovation pathway	Smart-port and strategy-led governance	Industry 4.0 technologies, Port 4.0 strategy, PCS, digital platforms and business model innovation	Digital and strategic connectivity, stakeholder integration and technology-enabled coordination	Smart-port integration, strategic connectivity, new value creation and business model transformation	Risk of technology-driven innovation without sufficient governance and stakeholder alignment
Motril-Granada	Blue Economy and territorial innovation configuration	Territorial and sustainability-oriented governance	Blue Economy projects, research collaboration, port-community engagement and sustainability initiatives	Territorial alignment, local collaboration and port-community integration	Blue Economy development, environmental positioning, territorial value and port-city sustainability	More limited evidence on digital maturity, ecosystem density and institutionalised innovation governance
Small and medium-sized Baltic ports	Capacity-building and resource-constrained innovation ecosystems	Regional and cross-border capacity-building governance	Training, knowledge transfer, organisational learning, absorptive capacity and cross-border cooperation	Cross-border learning, skills development and capacity-building	Digital readiness, regional resilience, competitiveness and organisational learning	Resource constraints; limited human capital; uneven digital maturity; infrastructure limitations

Source: Authors' elaboration based on the case-based literature reviewed in Sections 4.1–4.5

4.7. CONCEPTUAL FRAMEWORK: OPEN INNOVATION AS AN ECOSYSTEM-LEVEL COORDINATION MECHANISM

Based on the cross-case synthesis, this study proposes a conceptual framework to understand Open Innovation as an ecosystem-level coordination mechanism within port ecosystems. The framework does not claim to establish causal relationships or measure performance effects. Rather, it synthesises the reviewed literature into an analytical structure that explains how Open Innovation may support coordination among heterogeneous actors, infrastructures, and sustainability objectives.

The framework builds on the understanding of Open Innovation as purposive knowledge flows across organisational boundaries (Chesbrough, 2003; Chesbrough & Bogers, 2014), while extending this logic to ecosystem-level settings in which innovation depends on the alignment of interdependent actors, complementary resources and shared value propositions (Adner, 2017; Bogers et al., 2018; West & Bogers, 2017). In port ecosystems, this coordination role is particularly relevant because innovation adoption depends not only on technological availability, but also on interoperability, co-opetition, governance arrangements, stakeholder alignment and institutional capacity (de Langen et al., 2020; Roumboutsos et al., 2022; Tijan et al., 2021; Vanelslander et al., 2019).

The framework is organised around four interrelated components: enabling conditions, Open Innovation mechanisms, coordination functions, and sustainability-oriented val-

ue creation. These components are moderated by contextual constraints, including port scale, ecosystem maturity, governance fragmentation, absorptive capacity, resource availability, digital readiness and evaluation capacity.

First, enabling conditions refer to the institutional, organisational and technological factors that make Open Innovation possible in port ecosystems. The cross-case synthesis suggests that Open Innovation is more likely to become operational when port ecosystems possess governance capacity, institutional intermediation, digital infrastructure, stakeholder trust, absorptive capacity and a clear sustainability orientation. These conditions are not evenly distributed across port ecosystems. Large ports such as Rotterdam and Barcelona tend to have more developed innovation infrastructures, whereas smaller and medium-sized ports may depend more strongly on capacity-building, territorial collaboration, and external support.

Second, Open Innovation mechanisms are the practices through which knowledge, ideas, technologies, and resources circulate across organisational boundaries. These mechanisms include start-up engagement, research partnerships, public–private projects, institutional intermediaries, open data initiatives, digital platforms, collaborative experimentation, training programmes and Blue Economy projects. The reviewed cases indicate that these mechanisms vary according to the institutional configuration of each port ecosystem. In Rotterdam, Open Innovation is expressed through distributed experimentation; in Valencia, through institutional intermediation; in Barcelona, through smart-port and business-model innovation; in Motril-Granada, through territorial and Blue Economy collaboration; and in Baltic ports, through capacity-building and cross-border learning.

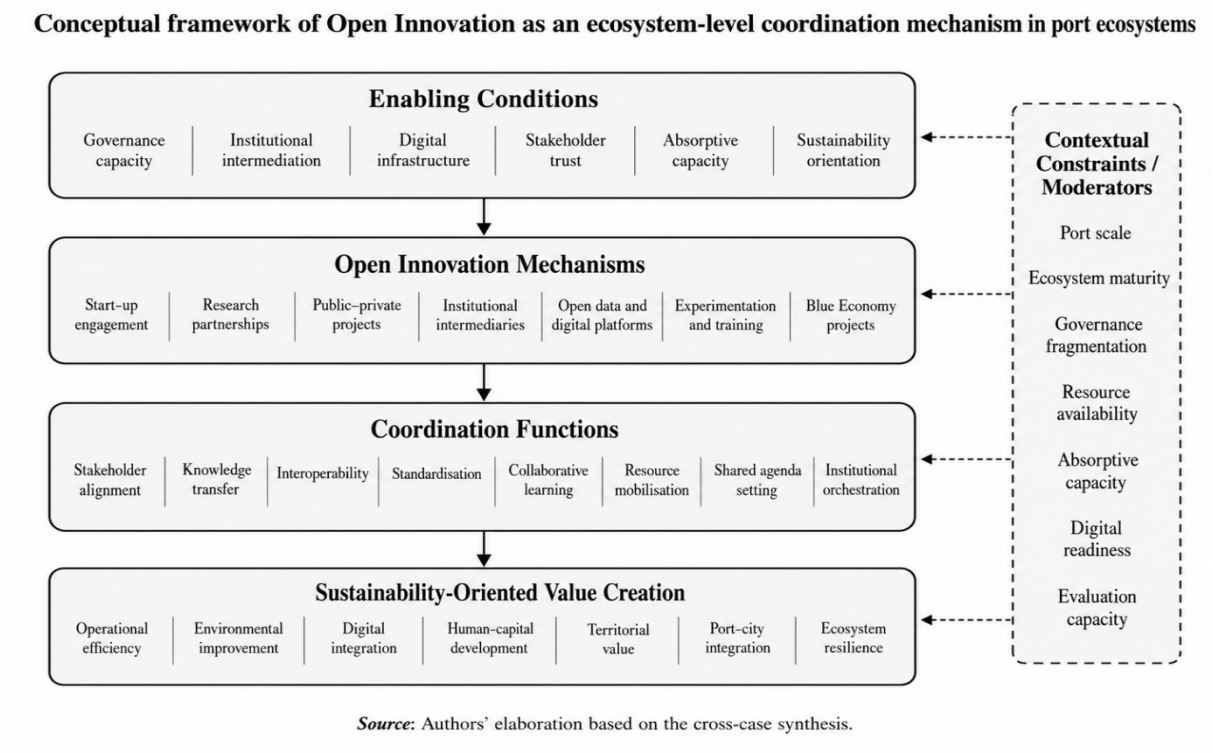
Third, coordination functions are the processes through which Open Innovation contributes to the alignment of actors, resources, standards, technologies, and objectives. In this framework, coordination is not treated as a general synonym for collaboration. Rather, it refers to the specific alignment processes that allow heterogeneous actors to act collectively around innovation and sustainability challenges. These functions include stakeholder alignment, knowledge transfer, interoperability, standardisation, collaborative learning, resource mobilisation, shared agenda setting and institutional orchestration.

Fourth, sustainability-oriented value creation refers to the outcomes that may emerge when Open Innovation mechanisms successfully support coordination. These outcomes include operational efficiency, environmental improvement, digital integration, human-capital development, territorial value, port-city integration, ecosystem resilience and long-term sustainable transformation. The framework therefore distinguishes between coordination as a process and value creation as an outcome. Open Innovation creates value not simply because actors collaborate, but because collaboration enables the alignment of knowledge, resources, infrastructures and strategic objectives across the ecosystem (De Martino, 2021; Tsvetkova & Hellström, 2022).

The framework also recognises that Open Innovation is constrained by several barriers. These include fragmented governance, a limited culture of innovation, weak standardisation, low absorptive capacity, resource scarcity, uneven digital maturity, a lack of evaluation frameworks, and difficulties in scaling innovation beyond individual projects. These constraints influence whether Open Innovation remains a set of isolated initiatives or becomes a systemic coordination mechanism. In this sense, the framework interprets Open Innovation as a mediating process between ecosystem conditions and sustainability-oriented value creation.

The proposed framework is presented in Figure 1.

Figure 1. Conceptual framework of Open Innovation as an ecosystem-level coordination mechanism in port ecosystems



Source: Authors' elaboration based on the cross-case synthesis

The proposed framework illustrates that Open Innovation does not inherently lead to sustainability-oriented value creation. Instead, its contribution is contingent upon the extent to which Open Innovation mechanisms fulfil coordination functions within a given port ecosystem. Enabling conditions influence the availability and effectiveness of these mechanisms, while contextual constraints moderate the progression from isolated collaboration to ecosystem-level coordination. Consequently, the framework provides a clear analytical distinction among the mechanisms facilitating knowledge circulation, the coordination functions aligning actors and resources, and the potential forms of value creation resulting from this alignment.

This distinction is important for port ecosystems because they involve multiple actors, including port authorities, terminal operators, shipping companies, logistics providers, technology firms, research institutions, public agencies and local communities. Therefore, innovation depends not only on technology adoption, but also on the capacity to coordinate interdependent stakeholders around shared goals, interoperable systems and sustainability-oriented transformation pathways.

The framework also provides a basis for future empirical testing. It suggests that governance capacity, institutional intermediation, digital infrastructure, absorptive capacity, and port scale may influence the extent to which Open Innovation mechanisms coordinate and generate sustainability-oriented value. These relationships are not treated here as empirically validated hypotheses, but as conceptual propositions derived from the cross-case synthesis. They are further discussed in Section 5.6 as directions for future research.

5. DISCUSSION

5.1. OPEN INNOVATION AS AN ECOSYSTEM-LEVEL COORDINATION MECHANISM

The cross-case synthesis supports the interpretation of Open Innovation as an ecosystem-level coordination mechanism in port ecosystems. This interpretation extends the traditional firm-centred understanding of Open Innovation, which emphasises purposive knowledge flows across organisational boundaries, towards a broader ecosystem perspective in which innovation depends on the alignment of multiple interdependent actors, resources, infrastructures and objectives (Chesbrough, 2003; Chesbrough & Bogers, 2014; Adner, 2017; Bogers et al., 2018; West & Bogers, 2017). In this sense, Open Innovation in port ecosystems should not be understood merely as the adoption of external ideas, the creation of start-up programmes or the presence of collaborative projects. Rather, its strategic relevance lies in its capacity to structure interaction, mobilise distributed knowledge and support collective action across organisations that are operationally interdependent but institutionally heterogeneous.

This distinction is particularly important in port ecosystems. Ports are complex socio-technical systems in which innovation involves port authorities, terminal operators, shipping companies, logistics providers, technology firms, public agencies, research institutions and local communities. These actors differ in mandates, resources, strategic priorities and time horizons. As a result, innovation cannot be reduced to isolated technological adoption or bilateral collaboration. It requires coordination mechanisms capable of aligning standards, data infrastructures, investment priorities, regulatory requirements, operational routines and sustainability objectives. The reviewed literature on smart ports, port governance and digital transformation confirms that innovation adoption in ports depends heavily on interoperability, co-opetition, institutional capacity and multi-actor coordination (de Langen et al., 2020; Roumboutsos et al., 2022; Tijan et al., 2021; Vanelslander et al., 2019).

The proposed framework therefore clarifies the analytical difference between Open Innovation mechanisms, coordination functions and sustainability-oriented value creation. Open Innovation mechanisms refer to the practices through which knowledge and resources circulate across organisational boundaries, such as research partnerships, institutional intermediaries, public–private projects, digital platforms, start-up engagement and collaborative experimentation. Coordination functions refer to what these mechanisms do within the ecosystem: they align actors, enable knowledge transfer, support interoperability, mobilise resources, facilitate standardisation and create shared agendas. Sustainability-oriented value creation refers to the outcomes that may result from such coordination, including operational efficiency, environmental improvement, human-capital development, territorial value, port-city integration and ecosystem resilience (De Martino, 2021; Tsvetkova & Hellström, 2022).

This distinction helps address a recurring ambiguity in literature. Collaboration is often treated as inherently beneficial, but collaboration alone does not necessarily generate innovation, coordination or sustainable value. Similarly, digital infrastructure may enable information exchange, but it does not automatically produce collective action. Open Innovation becomes a coordination mechanism only when knowledge flows, collaborative arrangements and boundary-spanning interactions are connected to shared objectives, governance structures and ecosystem-level capabilities. In this sense, the contribution of Open Innovation lies not simply in opening organisational boundaries, but in transforming openness into organised interaction, collective learning and coordinated transformation.

The cross-case synthesis also suggests that this coordination role varies according to ecosystem configuration. In large and mature ports, Open Innovation may support coordination by connecting experimentation, digital infrastructure and strategic innovation agendas. In intermediary-led ecosystems, it may operate through knowledge transfer, applied research and institutional orchestration. In smaller or resource-constrained ports, its coordination function may depend more strongly on capacity-building, absorptive capacity, territorial collaboration and external support. Therefore, Open Innovation should not be interpreted as a universal model that operates in the same way across all port ecosystems. Its effectiveness depends on the institutional, technological and organisational conditions through which openness is converted into coordination.

Overall, this interpretation advances the debate on Open Innovation in port ecosystems by shifting attention from the presence of collaborative initiatives to the functions those initiatives perform. The central issue is not whether a port ecosystem is "open" in a general sense, but whether Open Innovation mechanisms help coordinate actors, infrastructures and sustainability objectives in ways that support systemic transformation. This provides the conceptual basis for understanding Open Innovation as a coordination mechanism and prepares the discussion of how different governance configurations shape this process.

5.2. GOVERNANCE CONFIGURATIONS AND INSTITUTIONAL INTERMEDIATION

The cross-case synthesis shows that Open Innovation in port ecosystems is strongly shaped by governance configurations. Because ports are multi-actor systems involving public authorities, private operators, logistics firms, technology providers, research organisations and public agencies, innovation does not depend only on the willingness of individual actors to collaborate. It also depends on the institutional arrangements through which collaboration is organised, priorities are negotiated, resources are mobilised and collective action is sustained. In this sense, governance provides the institutional setting within which Open Innovation mechanisms can perform coordination functions.

This finding is consistent with the ecosystem perspective on innovation, which emphasises that value creation depends on the alignment of interdependent actors rather than on the capabilities of a single organisation alone (Adner, 2017; Bogers et al., 2018; West & Bogers, 2017). It also resonates with port governance literature, which highlights the role of port authorities, institutional arrangements, public–private relationships and decision-making structures in shaping port development and innovation trajectories (de Langen et al., 2020; Vanelslander et al., 2019; Zhang et al., 2019). From this perspective, Open Innovation requires not only open boundaries, but also governance arrangements capable of converting dispersed knowledge into coordinated action.

The reviewed cases suggest that there is no single governance model for Open Innovation in port ecosystems. In distributed innovation ecosystems, such as Rotterdam, coordination depends on the ability to connect multiple innovation spaces, experimental initiatives, start-ups, public actors and private firms without reducing openness to fragmented experimentation. In intermediary-led ecosystems, such as Valencia, institutional intermediation plays a more central role by connecting port actors, research institutions, firms and public agencies through applied research, training, knowledge transfer and innovation projects. In smart-port pathways, such as Barcelona, governance is closely linked to strategic digital transformation, business model innovation and the integration of technological infrastructures with stakeholder coordination. In smaller or territorially embedded port ecosystems, such as Motril-Granada and small and medium-sized Baltic ports, governance is more closely associated with capacity-building, local collaboration,

Blue Economy strategies and regional development objectives.

These differences indicate that institutional intermediation can be a critical enabler of Open Innovation. Intermediaries can reduce coordination costs, translate knowledge across communities, support trust-building, connect actors with different capabilities and help transform isolated projects into more structured innovation processes. In port ecosystems, this role is particularly important because actors often have different mandates, operational constraints and strategic horizons. Port authorities may prioritise regulation, land use and long-term infrastructure development; terminal operators may focus on operational efficiency; logistics firms may seek service reliability and cost reduction; technology providers may emphasise digital solutions; and public agencies may prioritise compliance, sustainability and regional development. Intermediaries can help bridge these differences by creating shared spaces for experimentation, knowledge exchange and collaborative problem-solving.

However, institutional intermediation also has limits. When Open Innovation depends too heavily on a single intermediary or a small group of institutional actors, the ecosystem may become vulnerable to centralisation, project dependency or limited diffusion of innovation capabilities. In such contexts, coordination may remain concentrated in formal programmes rather than becoming embedded in the routines, relationships and absorptive capacities of the wider ecosystem. This suggests that effective governance of Open Innovation requires a balance between orchestration and distributed participation. Too little coordination may produce fragmentation, while excessive centralisation may reduce experimentation, ownership and ecosystem-wide learning.

The distinction between governance and coordination is therefore analytically important. Governance refers to the institutional arrangements, authority structures and decision-making settings through which innovation is organised. Coordination refers to the alignment processes through which actors, resources, technologies and objectives are connected in practice. Open Innovation operates between these two dimensions: it is enabled by governance arrangements, but it contributes to coordination only when collaborative mechanisms generate knowledge transfer, interoperability, shared agendas and collective learning. This distinction helps explain why similar Open Innovation mechanisms may produce different outcomes across port ecosystems.

For port authorities and ecosystem intermediaries, the implication is that Open Innovation should be governed as a systemic capability rather than as a portfolio of isolated initiatives. This requires structures that support continuity, trust, evaluation, knowledge retention and cross-organisational learning. It also requires attention to differences in ecosystem maturity. Large ports may need governance arrangements capable of integrating multiple innovation initiatives, while smaller and medium-sized ports may require stronger support for absorptive capacity, skills development and regional collaboration. Thus, governance configurations shape not only whether Open Innovation occurs, but also whether it becomes a durable coordination mechanism capable of supporting sustainability-oriented transformation.

5.3. DIGITAL INFRASTRUCTURES, STANDARDS AND THE LIMITS OF TECHNOLOGY-LED INNOVATION

Digital infrastructure plays an important role in Open Innovation processes within port ecosystems, but the cross-case synthesis suggests that its contribution should not be interpreted deterministically. Technologies such as Port Community Systems, smart-port platforms, Internet of Things applications, blockchain, digital twins and data-sharing systems can facilitate information exchange, improve visibility and support interoper-

ability. However, they do not automatically generate coordination, collaboration or sustainability-oriented value creation. Their relevance depends on how they are embedded in governance arrangements, stakeholder relationships, standards and shared innovation objectives (Tijan et al., 2021; Roumboutsos et al., 2022; Vanelslander et al., 2019).

Port Community Systems, 5G applications and Open Innovation 4.0 approaches illustrate that digital technologies may support competitiveness, efficiency and sustainability, but only when technical deployment is connected to stakeholder adoption, process integration and systemic innovation capabilities (Carlan et al., 2016; Cavalli et al., 2021; Costa & Matias, 2020).

This distinction is important because smart-port literature often emphasises technological capabilities, while the governance and organisational conditions required for their effective use may receive less attention. Digital tools can reduce transaction costs, improve operational transparency and enable new forms of data-driven collaboration, but they may also reproduce fragmentation if actors do not share standards, incentives, trust or decision-making frameworks. In this sense, digital infrastructure should be understood as a coordination enabler rather than as a substitute for ecosystem governance.

Comparative analysis indicates that digitally advanced port ecosystems are better positioned to experiment with data-driven innovation, but digital maturity alone is insufficient. Large ports may possess advanced technological infrastructures, yet still face challenges related to interoperability, stakeholder alignment and the integration of multiple innovation initiatives. Conversely, smaller and medium-sized ports may lack advanced digital infrastructures but can still develop Open Innovation through capacity-building, collaborative learning and territorial partnerships. Therefore, the coordination function of Open Innovation depends not only on the technological sophistication of the ecosystem, but also on the capacity to connect digital tools with institutional arrangements and collective objectives.

This finding reinforces the need to avoid a technology-driven interpretation of port innovation. Digitalisation can support Open Innovation when it enables knowledge flows, shared visibility, interoperability and collaborative decision-making across the ecosystem. However, when digital projects remain isolated, vendor-driven or disconnected from governance structures, their capacity to generate systemic transformation is limited. The key issue is therefore not whether ports adopt digital technologies, but whether these technologies become part of coordinated innovation processes that align actors, resources and sustainability goals.

From this perspective, digital infrastructure occupies an intermediate position in the proposed framework. It is both an enabling condition and, in some cases, an Open Innovation mechanism. As an enabling condition, it provides the technical basis for connectivity and data exchange. As an Open Innovation mechanism, it can support collaborative experimentation, open data initiatives and digital platforms for stakeholder interaction. Nevertheless, its contribution to sustainability-oriented value creation depends on whether it performs coordination functions such as interoperability, standardisation, knowledge transfer and shared agenda setting.

Thus, the main implication is that port digitalisation should be governed as part of an ecosystem-level innovation strategy rather than as a set of isolated technological upgrades. For port authorities, intermediaries and policy actors, this means linking digital investment to governance capacity, stakeholder engagement, data-sharing rules, skills development and evaluation mechanisms. Without these conditions, digital infrastructure may improve specific operations but fail to support broader Open Innovation and sustainable port transformation.

5.4. SUSTAINABLE VALUE CREATION AS A COORDINATED OUTCOME

The cross-case synthesis also clarifies the relationship between Open Innovation, coordination and sustainability-oriented value creation. In port ecosystems, value creation should not be understood only in economic or operational terms. Because ports operate as logistics infrastructures, business networks, territorial interfaces and environmental pressure points, value creation includes multiple dimensions, such as operational efficiency, environmental performance, digital integration, knowledge development, human-capital formation, port-city relations, territorial development and ecosystem resilience (De Martino, 2021; Tsvetkova & Hellström, 2022).

This broader understanding is also consistent with research on open eco-innovation, port-city relations and Sustainable Development Goals in maritime and port sectors, which shows that value creation increasingly involves environmental, territorial, social and governance-related dimensions rather than only operational or economic performance (Garcia et al., 2019; Jansen & Hein, 2023; Diniz et al., 2023).

This multidimensional view is consistent with the broader literature on sustainable and ecosystem-based innovation, which emphasises that innovation outcomes increasingly depend on the capacity to generate value beyond the boundaries of a single firm or organisation (Adner, 2017; Bogers et al., 2018; West & Bogers, 2017). In port contexts, this is particularly relevant because no single actor controls all the resources, infrastructures, data flows or decision-making arenas required for sustainable transformation. Port authorities, terminal operators, logistics firms, technology providers, public agencies, research institutions and local communities contribute different resources and pursue different objectives. Sustainable value creation therefore depends on the ability to align these heterogeneous contributions through coordinated innovation processes.

The distinction between coordination and value creation is central to this paper's argument. Coordination refers to the process through which actors, resources, standards, technologies and sustainability objectives are aligned. Value creation refers to the outcomes that may result from this alignment. Open Innovation becomes relevant not simply because it increases the number of collaborations or external knowledge flows, but because it can transform dispersed knowledge and fragmented initiatives into coordinated action. In this sense, sustainability-oriented value creation is not an automatic consequence of openness; it depends on whether Open Innovation mechanisms perform coordination functions such as stakeholder alignment, interoperability, collaborative learning, resource mobilisation and shared agenda setting.

The reviewed cases suggest that sustainability-oriented value creation takes different forms according to the configuration of each port ecosystem. In more digitally advanced and mature ecosystems, value creation may be associated with smart-port integration, energy transition, data-driven logistics and business model innovation. In intermediary-led ecosystems, it may be expressed through knowledge transfer, applied research, skills development and institutionalised collaboration. In smaller or resource-constrained ports, it may depend more strongly on capacity-building, territorial collaboration, Blue Economy positioning and regional resilience. These differences show that sustainable value creation is context-dependent and mediated by governance capacity, absorptive capacity, digital readiness and ecosystem maturity.

This interpretation also cautions against treating sustainability as a generic or symbolic objective. Open Innovation contributes to sustainability only when collaborative mechanisms are connected to concrete coordination functions and evaluable outcomes. Without such alignment, sustainability initiatives may remain fragmented, project-based or disconnected from operational and territorial transformation. Therefore, port ecosys-

tems need not only sustainability ambitions but also mechanisms to translate those ambitions into coordinated innovation practices, shared metrics, and long-term ecosystem capabilities.

The main implication is that sustainable port transformation requires more than technological adoption or stakeholder participation. It requires the orchestration of knowledge flows, institutional arrangements, digital infrastructures and strategic objectives in ways that generate collective value. From this perspective, Open Innovation acts as a bridge between dispersed ecosystem resources and sustainability-oriented outcomes. Its contribution lies in enabling port ecosystems to move from isolated initiatives towards coordinated forms of value creation that are operationally effective, environmentally meaningful and territorially embedded.

5.5. THEORETICAL AND PRACTICAL IMPLICATIONS

This study has three main theoretical implications. First, it contributes to Open Innovation literature by extending the concept from a firm-centred knowledge-flow perspective to an ecosystem-level coordination perspective. While the foundational literature emphasises the purposive use of internal and external knowledge flows across organisational boundaries (Chesbrough, 2003; Chesbrough & Bogers, 2014), the analysis developed in this paper suggests that, in port ecosystems, the central issue is not only whether knowledge crosses organisational boundaries, but whether such knowledge flows help align interdependent actors, resources, digital infrastructures and sustainability objectives. This reframing contributes to the broader ecosystem view of innovation, in which value creation depends on actor interdependence, complementarity and alignment rather than on the capabilities of a single organisation alone (Adner, 2017; Bogers et al., 2018; West & Bogers, 2017).

Second, the study contributes to the port innovation and governance literature by clarifying the distinction among governance arrangements, coordination functions, and value-creation outcomes. Governance refers to the institutional setting through which innovation is organised; coordination refers to the alignment processes by which actors, standards, infrastructures, and objectives are connected; and value creation refers to the outcomes generated by this alignment. This distinction is relevant because port innovation is often discussed in terms of overlapping concepts such as collaboration, digitalisation, smart-port development, governance, and sustainability. By analytically separating these dimensions, the paper provides a clearer conceptual basis for examining how Open Innovation operates within port ecosystems.

Third, the proposed framework contributes to research on sustainable port transformation by showing that sustainability-oriented value creation is not an automatic result of openness, collaboration or digitalisation. Rather, it depends on whether Open Innovation mechanisms perform coordination functions within specific ecosystem conditions. This interpretation helps explain why similar innovation practices may produce different outcomes across ports with different levels of digital maturity, governance capacity, absorptive capacity and institutional intermediation. It also reinforces the need to examine Open Innovation as a context-dependent process shaped by port scale, ecosystem maturity, governance fragmentation and resource availability.

The practical implications are also significant. For port authorities, the findings suggest that Open Innovation should not be managed merely as a set of isolated projects, pilot initiatives or technology partnerships. Instead, it should be treated as a systemic capability for coordinating actors, infrastructures and sustainability objectives across the port ecosystem. This requires port authorities to act not only as landlords, regulators or infrastructure managers, but also as facilitators of knowledge exchange, interoperability,

stakeholder alignment and long-term innovation learning.

For innovation intermediaries, the study highlights the importance of bridging functions. Intermediaries can support Open Innovation by connecting firms, port authorities, research institutions, technology providers and public agencies; translating knowledge across organisational and disciplinary boundaries; reducing coordination costs; and supporting the continuity of collaborative projects. However, intermediation should not lead to excessive centralisation. Its value lies in enabling distributed participation, strengthening absorptive capacity and embedding innovation capabilities across the wider ecosystem.

For regional and policy actors, this also connects port Open Innovation with broader debates on maritime clusters, knowledge-intensive service activities, smart specialisation and quadruple- or quintuple-helix innovation ecosystems, where sustainable transformation depends on interaction among industry, government, academia, civil society and territorial actors (Monteiro, 2016; Gifford & McKelvey, 2019; Carayannis et al., 2021)

Finally, the study has implications for how port ecosystems evaluate innovation. If Open Innovation is understood as a coordination mechanism, then evaluation should not focus only on the number of projects, partnerships or technologies adopted. It should also assess whether innovation initiatives improve interoperability, stakeholder alignment, collaborative learning, resource mobilisation and sustainability-oriented value creation. This broader evaluation perspective can help port ecosystems move from fragmented initiatives towards more systemic and durable forms of innovation governance.

5.6. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study has several limitations that should be acknowledged. First, it is based on secondary evidence and does not include primary empirical data such as interviews, surveys, direct observation or longitudinal fieldwork. As a result, the analysis depends on the availability, depth and methodological quality of the reviewed literature. The findings should therefore be interpreted as an analytical synthesis of existing evidence rather than as direct empirical validation of Open Innovation practices in the selected port ecosystems.

Second, the selected cases differ in evidential depth, institutional maturity, geographical context and port scale. Rotterdam, Valencia and Barcelona are more extensively documented in the literature, whereas Motril-Granada and small and medium-sized Baltic ports are represented through more focused or aggregated evidence. This asymmetry limits direct comparison between cases. However, the objective of the study was not to rank ports or produce statistically representative findings, but to identify analytically distinct Open Innovation configurations and explore how they operate under different ecosystem conditions.

Third, the proposed framework should be understood as a conceptual contribution rather than as a validated causal model. It identifies possible relationships between enabling conditions, Open Innovation mechanisms, coordination functions, contextual constraints and sustainability-oriented value creation. However, these relationships require further empirical examination. Future studies could test and refine the framework through comparative case studies, interviews with port authorities and ecosystem actors, surveys, longitudinal analysis or mixed-methods research.

Future research could examine the conceptual relationships proposed in Figure 1. In particular, the following propositions may guide future empirical studies:

P_1. Governance capacity and institutional intermediation

The stronger the governance capacity and institutional intermediation within a port ecosystem, the more likely Open Innovation mechanisms are to support stakeholder alignment, knowledge transfer and collaborative learning.

P_2. Digital infrastructure and coordination

Digital infrastructure contributes to Open Innovation only when it is embedded in governance arrangements, interoperability standards and shared innovation objectives.

P_3. Absorptive capacity and knowledge mobilisation

Port ecosystems with higher absorptive capacity are more likely to transform external knowledge into coordinated innovation practices and sustainability-oriented outcomes.

P_4. Scale and capacity-building

In smaller and medium-sized ports, Open Innovation is more dependent on capacity building, human capital development, and cross-border learning than on advanced digital infrastructure alone.

P_5. Coordination and sustainable value creation

Sustainability-oriented value creation emerges when Open Innovation mechanisms support coordination functions such as stakeholder alignment, collaborative learning, resource mobilisation, interoperability, and shared agenda-setting.

P_6. Barriers to systemic transformation

Governance fragmentation, limited resources, weak standardisation, and insufficient evaluation frameworks reduce Open Innovation's capacity to move from isolated projects to ecosystem-level transformation.

These propositions are not presented as empirically tested hypotheses, but as analytical relationships derived from the cross-case synthesis. They provide a basis for future research to examine how Open Innovation operates across different types of port ecosystems and under different institutional, technological and territorial conditions. Future empirical work could also compare large hub ports, intermediary-led ecosystems, smart-port strategies, and smaller resource-constrained ports to assess how governance capacity, digital readiness, and absorptive capacity affect the transition from isolated innovation initiatives to ecosystem-level coordination.

Finally, future research should develop more robust evaluation frameworks for Open Innovation in port ecosystems. Existing studies often describe collaborative projects, digital initiatives or sustainability strategies, but less frequently assess whether these initiatives generate measurable coordination effects or long-term ecosystem capabilities. Further research could therefore examine indicators such as interoperability, stakeholder alignment, knowledge retention, collaborative learning, resource mobilisation, environmental outcomes, port-city value and ecosystem resilience. Such work would help move the field from descriptive accounts of innovation initiatives towards stronger empirical assessment of Open Innovation as a coordination mechanism for sustainable port transformation.

6.CONCLUSION

This study examined how Open Innovation is operationalised as a coordination mechanism in European port ecosystems. Drawing on a semi-structured literature review and qualitative cross-case comparative synthesis, the paper analysed five Open Innovation configurations: distributed experimentation in Rotterdam, institutional intermediation in Valencia, smart-port and business-model innovation in Barcelona, Blue Economy and territorial innovation in Motril-Granada, and capacity-building in small and medium-sized Baltic ports.

The main contribution of the study is the conceptualisation of Open Innovation as an ecosystem-level coordination mechanism. Rather than treating Open Innovation merely as collaboration, external knowledge sourcing or technology adoption, the paper shows that its relevance in port ecosystems lies in its capacity to align heterogeneous actors, re-

sources, digital infrastructures, standards and sustainability objectives. This distinction clarifies the relationship between Open Innovation mechanisms, coordination functions and sustainability-oriented value creation.

The proposed conceptual framework contributes to the literature by explaining how enabling conditions, Open Innovation mechanisms and coordination functions may interact to support sustainable port transformation. It also highlights that Open Innovation is context-dependent: its effectiveness is shaped by governance capacity, institutional intermediation, absorptive capacity, digital readiness, port scale and ecosystem maturity. Therefore, openness should not be understood as inherently beneficial, but as valuable when it is converted into organised interaction, collective learning and coordinated action.

The study is limited by its reliance on secondary evidence and by the unequal evidential depth of the selected cases. The proposed framework should therefore be interpreted as an analytical contribution rather than as an empirically validated causal model. Future research should test and refine the framework through primary empirical studies, comparative port research, longitudinal analyses, and mixed methods designs to assess how Open Innovation contributes to coordination, sustainable value creation, and ecosystem resilience across different port contexts.

Declaration of generative ai and ai-assisted technologies in the writing process

During the preparation of this work, the author(s) used app.litmaps.com to visualise how papers relate to one another and to discover relevant new papers. We also used Scite.ai and SciSpace.ai to organise and chat with the documents, getting answers and explanations. After using these tools/services, the author(s) reviewed and edited the content as needed and take full responsibility for the publication's content.

Funding

Content produced within the scope of the agenda "NEXUS - Pacto de Inovação – Transição Verde e Digital para Transportes, Logística e Mobilidade", financed by the Portuguese Recovery and Resilience Plan (PRR), with no. C645112083-00000059 (investment project n.º 53)

Acknowledgment

NECE - Research Centre for Business Sciences funded by the Multiannual Funding Program of R&D Centers of FCT—Fundação para a Ciência e Tecnologia, Portugal, under Grant number UID/04630/2025, DOI: https://doi.org/10.54499/UID/04630/2025

REFERENCES

Acciaro, M., & Sys, C. (2020). Innovation in the maritime sector: Aligning strategy with outcomes. *Maritime Policy and Management*, *47*(8), 1045–1063. https://doi.org/10.1080/03088839.2020.1737335

Adams, R., Jeanrenaud, S., Bessant, J., Denyer, D., & Overy, P. (2016). Sustainability-oriented innovation: A systematic review. *International Journal of Management Reviews*, *18*(2), 180–205. https://doi.org/10.1111/ijmr.12068

Adner, R. (2017). Ecosystem as Structure. *Journal of Management*, *43*(1), 39–58. https://doi.org/10.1177/0149206316678451

Alsharaideh, A. M. A., Alzubi, M. M. S., Alqudah, A. M. A., Alqudah, O. M. A., & Darabah, K. (2026). AI-Enabled Frugal Innovation: Extending the Dynamic Capabilities Framework for Sustainable Development. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 435-455. https://doi.org/10.2478/eoik-2026-0044

Bogers, M., Chesbrough, H., & Moedas, C. (2018). Open Innovation: Research, Practices, and Policies. *Https://Doi.Org/10.1177/0008125617745086*, *60*(2), 5–16. https://doi.org/10.1177/0008125617745086

Booth, A., Papaioannou, D., & Sutton, A. (2016). *Systematic Approaches to a Successful Literature Review* (M. Steele, Ed.; Second Edition). SAGE Publications Inc. https://www.researchgate.net/publication/235930866_Systematic_Approaches_to_a_Successful_Literature_Review

Carayannis, E. G., Grigoroudis, E., Stamati, D., & Valvi, T. (2021). Social business model innovation: A quadruple/quintuple helix-based social innovation ecosystem. *IEEE Transactions on Engineering Management*, *68*(1), 235–248. https://doi.org/10.1109/TEM.2019.2914408

Carlan, V., Sys, C., & Vanelslander, T. (2016). How port community systems can contribute to port competitiveness: Developing a cost-benefit framework. *Research in Transportation Business and Management*, *19*, 51–64. https://doi.org/10.1016/j.rtbm.2016.03.009

Cavalli, L., Lizzi, G., Guerrieri, L., Querci, A., De Bari, F., Barbieri, G., Ferrini, S., Di Meglio, R., Cardone, R., Tardo, A., Pagano, P., Tesei, A., & Lattuca, D. (2021). Addressing efficiency and sustainability in the port of the future with 5G: The experience of the Livorno Port. A methodological insight to measure innovation technologies' benefits on port operations. *Sustainability*, *13*(21), 12146. https://doi.org/10.3390/su132112146

Chenail, R. (2016). Bringing Method to the Madness: Sandelowski and Barroso's Handbook for Synthesizing Qualitative Research. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2009.2820

Chesbrough, H. (2003). Open innovation: The new imperative for creating and profiting from technology. *Harvard Business School Press*, Boston, Massachusetts.

Chesbrough, H., & Bogers, M. (2014). Explicating open innovation: Clarifying an emerging paradigm for understanding innovation. *Oxford University Press*, *New Frontiers in Open Innovation*, 3–28. https://doi.org/10.1093/acprof:oso/9780199682461.003.0001

Costa, J., & Matias, J. C. O. (2020). Open innovation 4.0 as an enhancer of sustainable innovation ecosystems. *Sustainability (Switzerland)*, *12*(19). https://doi.org/10.3390/su12198112

Dahlander, L., & Gann, D. M. (2010). How open is innovation? *Research Policy*, *39*(6), 699–709. https://doi.org/10.1016/j.respol.2010.01.013

De Langen, P. W., Sornn-Friese, H., & Hallworth, J. (2020). The role of port development companies in transitioning the port business ecosystem: The case of Port of Amsterdam's circular activities. *Sustainability*, *12*(11), 4397. https://doi.org/10.3390/su12114397

De Martino, M. (2021). Value creation for sustainability in port: Perspectives of analysis and future research directions. *Sustainability (Switzerland)*, *13*(21). https://doi.org/10.3390/su132112268

Dubois, A., & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research*, *55*(7), 553–560. https://doi.org/10.1016/S0148-2963(00)00195-8

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *The Academy of Management Review*, *14*(4), 532. https://doi.org/10.2307/258557

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory Building From Cases: Opportunities And Challenges. *Academy of Management Journal*, *50*(1), 25–32. https://doi.org/10.5465/amj.2007.24160888

Enkel, E., Bell, J., & Hogenkamp, H. (2011). Open Innovation Maturity Framework. *International Journal of Innovation Management*, *15*(06), 1161–1189. https://doi.org/10.1142/S1363919611003696

Enkel, E., Gassmann, O., & Chesbrough, H. (2009). Open R&D and open innovation: exploring the phenomenon. *R&D Management*, *39*(4), 311–316. https://doi.org/10.1111/j.1467-9310.2009.00570.x

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Garrido Salsas, J., Saurí, S., Rúa, C., & Torrent, J. (2022). Conceptualisation of the Port of the Future based on the Business Canvas Model: Case study of the Vision 2040 for Barcelona. *Case Studies on Transport Policy*, *10*(2), 1427–1437. https://doi.org/10.1016/j.cstp.2022.05.002

González-Cancelas, N., Molina Serrano, B., Soler-Flores, F., & Camarero-Orive, A. (2020). Using the SWOT methodology to know the scope of the digitalization of the spanish ports. *Logistics*, *4*(3). https://doi.org/10.3390/logistics4030020

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Ha, T. M. (2026). How Digital Capabilities Drive Innovation in Banking: Extending the Resource-Based View in the Era of Digital Transformation. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 353-373. https://doi.org/10.2478/eoik-2026-0040

Henríquez, R., Martínez de Osés, F. X., & Martínez Marín, J. E. (2022). Technological drivers of seaports' business model innovation: An exploratory case study on the port of Barcelona. *Research in Transportation Business and Management*, *43*. https://doi.org/10.1016/j.rtbm.2022.100803

Kazemargi, N., Tavoletti, E., Appolloni, A., & Cerruti, C. (2022). Managing open innovation within supply networks in mature industries. *European Journal of Innovation Management*, *25*(6), 1106–1130. https://doi.org/10.1108/EJIM-12-2021-0606

Kimpimäki, J. P., Malacina, I., & Lähdeaho, O. (2022). Open and sustainable: An emerging frontier in innovation management? *Technological Forecasting and Social Change*, *174*. https://doi.org/10.1016/j.techfore.2021.121229

Lichtenthaler, U. (2011). Open Innovation: Past Research, Current Debates, and Future Directions. *Academy of Management Perspectives*, *25*(1), 75–93. https://doi.org/10.5465/amp.25.1.75

Lippolis, S., Ruggieri, A., & Leopizzi, R. (2023). Open Innovation for sustainable transition: The case of Enel "Open Power". *Business Strategy and the Environment*. https://doi.org/10.1002/bse.3361

Mendes Constante, J., de Langen, P. W., & Furió Pruñonosa, S. (2023). Innovation ecosystems in ports: a comparative analysis of Rotterdam and Valencia. *Journal of Shipping and Trade*, *8*(1). https://doi.org/10.1186/s41072-023-00145-w

Meyer, C., Gerlitz, L., & Henesey, L. (2021). Cross-border capacity-building for port ecosystems in small and medium-sized Baltic ports. *TalTech Journal of European Studies*, *11*(1), 113–132. https://doi.org/10.2478/bjes-2021-0008

Meyer, C., Gerlitz, L., & Prause, G. (2023). Small and medium-sized port greening initiatives as trigger for a servitisation port ecosystem. *Environmental and Climate Technologies*, *27*(1), 476–488. https://doi.org/10.2478/rtuect-2023-0035

Meyer, C., Gerlitz, L., & Prause, G. (2024). Smart city and smart port concepts: A conceptualisation for digital small and medium-sized port-city innovation ecosystems. In I. Kabashkin, I. Yatskiv, & O. Prentkovskis (Eds.), *Lecture Notes in Networks and Systems: Vol. 913 LNNS* (pp. 41–53). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-031-53598-7_4

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis: A methods sourcebook (3rd ed.). *Sage*.

Monios, J., Wilmsmeier, G., Tello, G. A. M., & Pomaska, L. (2024). A new conception of port governance under climate change. *Journal of Transport Geography*, *120*, 103988. https://doi.org/10.1016/j.jtrangeo.2024.103988

Roumboutsos, A., Sys, C., & Vanelslander, T. (2022). Imitation, co-opetition and open innovation in network industries: Cases from ports. *Case Studies on Transport Policy*, *10*(3), 1627–1639. https://doi.org/10.1016/j.cstp.2022.06.002

Rupo, D., Perano, M., Centorrino, G., & Vargas-Sanchez, A. (2018). A framework based on sustainability, open innovation, and value cocreation paradigms—A case in an Italian maritime cluster. *Sustainability*, *10*(3), 729. https://doi.org/10.3390/su10030729

Seisdedos, M. R., & Carrasco, P. F. (2020). Port projects in blue economy: Port of Motril-Granada. *Journal of Coastal Research*, 940–944. https://doi.org/10.2112/SI95-183.1

Seisenbekov, A., Beisenova, M., Koshetayev, D., Akhmetova, Z., & Suyunbayev, S. (2026). The Impact of Digitalization and Innovation on Postal and Courier Services In the Context of Sustainable Economic Development: Evidence from Kazakhstan. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 249-268. https://doi.org/10.2478/eoik-2026-0035

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Stake, R. E. (1995). *The art of case study research*. Sage Publications.

Suárez-Gargallo, C., & Zaragoza-Sáez, P. (2023). Port authority of Cartagena: Evidence of a sustainability balanced scorecard. *Sustainable Development*, *31*(5), 3761–3785. https://doi.org/10.1002/sd.2624

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology*, *8*(1), 45. https://doi.org/10.1186/1471-2288-8-45

Tijan, E., Jović, M., Panjako, A., & Žgaljić, D. (2021). The role of port authority in port governance and port community system implementation. *Sustainability*, *13*(5), 2795. https://doi.org/10.3390/su13052795

Timmermans, S., & Tavory, I. (2012). Theory Construction in Qualitative Research. *Sociological Theory*, *30*(3), 167–186. https://doi.org/10.1177/0735275112457914

Torraco, R. J. (2005). Writing Integrative Literature Reviews: Guidelines and Examples. *Human Resource Development Review*, *4*(3), 356–367. https://doi.org/10.1177/1534484305278283

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Tsvetkova, A., & Hellström, M. (2022). Creating value through autonomous shipping: An ecosystem perspective. *Maritime Economics and Logistics*, *24*(2), 255–277. https://doi.org/10.1057/s41278-022-00216-y

Vanelslander, T., Sys, C., Lam, J. S. L., Ferrari, C., Roumboutsos, A., Acciaro, M., Macário, R., & Giuliano, G. (2019). A serving innovation typology: Mapping port-related innovations. *Transport Reviews*, *39*(5), 611–629. https://doi.org/10.1080/01441647.2019.1587794

West, J., & Bogers, M. (2017). Open innovation: current status and research opportunities. *Innovation*, *19*(1), 43–50. https://doi.org/10.1080/14479338.2016.1258995

West, J., Chesbrough, H., & Vanhaverbeke, W. (2006). Open Innovation: A Research Agenda. In *Open Innovation* (pp. 285–308). Oxford University PressOxford. https://doi.org/10.1093/oso/9780199290727.003.0014

Witte, P., Slack, B., Keesman, M., Jugie, J.-H., & Wiegmans, B. (2018). Facilitating start-ups in port-city innovation ecosystems: A case study of Montreal and Rotterdam. *Journal of Transport Geography*, *71*, 224–234. https://doi.org/10.1016/j.jtrangeo.2017.03.006

Wohlleber, A. J., Bock, M., Birkel, H., & Hartmann, E. (2024). Implementing vital dynamic capabilities to succeed in digital transformation: A multiple-case study in maritime container shipping. *IEEE Transactions on Engineering Management*, *71*, 13627–13645. https://doi.org/10.1109/TEM.2022.3201770

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: meta-narrative reviews. *BMC Medicine*, *11*(1), 20. https://doi.org/10.1186/1741-7015-11-20

Yin, R. K. (2018). *Case Study research: Design and methods* (Ed. K. R. Wiley, Ed.; 6th ed.). Sage Publications, Inc.

Zhang, Q., Zheng, S., Geerlings, H., & El Makhloufi, A. (2019). Port governance revisited: How to govern and for what purpose? *Transport Policy*, *77*, 46–57. https://doi.org/10.1016/j.tranpol.2019.03.001

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

PSYCHOSOCIAL DETERMINANTS OF ORGANIZATIONAL CONFLICT IN A DIGITAL WORK ENVIRONMENT: A NARRATIVE REVIEW

Nino Paresashvili[1*], Teona Edzgveradze[2]

Received 26.03.2026. | Sent to review 15.04.2026. | Accepted 19.08.2026.

Review Article

[1] Academic Doctor of Economics, Department of Management in a Global Environment, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

[2] PhD Student, Sokhumi State University, Tbilisi, Georgia

***Corresponding Author:**
Nino Paresashvili

Email:
nino.paresashvili@tsu.ge

JEL Classification:
D74, M12, M15

Doi: 10.61432/CPNE0401219p

UDK: 159.944.4:331.5.024.52

ABSTRACT

Digital transformation has reshaped both organizational technologies and the social dynamics of work. This structured narrative review examines how technostress, communication asymmetry, role ambiguity, information overload or scarcity, emotional exhaustion, and limited interpersonal cues contribute to conflict in digitally mediated workplaces. Drawing on peer-reviewed studies and institutional documents published mainly between 2000 and 2025, the review focuses on remote and hybrid work, virtual teams, psychosocial risks, digital leadership, and public-sector modernization. A transparent search strategy, thematic synthesis, and source-quality assessment were applied. The findings reveal that digitalization can enhance autonomy, flexibility, learning, and access to information, but may also intensify cognitive demands, weaken work-life boundaries, reduce trust, and heighten sensitivity to conflict. An integrated framework is proposed in which digital work design affects conflict through fatigue, resilience, fairness perceptions, and trust, while leadership, organizational support, digital competence, autonomy, and clear communication moderate these effects. Georgian public-sector reforms are used as institutional illustrations without implying unsupported causality. The review concludes with recommendations for psychosocial risk assessment, communication governance, digital-disconnection policies, participatory change management, managerial development, and early conflict detection.

Keywords: *Organizational Conflict, Digital Work Environment, Psychosocial Risk, Technostress, Emotional Resilience, Public Sector*

1. INTRODUCTION

Digital transformation has become a core component of organizational development, enabling coordination through cloud systems, digital platforms, algorithmic tools, and remote work arrangements. However, these technologies also reshape organizational culture, authority, visibility, and interaction, making their social effects inseparable from their operational benefits (Grover et al., 2022).

Digitally mediated work produces mixed outcomes. It may enhance autonomy, flexibility, and concentration, while also weakening social ties, increasing work–family interference, and intensifying stress under high coordination demands (Gajendran et al., 2024; Hill et al., 2024). In conflict settings, fragmented communication, delayed feedback, am-

biguous tone, and limited nonverbal cues may increase misunderstandings and hinder their resolution.

Conflict is not uniformly dysfunctional. Task conflict may support learning and decision quality when trust is present, whereas relationship, status, and prolonged process conflict are more strongly associated with strain and reduced performance (Behfar et al., 2008). Digital environments may blur these distinctions by transforming substantive disagreements into interpersonal tensions.

Technostress is a central mechanism linking digital work to conflict. It arises from overload, constant connectivity, technological complexity, uncertainty, and expectations of continuous availability. Although these demands may generate fatigue and distress, supportive system design, autonomy, training, and organizational resources can reduce their negative effects (Bahamondes-Rosado et al., 2023; Molino et al., 2020; Tarafdar et al., 2019).

Public institutions provide a particularly relevant context because digital modernization occurs within hierarchical, procedural, and politically visible structures. In Georgia, digital government reforms have expanded electronic service delivery and interagency coordination, yet their psychosocial consequences remain underexplored compared with their legal, administrative, and technological dimensions (Common, 2011; Government of Georgia, 2023; Administration of the Government of Georgia, 2023).

This paper synthesizes research on the psychosocial determinants of conflict in digital work environments and explains how digital work design may generate, intensify, or mitigate conflict. It integrates conflict management, technostress, work design, occupational well-being, and digital government literature, distinguishes psychosocial demands from protective resources, proposes a conceptual framework, and derives practical implications for organizations and public-sector policymakers.

2. METHODOLOGY OF THE REVIEW

The study adopts a structured narrative review design, suitable for integrating multidisciplinary and methodologically diverse evidence that cannot be meaningfully synthesized through meta-analysis. The approach emphasizes conceptual comparison and interpretation while applying transparent procedures for source identification, selection, and evaluation (Creswell & Creswell, 2018).

The literature search was conducted and updated in 2026 and covered publications from January 2000 to December 2025, with earlier works included only when they provided foundational theories of conflict or stress. Searches were performed in Scopus, Web of Science Core Collection, ScienceDirect, SAGE Journals, SpringerLink, Wiley Online Library, and Google Scholar. Institutional documents were retrieved from relevant Georgian authorities and international organizations, including Eurofound, the OECD, UNDP, and the World Health Organization. For the Georgian public-sector context, the review also drew on the Civil Service Bureau of Georgia (2022).

Search terms combined concepts related to digital and virtual work with psychosocial and conflict-related factors, including technostress, communication asymmetry, role ambiguity, information overload, psychological safety, resilience, and conflict management. Georgia-specific searches also included public administration reform, civil service, electronic document management, and digital public services.

Sources were included when they directly addressed relationships between digital work, psychosocial risks, employee well-being, communication, conflict, leadership, organizational support, or public-sector digital transformation. Eligible materials comprised empirical studies, theoretical articles, reviews, meta-analyses, and authoritative institutional reports. Duplicate publications, unsupported opinion pieces, purely technical studies,

and sources with limited workplace relevance were excluded.

Quality appraisal was adapted to the type of evidence. Scholarly studies were assessed for methodological transparency, research design, reporting quality, theoretical contribution, and relevance. Reviews were evaluated according to the transparency of their search and synthesis procedures, while institutional reports were included only when issued by authoritative bodies and directly relevant to public administration, digitalization, workforce capability, or psychosocial policy. No formal risk-of-bias score was calculated.

The final corpus consisted of 31 sources, including 23 scholarly publications and eight institutional or policy documents. The evidence was coded into six themes: the dual effects of digital work; technostress and cognitive fatigue; communication and information problems; role ambiguity, fairness, and resilience; leadership and conflict management; and Georgian public-sector conditions. The synthesis focused on patterns of agreement, divergence, boundary conditions, and research gaps.

The review is limited by the absence of a registered systematic protocol and pooled effect estimates. Much of the empirical evidence also derives from pandemic-era remote work and private-sector settings. Because direct research on employee conflict in Georgian public institutions remains limited, institutional documents are used to illustrate reform conditions rather than establish causal psychosocial effects.

Table 1. Review search, selection, and synthesis protocol

Protocol element	Specification
Review type	Structured narrative review with thematic and comparative synthesis.
Time coverage	January 2000–December 2025; earlier foundational sources retained selectively.
Academic sources	Scopus, Web of Science Core Collection, ScienceDirect, SAGE Journals, SpringerLink, Wiley Online Library, and Google Scholar.
Institutional sources	Government of Georgia, Civil Service Bureau of Georgia, Digital Governance Agency, Eurofound, OECD, UNDP, and World Health Organization.
Core concepts	Digital/virtual/remote/hybrid work; organizational conflict; technostress; communication asymmetry; role ambiguity; emotional resilience; leadership; psychosocial risk; public-sector digitalization.
Inclusion	Peer-reviewed empirical and review studies, theoretical papers, and authoritative institutional reports directly relevant to workplace psychosocial or conflict processes.
Exclusion	Duplicates, unsupported opinion pieces, purely technical studies, and studies without relevant workplace or psychosocial outcomes.
Quality appraisal	Methodological clarity, relevance, reporting adequacy, theoretical contribution, review transparency, and authority of institutional source.
Analytical output	Six thematic domains, cross-study comparison, identification of contradictions and gaps, conceptual framework, and actionable recommendations.

Source: Developed by the authors based on the review design and literature search, selection, and synthesis procedures applied in this study

3. CRITICAL SYNTHESIS OF THE LITERATURE

3.1. DIGITAL WORK AS BOTH A RESOURCE AND A DEMAND

The literature consistently presents digital work as a combination of resources and demands. It can increase flexibility, improve access to information, support concentration, and reduce spatial constraints. However, it may also intensify connectivity, coordination complexity, platform fragmentation, isolation, and work–life boundary erosion. Accordingly, remote work is neither inherently beneficial nor harmful; its effects depend on the conditions under which it is organized (Eurofound, 2023; Gajendran et al., 2024; Hill et al., 2024; Ipsen et al., 2021).

From a job demands–resources perspective, conflict becomes more likely when digital demands exceed available resources. The effects of technology therefore depend on workload, autonomy, organizational support, employee competence, task interdependence, and communication control (Bakker & Demerouti, 2017; Wang et al., 2021). Digitalization is particularly conflict-prone when expectations increase without corresponding clarification of responsibilities or communication norms.

The literature also identifies an autonomy paradox. After-hours connectivity may provide flexibility, but it can simultaneously normalize constant availability and weaken recovery. Autonomy may reduce the strain associated with connectivity, whereas high work intensity and poorly defined work–life boundaries undermine well-being (Petcu et al., 2023; Van Zoonen, 2023). Its role is therefore conditional: employee-controlled connectivity differs substantially from availability imposed by managerial expectations or organizational culture.

3.2. TECHNOSTRESS, COGNITIVE FATIGUE, AND CONFLICT SENSITIVITY

Technostress is a work-design problem arising from the interaction between technological demands, individual resources, and organizational practices. Its main sources include overload, intrusion into nonwork time, complexity, uncertainty, frequent technological change, and perceived inadequacy. Evidence consistently links techno-overload and techno-invasion to fatigue, burnout, and reduced job satisfaction, particularly where training and organizational support are limited (Bahamondes-Rosado et al., 2023; Molino et al., 2020).

Technostress may also intensify conflict indirectly. Cognitive fatigue impairs attention and interpretation, while emotional exhaustion reduces tolerance for uncertainty and frustration. Employees who feel technologically insecure may perceive routine feedback as criticism or threat. Consequently, technical or procedural disagreements may escalate into perceptions of exclusion, disrespect, or blame.

Not all technology-related demands are harmful. Challenge–hindrance research suggests that demanding tasks can promote learning and performance when they are meaningful, controllable, and adequately supported (Cavanaugh et al., 2000; LePine et al., 2005). Similarly, the distinction between techno-eustress and techno-distress indicates that organizational conditions determine whether digital demands become developmental or harmful (Tarafdar et al., 2019). Organizations should therefore reduce unnecessary complexity, unpredictability, and boundary violations while preserving autonomy and learning opportunities.

3.3. COMMUNICATION ASYMMETRY, REDUCED SOCIAL CUES, AND INFORMATION PROBLEMS

Digital communication alters how employees access and interpret contextual information. Unlike face-to-face interaction, asynchronous communication provides fewer opportunities for immediate clarification and reduces access to tone, gesture, timing, and shared situational awareness. Employees may therefore receive identical formal information while having unequal access to the context in which decisions were made, creating communication asymmetry.

This asymmetry may involve both information overload and information deficit. Overload results from excessive, duplicated, or poorly prioritized communication across multiple platforms, whereas information deficit arises when instructions lack rationale, role clarity, decision history, or feedback. These conditions can coexist, simultaneously reducing attention and increasing uncertainty. Employees may then rely on assumptions, defensive documentation, avoidance, or formal escalation.

Research on virtual teams identifies trust, leadership, knowledge sharing, cultural diversity, and coordination processes as central determinants of conflict (Caputo et al., 2023).

The key issue is therefore not physical distance itself, but the effectiveness of the mechanisms that replace direct interaction. Clear communication protocols, accessible decision records, regular synchronous clarification, and psychologically safe feedback can prevent task disagreements from becoming relationship conflicts.

3.4. ROLE AMBIGUITY, FAIRNESS PERCEPTIONS, AND EMOTIONAL RESILIENCE

Digital transformation often redistributes tasks before formal roles, authority structures, and performance criteria are revised. Employees may be uncertain about process ownership, official communication channels, response expectations, or the use of automated indicators in performance evaluation. In interdependent work, such ambiguity can delay workflows and generate reciprocal blame.

Fairness perceptions provide an additional pathway to conflict. Digital monitoring, unequal access to information, inconsistent flexibility, and uneven training opportunities may undermine distributive, procedural, and interactional justice. Conflict becomes more likely when digitalization expands managerial control without corresponding employee participation or when implementation failures are attributed to individuals rather than system design. Georgian organizational research similarly associates conflict with insufficient feedback, unclear role allocation, and perceived unfairness (Paresashvili et al., 2025).

Emotional resilience, self-efficacy, and coping capacity can moderate these pressures, but they should not substitute for effective organizational design. Sustainable prevention requires both individual resources and structural interventions. These include employee participation, supportive leadership, manager training, clear role allocation, and psychologically safe working conditions (World Health Organization, 2022).

3.5. CONFLICT TYPE, LEADERSHIP, AND ORGANIZATIONAL SUPPORT

Conflict outcomes depend on both conflict type and management approach. Task conflict may support learning when it remains limited, evidence-based, and detached from status or identity threats. Relationship conflict is more damaging because it erodes trust and shapes the interpretation of subsequent interactions. In digital environments, process conflict may be particularly common, arising from disagreements over task ownership, sequencing, communication channels, response expectations, and automated workflows.

Leadership plays a central role in determining whether digital friction becomes constructive or dysfunctional. Avoidant leadership permits misunderstandings to accumulate, while authoritarian leadership may suppress employee voice and encourage passive resistance. By contrast, adaptive digital leaders clarify expectations, interpret data cautiously, encourage questions, and intervene before written disagreements become personal. Supportive conflict-management practices are associated with stronger trust and job satisfaction (Anastasiou, 2020; Behfar et al., 2008).

Organizational support should combine reliable systems, technical assistance, training, temporary workload adjustments, psychosocial resources, and credible conflict-resolution procedures. Although digital competence is important, training alone cannot resolve contradictory instructions or unrealistic demands. Effective prevention therefore requires alignment between technology, work design, communication practices, and managerial behavior.

3.6. PUBLIC-SECTOR SPECIFICITY AND THE GEORGIAN CONTEXT

Public-sector digitalization operates within legal accountability, political oversight, interagency dependence, and formal hierarchy. Although digital systems can strengthen transparency and consistency, they may also increase psychosocial demands by requiring employees to manage legacy procedures, multiple service channels, and reforms extend-

ing across institutional boundaries. Consequently, digital-government frameworks increasingly emphasize workforce capability, human-centered services, and organizational readiness rather than technology acquisition alone (Burtscher et al., 2024; OECD, 2024a).

Georgia's Public Administration Reform Strategy 2023–2026 integrates policy coordination, civil service management, accountability, and public-service delivery (Government of Georgia, 2023). From a psychosocial perspective, this is significant because digital reforms affect not only citizen access but also internal roles, performance expectations, communication patterns, and managerial responsibilities. The Administration of the Government of Georgia (2023) similarly presents modernization as a cross-institutional process rather than an isolated information-technology initiative.

The expansion of the my.gov.ge portal illustrates the scale of this transformation. By 2024, approximately 400 services had been integrated and used more than 13.3 million times (Digital Governance Agency, 2025). These figures do not demonstrate employee stress or conflict, but they indicate substantial coordination, training, and role-clarification requirements. When organizational support fails to match technical expansion, the psychosocial risks identified in the wider literature may become more pronounced.

Earlier research suggests that Georgian public-administration reform is shaped by institutional history, hierarchy, and implementation capacity (Common, 2011). Studies also associate sustainable organizational functioning with effective communication, managerial involvement, job satisfaction, and constructive conflict management (Paresashvili & Avsajanishvili, 2023, 2024; Paresashvili et al., 2020). However, direct institution-level evidence remains limited, highlighting the need for research linking specific digital reforms to employee experiences, conflict patterns, and service outcomes.

Table 2. Critical synthesis: areas of agreement, debate, and research gaps

Theme	Evidence with broad agreement	Important qualification or debate	Research gap
Remote/hybrid work	Can increase flexibility and autonomy but may weaken social connection and boundaries.	Effects depend on work design, intensity, voluntariness, and task interdependence.	More longitudinal evidence outside pandemic conditions.
Technostress	Overload, invasion, complexity, and rapid change are associated with fatigue and lower well-being.	Some digital demands can support learning when employees have control and resources.	Direct tests of technostress as an antecedent of conflict escalation.
Communication	Reduced context and fragmented channels can increase misunderstanding and defensive behavior.	Digital traceability and visibility can also improve accountability and knowledge access.	Comparative evidence on which channel protocols prevent specific conflict types.
Resilience	Self-efficacy and coping resources may buffer stress.	Overemphasis on individual resilience can obscure harmful work design.	Multilevel models combining individual, team, and institutional resources.
Leadership	Supportive, transparent, and responsive leadership improves adaptation and trust.	Leadership training is ineffective without workload, role, and system changes.	Evaluation of digital-leadership interventions in public organizations.
Georgian public sector	Digital service delivery and public administration reform are expanding.	Institutional scale does not itself prove psychosocial harm or benefit.	Employee-level and institution-level empirical studies linking digital reforms, conflict, well-being, and service quality.

Source: Compiled by the authors through a critical synthesis of the reviewed literature

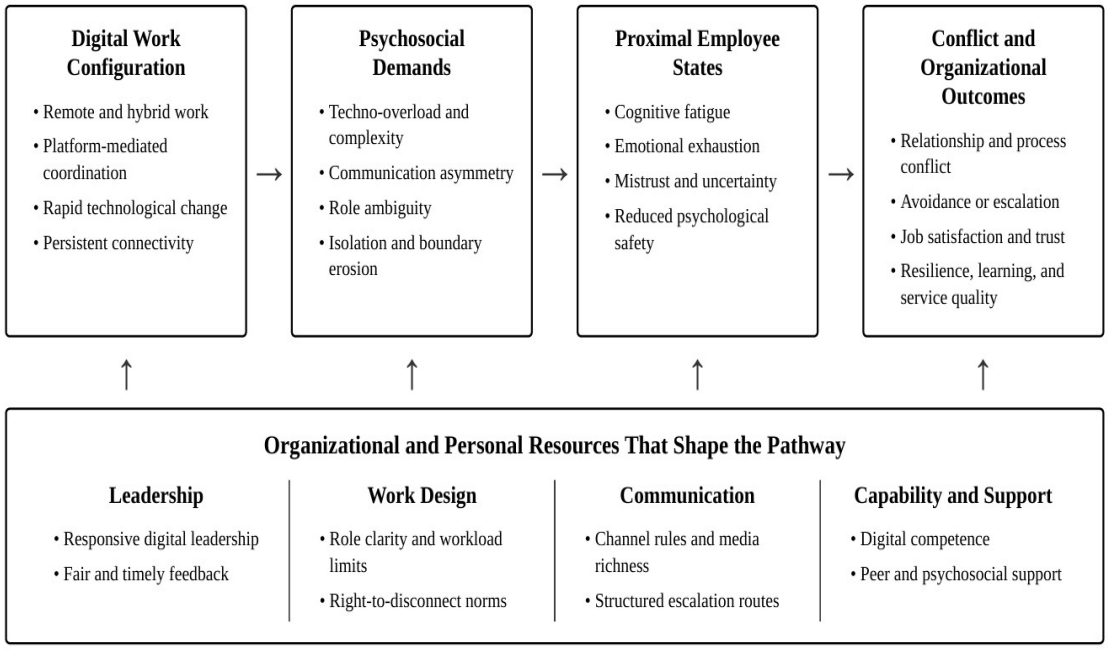
4. CONCEPTUAL FRAMEWORK: PSYCHOSOCIAL PATHWAYS TO DIGITAL CONFLICT

The literature supports an integrated pathway model rather than a direct causal link between digitalization and conflict. Digital transformation first reshapes work design by altering communication channels, information visibility, task interdependence, monitoring, temporal boundaries, and the pace of change. These shifts generate psychosocial demands such as technostress, information overload or deficit, role ambiguity, reduced social cues, and boundary erosion.

These demands affect conflict through employees' cognitive and emotional states. Cognitive fatigue impairs attention, emotional exhaustion reduces interpersonal tolerance, perceived unfairness heightens threat sensitivity, and declining trust alters the interpretation of ambiguous messages. Consequently, task and process disagreements are more likely to become personalized, avoided, or escalated, with implications for job satisfaction, engagement, performance, turnover intentions, institutional resilience, and service quality.

The model also identifies several protective moderators, including adaptive digital leadership, organizational support, digital competence, autonomy, psychological safety, clear communication protocols, participatory change management, and accessible conflict-resolution mechanisms. These resources do not remove disagreement but help ensure that it remains constructive, proportionate, and manageable.

Figure 1. Integrated conceptual framework of psychosocial determinants of organizational conflict in digital work environments



Source: Developed by the authors based on the reviewed literature

4.1. ANALYTICAL PROPOSITIONS

Proposition 1. Digital work intensity affects organizational conflict mainly through indirect pathways. Technostress, communication asymmetry, role ambiguity, and emotional exhaustion transmit much of this effect.

Proposition 2. Job autonomy, digital competence, organizational support, and clear communication governance reduce the likelihood that digital demands will develop into conflict.

Proposition 3. Hierarchical rigidity, fragmented responsibility, and low psychological safety strengthen conflict pathways during public-sector digital transformation.

Proposition 4. Constructive conflict management can preserve the learning value of task disagreement. Delayed or avoidant responses make it more likely that digital task and process conflict will develop into relationship conflict.

5. PRACTICAL RECOMMENDATIONS FOR ORGANIZATIONS AND POLICYMAKERS

Effective prevention requires coordinated action across technology governance, human resource management, leadership, occupational well-being, and conflict-resolution systems. The conceptual framework suggests the following measures.

- **Assess psychosocial risks before implementation.** Organizations should evaluate expected changes in workload, role ownership, monitoring, information access, response expectations, and work–life boundaries before introducing or modifying digital systems. The assessment should involve employees, managers, IT staff, and occupational well-being specialists.
- **Establish a clear communication architecture.** Official channels should be defined for instructions, urgent matters, routine coordination, and conflict escalation. Response-time expectations, decision records, and contextual information should be standardized, with synchronous communication used for complex or sensitive issues.
- **Protect disconnection and workload boundaries.** Organizations should limit nonessential communication outside working hours and avoid equating online visibility with performance. Where after-hours work is necessary, rotation, compensation, and recovery arrangements should be introduced.
- **Strengthen digital leadership and conflict-management competence.** Managers should be trained to recognize technostress, interpret performance data cautiously, distinguish task from relationship conflict, and transfer emotionally charged exchanges to more appropriate communication channels.
- **Use participatory and staged implementation.** New systems should be piloted with representative users, followed by structured feedback and workflow revision. Transparent communication about resulting changes can strengthen procedural fairness and reveal overlooked interdependencies.
- **Provide accessible early-resolution mechanisms.** Employees should have confidential channels for raising concerns and clear procedures for resolving digital-work conflicts. Neutral facilitators or HR specialists should be involved when internal resolution is unsuccessful.
- **Monitor psychosocial and conflict indicators.** Post-implementation evaluation should combine employee surveys with indicators such as after-hours communication, support requests, unresolved task transfers, absenteeism, turnover intentions, grievances, and recurring workflow errors. These data should support organizational improvement rather than individual surveillance.
- **Integrate employee well-being into digital-government reform.** Public-sector digitalization should include funded workforce development, role and process mapping, interagency coordination, and employee well-being indicators alongside measures of service use and efficiency (Burtscher et al., 2024; OECD, 2024b).

5.1. IMPLEMENTATION PRIORITIES AND MONITORING

Implementation should follow a phased and coordinated approach. Before acquiring or introducing a digital system, organizations should conduct a psychosocial digital-change assessment involving project sponsors, human resource specialists, IT staff, and occupa-

tional well-being professionals. The process should produce a documented risk register and mitigation plan.

Within the first three months, organizations should establish communication protocols and digital-disconnection policies. Senior and line managers, supported by HR, should clarify official channels, response expectations, task ownership, and after-hours availability. Progress may be assessed through reduced channel duplication, clearer responsibilities, and fewer nonessential after-hours messages.

Within three to six months, organizations should introduce digital leadership training and early conflict-resolution mechanisms. Managers should be trained to recognize technostress, moderate digital conflict, and provide psychologically safe feedback. HR, ethics or compliance units, and neutral facilitators should provide accessible resolution procedures. Relevant indicators include training completion, improved team feedback, shorter resolution times, and fewer recurring disputes.

Employee participation should continue throughout piloting and implementation. Project teams should document feedback and report how it influenced system or workflow design. After implementation, psychosocial and organizational indicators including technostress, role clarity, trust, communication quality, after-hours workload, and conflict frequency should be reviewed quarterly. These measures should support organizational improvement rather than individual surveillance.

6. DISCUSSION

This review demonstrates that organizational conflict in digital work environments is fundamentally a socio-technical phenomenon. Digital technologies do not replace traditional sources of conflict, such as resource dependence, incompatible goals, status differences, or perceived unfairness. Rather, they reshape how employees experience and interpret these conditions by altering communication, coordination, and work boundaries.

The review's main contribution is a framework linking digital work design to conflict through psychosocial mediators. While previous studies have largely examined technostress, remote work, and virtual-team conflict separately, the proposed framework integrates these perspectives by showing how digital demands influence fatigue, trust, resilience, and fairness perceptions, which subsequently affect conflict emergence and escalation. It also highlights organizational resources as key moderators, emphasizing that individual coping alone is insufficient.

The literature reveals important methodological limitations. Most studies rely on cross-sectional self-reports, pandemic-era samples, and private-sector settings, limiting causal inference. Future research should adopt longitudinal, multilevel, and mixed-method designs to distinguish task, process, and relationship conflict while examining both technological demands and organizational resources.

For Georgia, future research should move beyond general discussions of digital modernization toward institution-level evidence. Comparative studies across public organizations with different levels of digital maturity could examine employee experiences before and after digital implementation and relate psychosocial factors to service quality, implementation effectiveness, and citizen outcomes. Such evidence would provide a stronger basis for human-centered public administration reform.

7. CONCLUSION

Digital transformation has reconfigured organizational communication, coordination, and conflict. Although digital work can enhance flexibility, autonomy, learning, and information access, it may also generate technostress, communication fragmentation, role

ambiguity, emotional exhaustion, perceived unfairness, and declining trust. Whether these pressures develop into destructive conflict depends primarily on work design, leadership, organizational support, communication governance, and employee participation.

Conflict in digital environments should therefore be addressed through a preventive socio-technical approach. Clear role definitions, communication protocols, realistic work boundaries, digital competence, adaptive leadership, psychologically safe feedback, participatory implementation, and accessible early-resolution mechanisms can reduce conflict escalation. These measures also strengthen organizational sustainability by protecting employee well-being, institutional trust, and adaptive capacity.

In Georgia, the expansion of digital public services and administrative reform highlights the need to integrate workforce capability and psychosocial risk into digital-governance policy. Although current initiatives demonstrate substantial technological progress, direct evidence on employee conflict and well-being remains limited. Future longitudinal and comparative research should test the proposed framework and identify interventions that improve both employee outcomes and public-service performance.

REFERENCES

Administration of the Government of Georgia. (2023). *Handbook on public administration reform in Georgia*. https://www.undp.org/publications/par-handbook-2023

Anastasiou, S. (2020). The significant effect of leadership and conflict management on job satisfaction. *Academic Journal of Interdisciplinary Studies, 9*(6), 9–17. https://doi.org/10.36941/ajis-2020-0107

Bahamondes-Rosado, M. E., Cerdá-Suárez, L. M., Dodero Ortiz de Zevallos, G. F., & Espinosa-Cristia, J. F. (2023). Technostress at work during the COVID-19 lockdown phase (2020–2021): A systematic review of the literature. *Frontiers in Psychology, 14*, Article 1173425. https://doi.org/10.3389/fpsyg.2023.1173425

Bakker, A. B., & Demerouti, E. (2017). Job demands–resources theory: Taking stock and looking forward. *Journal of Occupational Health Psychology, 22*(3), 273–285. https://doi.org/10.1037/ocp0000056

Behfar, K. J., Peterson, R. S., Mannix, E. A., & Trochim, W. M. K. (2008). The critical role of conflict resolution in teams: A close look at the links between conflict type, conflict management strategies, and team outcomes. *Journal of Applied Psychology, 93*(1), 170–188. https://doi.org/10.1037/0021-9010.93.1.170

Burtscher, M., Piano, S., & Welby, B. (2024). *Developing skills for digital government: A review of good practices across OECD governments* (OECD Social, Employment and Migration Working Papers No. 303). OECD Publishing. https://doi.org/10.1787/f4dab2e9-en

Caputo, A., Kargina, M., & Pellegrini, M. M. (2023). Conflict in virtual teams: A bibliometric analysis, systematic review, and research agenda. *International Journal of Conflict Management, 34*(1), 1–31. https://doi.org/10.1108/IJCMA-07-2021-0117

Cavanaugh, M. A., Boswell, W. R., Roehling, M. V., & Boudreau, J. W. (2000). An empirical examination of self-reported work stress among U.S. managers. *Journal of Applied Psychology, 85*(1), 65–74. https://doi.org/10.1037/0021-9010.85.1.65

Civil Service Bureau of Georgia. (2022). *Civil Service Bureau's report of 2022 activity*. https://www.csb.gov.ge/

Common, R. (2011). International trends in HRM in the public sector: Reform attempts in the Republic of Georgia. *International Journal of Public Sector Management, 24*(5), 421–434. https://doi.org/10.1108/09513551111147150

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications. https://collegepublishing.sagepub.com/products/research-design-5-255675

Digital Governance Agency. (2025). *Digital Governance Agency 2024 annual report*. Government of Georgia. https://www.dga.gov.ge/?id=KaT4g2ROuR&m=articles

Eurofound. (2023). *Hybrid work in Europe: Concept and practice*. Publications Office of the European Union. https://doi.org/10.2806/26474

Gajendran, R. S., Ponnapalli, A. R., Wang, C., & Javalagi, A. A. (2024). A dual pathway model of remote work intensity: A meta-analysis of its simultaneous positive and negative effects. *Personnel Psychology, 77*(4), 1351–1386. https://doi.org/10.1111/peps.12641

Government of Georgia. (2023). *Public Administration Reform Strategy of Georgia 2023–2026* (Government Decree No. 66). https://www.matsne.gov.ge/ka/document/view/5723982

Grover, V., Tseng, S.-L., & Pu, W. (2022). A theoretical perspective on organizational culture and digitalization. *Information & Management, 59*(4), Article 103639. https://doi.org/10.1016/j.im.2022.103639

Hill, N. S., Axtell, C., Raghuram, S., & Nurmi, N. (2024). Unpacking virtual work's dual effects on employee well-being: An integrative review and future research agenda. *Journal of Management, 50*(2), 752–792. https://doi.org/10.1177/01492063221131535

Ipsen, C., van Veldhoven, M., Kirchner, K., & Hansen, J. P. (2021). Six key advantages and disadvantages of working from home in Europe during COVID-19. *International Journal of Environmental Research and Public Health, 18*(4), Article 1826. https://doi.org/10.3390/ijerph18041826

LePine, J. A., Podsakoff, N. P., & LePine, M. A. (2005). A meta-analytic test of the challenge stressor–hindrance stressor framework: An explanation for inconsistent relationships among stressors and performance. *Academy of Management Journal, 48*(5), 764–775. https://doi.org/10.5465/amj.2005.18803921

Molino, M., Ingusci, E., Signore, F., Manuti, A., Giancaspro, M. L., Russo, V., Zito, M., & Cortese, C. G. (2020). Wellbeing costs of technology use during COVID-19 remote working: An investigation using the Italian translation of the technostress creators scale. *Sustainability, 12*(15), Article 5911. https://doi.org/10.3390/su12155911

OECD. (2024a). *2023 OECD Digital Government Index: Results and key findings* (OECD Public Governance Policy Papers No. 44). OECD Publishing. https://doi.org/10.1787/1a89ed5e-en

OECD. (2024b). *Global trends in government innovation 2024: Fostering human-centred public services*. OECD Publishing. https://doi.org/10.1787/c1bc19c3-en

Paresashvili, N., & Avsajanishvili, E. (2023). Stress as a method of increasing performance and stimulating innovation: A synthesis of literature. *Economics and Business, 37*, 236–246. https://doi.org/10.2478/eb-2023-0015

Paresashvili, N., & Avsajanishvili, E. (2024). The role of stress and conflict management in sustainable business processes. *Rural Environment. Education. Personality, 17*, 91–99. https://doi.org/10.22616/REEP.2024.17.010

Paresashvili, N., Gurbanov, N., Gechbaia, B., Goletiani, K., & Edzgveradze, T. (2020). Significant issues of organizational conflict management. In *Proceedings of the 55th International Scientific Conference on Economic and Social Development* (pp. 457–464). https://esd-conference.com/publications-archive

Paresashvili, N., Okruashvili, N., Melkoshvili, T., Chitaladze, K., Nikvashvili, M., & Edzgveradze, T. (2025). The role of conflict management strategies in improving job satisfaction and associated challenges. *TPM: Testing, Psychometrics, Methodology in Applied Psychology, 32*(S7), 2683–2690. https://tpmap.org/submission/index.php/tpm/article/view/3824

Petcu, M. A., Sobolevschi-David, M. I., Crețu, R. F., Curea, S. C., Hristea, A. M., Oancea-Negescu, M. D., & Tutui, D. (2023). Telework: A social and emotional perspective of the impact on employees' wellbeing in the COVID-19 pandemic. *International Journal of Environmental Research and Public Health, 20*(3), Article 1811. https://doi.org/10.3390/ijerph20031811

Tarafdar, M., Cooper, C. L., & Stich, J.-F. (2019). The technostress trifecta—Techno eustress, techno distress and design: Theoretical directions and an agenda for research. *Information Systems Journal, 29*(1), 6–42. https://doi.org/10.1111/isj.12169

van Zoonen, W. (2023). Staying connected and feeling less exhausted: The autonomy benefits of after-hour connectivity. *Journal of Occupational and Organizational Psychology, 96*(1), 242–263. https://doi.org/10.1111/joop.12422

Wang, B., Liu, Y., Qian, J., & Parker, S. K. (2021). Achieving effective remote working during the COVID-19 pandemic: A work design perspective. *Applied Psychology, 70*(1), 16–59. https://doi.org/10.1111/apps.12290

World Health Organization. (2022). *WHO guidelines on mental health at work*. https://www.who.int/publications/i/item/9789240053052

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

ECONOMIC MECHANISM FOR AGRICULTURAL E-COMMERCE DEVELOPMENT IN KAZAKHSTAN

Azamat Zhanseitov[1]*

Received 08.03.2026. | Send to review 15.04.2026. | Accepted 20.08.2026.

Original Article

[1] Turan-Astana University, Astana, Kazakhstan

***Corresponding Author:**
Azamat Zhanseitov

Email:
a.zhanseitov@apa.kz

JEL Classification:
L81; O18; O33; Q13; Q16; R11

Doi: 10.61432/CPNE0401231z

UDK: 004.738.5:005.591.5(574)

ABSTRACT
Agricultural e-commerce can improve market access, price transparency, and commercial opportunities for rural producers, but its development requires more than basic internet connectivity. This study assesses regional readiness for agricultural e-commerce in Kazakhstan and proposes a policy mechanism based on the DalaMart platform. The empirical analysis uses an unbalanced panel of 95 observations covering 17 regions from 2018 to 2024. A fixed-effects model examines the relationship between rural internet penetration and digital literacy, fixed internet subscriptions, rural telephone use, road quality, and a national time trend. A composite digital-agricultural readiness index is applied only to compare regional conditions and should not be interpreted as a direct indicator of online sales. The results show considerable territorial inequality. The average readiness index is 0.714 in leading regions, compared with 0.424 in lagging regions. Digital literacy is positively associated with rural internet penetration ($\beta = 0.214$; $p < 0.05$), while the national time trend is also positive and highly significant ($\beta = 2.774$; $p < 0.001$). Infrastructure variables are not statistically significant within regions during the observed period. This finding is interpreted cautiously because regional fixed effects absorb persistent differences, while infrastructure indicators change only gradually. DalaMart is presented as a policy design rather than an empirically validated impact model. The proposed mechanism combines connectivity, practical producer training, verified marketplace transactions, logistics, digital payments, product traceability, and data-driven services. The study concludes that agricultural e-commerce policies should evaluate completed transactions, delivery performance, producer margins, and repeat demand rather than relying only on platform registrations or connectivity indicators.

Keywords: *agricultural e-commerce, DalaMart, digital literacy, regional readiness, rural markets, platform economy, logistics, Kazakhstan*

1. INTRODUCTION

Digital platforms are transforming how agricultural products are marketed, ordered, paid for and delivered. For producers, e-commerce can lower buyer-search costs, improve access to market information, and create more direct links with retailers, processors, and consumers. For buyers, digital platforms can increase transparency regarding product

origin, price, quality, and delivery conditions (Aumeboonsuke & Caplanova, 2026). These benefits are especially relevant in countries with geographically dispersed production and supply chains involving multiple intermediaries.

Kazakhstan provides an important setting for examining agricultural e-commerce because its strong agricultural potential is combined with long distances, low population density, and unequal rural infrastructure. Regional conditions vary considerably, from commercial grain-producing areas and livestock regions to peri-urban horticultural zones and remote settlements with limited logistics services. Consequently, the same digital platform is unlikely to produce uniform outcomes. Regions with reliable connectivity, stronger digital skills, and developed commercial networks may progress quickly toward formal online transactions, while less prepared regions may remain dependent on informal communication and ordering.

A key distinction in this study is between digital readiness and actual e-commerce adoption (Shojaei et al., 2026). Internet access is necessary, but it does not automatically produce searchable product catalogues, digital payments, coordinated delivery, traceability, or repeat purchases. Agricultural e-commerce should therefore be viewed as an institutional system in which product information, orders, payments, logistics, and dispute procedures are standardized and verifiable. Its development requires infrastructure, organizational capacity, and effective market rules.

The theoretical framework draws on transaction-cost economics, information-asymmetry theory, and diffusion theory. Platforms can reduce search, negotiation, and monitoring costs (Williamson, 1985), while verified identities and reliable product information can reduce information asymmetry (Akerlof, 1970). Diffusion theory further highlights the importance of perceived usefulness, complexity, and observable benefits (Rogers, 2003). Recent studies also emphasize digital literacy, trust, logistics, and consumer confidence as essential conditions for rural e-commerce development (He et al., 2024; Hendricks & Mwapwele, 2024; Liu et al., 2022; Sun & Yu, 2025).

The study has two objectives. First, it evaluates regional readiness for agricultural e-commerce in Kazakhstan using a composite index and a fixed-effects panel model. Second, it translates the empirical findings into a policy mechanism centred on DalaMart, proposed as a pilot platform integrating transactions, logistics, and data-based services. The analysis does not estimate actual e-commerce turnover or the causal impact of DalaMart. Instead, its main contribution is the regional assessment of readiness and the development of a differentiated implementation strategy.

2. THEORETICAL FRAMEWORK

Agricultural trade involves substantial costs related to buyer search, negotiation, packaging, transport, payment, and complaint handling. These costs are especially high for small, geographically dispersed, and weakly standardized producers. A specialized digital marketplace can reduce them by providing reusable product profiles, transparent rules, and standardized transaction procedures.

Unlike generic messaging applications, agricultural e-marketplaces can offer searchable supply, verified identities, payment protection, transaction histories, and coordinated commercial services. Their value depends not only on enabling contact but also on building trust, supporting fulfilment, and measuring buyer satisfaction (Garcia-Gallego et al., 2025; Jahan et al., 2025; Mayorga-Abril et al., 2026).

Digital readiness combines infrastructure and human capability. Connectivity enables access, while digital literacy determines whether producers can create product listings, compare offers, process payments, manage orders, and resolve complaints. Practical training

is therefore more important than general computer literacy because successful participation requires the ability to complete the full transaction cycle (Nguyen et al., 2025).

Territorial conditions also shape adoption outcomes. Because agricultural products are physical, often perishable, and costly to transport, road quality, storage, aggregation capacity, and delivery density determine whether online demand can be fulfilled. Digital commerce and rural logistics must therefore develop together, which explains why the same platform may perform differently across regions (Liu et al., 2022).

International evidence supports this interpretation. Studies from China emphasize public policy, farmer awareness, and benefit-sharing mechanisms, while research from Spain, Poland, and Bangladesh highlights the importance of trust, product information, quality perception, and delivery experience (Wei & Ruan, 2022; Barska & Wojciechowska-Solis, 2020; Garcia-Gallego et al., 2025; Jahan et al., 2025). Comparative research on China and the European Union similarly shows that digital tools create value when integrated with production, logistics, and service systems (Qin et al., 2022).

Research from Kazakhstan also points to the importance of governance, institutional coordination, data flows, and market-support infrastructure (Akilzhanova et al., 2025; Yessengeldin et al., 2026b). DalaMart should therefore be viewed not as an isolated application but as part of a wider regulatory and service-delivery system.

The proposed economic mechanism includes five connected functions: access, capability, transaction, fulfilment, and scaling. DalaMart would serve as a pilot platform linking these functions through marketplace rules, logistics, payments, and analytics. Public support should remain conditional on transparent fees, interoperability, data portability, competition, and independently measured outcomes, ensuring that the platform supports producers without creating a protected monopoly.

3.MATERIALS AND METHODS

3.1. DATA AND VARIABLES

The empirical analysis covers 17 regions of Kazakhstan from 2018 to 2024. Although the theoretical maximum is 119 region-year observations, the final sample includes 95 observations after removing cases with missing values. Missing data mainly result from incomplete historical records for newly established regions and gaps in official statistics. No interpolation was used because estimated values could distort within-region variation in a short panel. The resulting dataset is therefore unbalanced.

Rural internet penetration is the dependent variable, measured as the share of the rural population aged 16-74 with internet access. It is used as an indicator of digital readiness rather than as a measure of actual agricultural e-commerce activity, such as sales, transactions, or platform revenues. This distinction allows the study to assess enabling conditions but limits conclusions about market performance.

The main explanatory variable is digital literacy, measured as the proportion of the population with basic digital skills. Control variables include the logarithm of fixed internet subscribers, the logarithm of rural telephone users, the road quality index, and a linear time trend. Data were obtained from the Bureau of National Statistics of Kazakhstan and other official sectoral sources. The short panel is appropriate for identifying within-region associations, although it is less effective for estimating the influence of infrastructure variables that change slowly over time.

3.2. COMPOSITE INDEX CONSTRUCTION

A composite digital-agricultural readiness index is used for territorial comparison. Five indicators are normalised to the interval from zero to one: rural internet penetration, dig-

ital literacy, road quality, enterprise digitalisation intensity and smart-farm prevalence. The index is calculated as the equal-weighted mean of these normalised components:

$$Readiness_{it} = (Internet_{it}^{N} + DigitalLiteracy_{it}^{N} + RoadQuality_{it}^{N} + EnterpriseDigitalisation_{it}^{N} + SmartFarm_{it}^{N}) / 5 \quad (1)$$

Equal weighting is used to ensure transparency and avoid prioritizing any readiness dimension without strong empirical justification. The index is not included as a causal variable in the fixed-effects model but is used only to group regions for implementation planning. Regions scoring above 0.65 are classified as leaders, those between 0.50 and 0.65 as middle-tier, and those below 0.50 as lagging. These policy-oriented thresholds distinguish advanced, transitional, and foundation-building contexts rather than absolute levels of agricultural performance.

The robustness of the classification was assessed using two alternative weighting schemes: one emphasizing digital capability through internet penetration and digital literacy, and another emphasizing infrastructure and logistics through road quality and enterprise digitalization. Although regional scores vary under these alternatives, the main conclusion remains unchanged: readiness differs substantially across territories and requires differentiated policy responses. Equal weighting is retained because it is transparent, reproducible, and less dependent on subjective assumptions.

3.3. ECONOMETRIC SPECIFICATION

A regional fixed-effects model is estimated to remove unobserved time-invariant characteristics such as geography, historical settlement patterns and persistent agricultural specialisation. The specification is:

$$Y_{it} = \alpha_i + \beta_1 DL_{it} + \beta_2 FI_{it} + \beta_3 RT_{it} + \beta_4 RQ_{it} + \beta_5 T_t + \varepsilon_{it} \quad (2)$$

In the model, (Y) denotes rural internet penetration; (DL) digital literacy; (FI) fixed internet subscriptions; (RT) rural telephone use; (RQ) road quality; and (T) the time trend. Regional fixed effects are represented by (α_i), while (ε_{it}) is the error term. Estimation uses the within estimator with robust standard errors. Variance inflation factors are below five, suggesting that multicollinearity is not a serious concern.

The model captures associations within regions and does not establish causal effects on agricultural e-commerce sales or the effectiveness of DalaMart.

Evidence from the survey of 120 farms conducted by Yessengeldin et al. (2026a) is used only as an external plausibility check. Two descriptive indicators are referenced: the share of farms using electronic sales channels and the share exhibiting high digital maturity. These data are not included in the regression and are not treated as a separate empirical dataset, allowing the study to maintain its focus on regional readiness.

4.RESULTS AND DISCUSSION

4.1. REGIONAL READINESS

The regional index shows a clear readiness gap. Five leading regions - Akmola, North Kazakhstan, Pavlodar, Kostanay and Zhetysu - have a mean score of 0.714. Five middle-tier regions have a mean of 0.574, while seven lagging regions average 0.424. The difference between leader and lagging means is approximately 0.290, which is large relative to the index scale. The results indicate that national programmes operate within substantially different territorial environments.

Table 1. Regional digital-agricultural readiness groups

Group	Number of regions	Mean index	Index range	Representative regions
Leader	5	0.714	0.67-0.79	Akmola; North Kazakhstan; Pavlodar; Kostanay; Zhetysu
Middle-tier	5	0.574	0.51-0.62	East Kazakhstan; Almaty; Karaganda; Zhambyl; Turkestan
Lagging	7	0.424	0.35-0.49	Abay; Aktobe; West Kazakhstan; Kyzylorda; Atyrau; Mangystau; Ulytau

Source: Author's calculations based on Bureau of National Statistics and official agricultural digitalisation data

4.2. FIXED-EFFECTS ESTIMATES

The fixed-effects results are presented in Table 2. The model explains a high share of within-region variation in rural internet penetration (within R-squared = 0.857). Digital literacy has a positive and statistically significant coefficient. A one-percentage-point increase in digital literacy is associated with a 0.214-percentage-point increase in rural internet penetration, holding other included factors constant. The national time trend is also positive and highly significant, indicating broad technological diffusion across the country.

Table 2. Fixed-effects model of rural internet penetration

Variable	Coefficient	Robust standard error	t-statistic	Significance
Digital literacy	0.214	0.089	2.40	$p < 0.05$
Fixed internet subscribers, ln	0.108	0.124	0.87	Not significant
Rural telephone users, ln	0.071	0.091	0.78	Not significant
Road quality index	0.063	0.078	0.81	Not significant
Time trend	2.774	0.183	15.16	$p < 0.001$

Notes: N = 95 region-year observations; 17 regional fixed effects; within R-squared = 0.857; overall R-squared = 0.912

Source: Author's calculations

4.3. INTERPRETATION, ROBUSTNESS AND INTERNATIONAL COMPARISON

The lack of statistical significance for fixed internet subscriptions, rural telephone use, and road quality should not be taken to mean that infrastructure is unimportant. In a fixed-effects model, persistent regional differences are absorbed by the regional effects, while slowly changing infrastructure indicators provide limited within-region variation over a short period. Moreover, the road quality index does not capture important logistical factors such as last-mile delivery, cold-chain capacity, collection points, and route reliability. The results therefore suggest that digital literacy and broader technological diffusion are more visible short-term drivers of rural internet access, while physical infrastructure remains essential for fulfilment and regional inclusion.

The positive association between digital literacy and rural internet penetration has clear policy implications. Training should focus on practical transaction skills, including creating verified profiles and product listings, setting prices and delivery terms, using digital payments, and completing orders. General computer courses alone are unlikely to support effective e-commerce participation. This interpretation is consistent with studies showing that rural e-commerce depends on skills, trust, and logistics as well as platform access (Hendricks & Mwapwele, 2024; He et al., 2024; Liu et al., 2022).

The findings also align with international evidence. Studies from China emphasize the

combined role of policy support, logistics, and farmer participation, while European research highlights trust, product information, and viable business models for small producers (Wei & Ruan, 2022; Qin et al., 2022; Garcia-Gallego et al., 2025). Evidence from Poland and Bangladesh further shows that consumer confidence and delivery quality influence online market outcomes (Barska & Wojciechowska-Solis, 2020; Jahan et al., 2025). This study extends these insights by linking them to regional readiness differences in Kazakhstan and proposing a staged rather than uniform implementation approach.

Farm-level evidence provides a limited external benchmark. Yessengeldin et al. (2026a) found that 44.2% of surveyed farms used electronic sales channels, while only 11.7% had achieved high digital maturity. Although these values are not re-estimated here, they support the distinction between access, initial adoption, and fully developed e-commerce use. The main policy challenge is therefore to move producers from basic online communication toward verified transactions and reliable fulfilment.

5. DALAMART ECONOMIC MECHANISM

5.1. SCOPE OF THE POLICY PROPOSAL

DalaMart is recommended as a pilot mechanism, not presented as an already validated policy intervention. The fixed-effects model supports the need for differentiated regional targeting, while the DalaMart proposal translates this finding into an implementation design. The empirical results do not prove that DalaMart will increase producer income, reduce logistics costs or expand e-commerce sales. Those outcomes require a separate impact evaluation using direct transaction, logistics and producer-income data.

The platform should support both business-to-business and business-to-consumer transactions, but its public-policy value depends on openness. DalaMart should operate as a competitive pilot rather than a protected monopoly. Public support should be conditional on transparent fees, data portability, interoperable interfaces, non-discriminatory seller rules and independent monitoring. This distinction between empirical findings and policy recommendation reduces the risk of overstating the study's conclusions.

5.2. PLATFORM ARCHITECTURE

DalaMart is recommended as a mobile-first pilot marketplace integrating verified registration, standard catalogues, B2B and B2C ordering, digital payments, transparent fees, delivery options and dispute procedures. Later modules can add certification, traceability, analytics, forecasting and links to finance.

Table 3. DalaMart implementation mechanism

Layer	Main constraint	DalaMart and supporting policy	Performance indicator
1. Access	Uneven connectivity and service coverage	Mobile-first interface; assisted rural access points; regional onboarding partners	Active service area; connection reliability
2. Capability	Low practical digital-selling skills	Task-based training; catalogue templates; cooperative digital specialists	Verified profiles; complete product cards
3. Transaction	Informal orders and weak trust	Verified sellers; standard terms; payments; ratings; dispute process	Verified orders; payment completion; repeat buyers
4. Fulfilment	High logistics cost and perishability	Aggregation; delivery partners; cold-chain options; traceability	Delivery time; cancellation rate; spoilage rate
5. Scaling	Limited finance and market intelligence	Transaction analytics; demand forecasts; finance based on verified history	Sales growth; market radius; access to finance

Source: Author's proposal. DalaMart is a recommended pilot and has not been impact-evaluated in this study

5.3. DIFFERENTIATED REGIONAL ROLLOUT

Leader regions should serve as demonstration and scaling sites. Given their stronger readiness, pilots can focus on advanced B2B contracts, integrated payments, export traceability, and data-based demand planning. Performance should be assessed through producer margins, repeat purchases, delivery reliability, and the share of verified transactions. Public support should concentrate on interoperability, independent evaluation, and temporary assistance for shared infrastructure where market failures persist.

Middle-tier regions require a combined platform and logistics package. Although they have sufficient readiness to participate, they often need stronger coordination among producers, buyers, and delivery providers. Useful measures include group onboarding, standardized catalogue templates, regional aggregation partners, and anchor buyers capable of generating initial transaction volume.

Lagging regions need a foundation-building approach. Assisted access points, cooperative digital specialists, and local aggregation hubs can help overcome skills and delivery barriers. Any subsidies should be temporary and linked to verified registration, completed orders, and repeat use. The immediate priority in these regions is to convert basic digital access into reliable transactions and fulfilment routines.

5.4. FINANCING, GOVERNANCE AND MONITORING

A three-stage incentive scheme is proposed. The first stage supports producer onboarding and verified product information. The second partially covers initial transaction and logistics costs to address low order density. The third co-finances expansion only when platform data demonstrate sustained demand and reliable fulfilment. This approach rewards actual use rather than equipment purchases and reduces the risk of supporting inactive accounts.

Governance should ensure transparent fees, understandable ranking rules, data portability, and human review of automated decisions. Consumer protection should cover accurate product descriptions, delivery obligations, refunds, and perishable goods. Producers should have access to transaction histories and clear procedures for suspension, complaints, and ranking changes. Such safeguards reflect the need for coordinated institutional support in agricultural digitalisation (Akilzhanova et al., 2025; Yessengeldin et al., 2026b).

Monitoring should distinguish readiness, adoption, formalisation, and market outcomes. Key indicators include active verified sellers, completed orders, digital payments, delivery times, cancellations, spoilage, repeat purchases, producer margins, and market reach. Registration numbers alone are insufficient because they do not demonstrate actual sales or reliable logistics.

5.5. IMPLEMENTATION RISKS AND EVALUATION LIMITS

The first risk is the platform coordination problem. Producers may avoid preparing catalogues when buyer demand is weak, while buyers may stay away when supply and delivery are unreliable. Pilots should therefore focus on selected products and territories where sufficient transaction density can be created. Cooperative aggregation, anchor buyers, and temporary logistics support can help overcome this initial network barrier.

A second risk concerns market power and data concentration. A dominant platform may increase fees, favour related services, or restrict access to transaction data. Public support should therefore require data portability, non-discriminatory seller rules, transparent rankings, and regular competition review. Clear consent, purpose limitation, and data-retention rules are also necessary because agricultural data may reveal commercially sensitive information (Wolfert et al., 2017).

A third risk is inadequate fulfilment capacity. Perishable goods require suitable packag-

ing, storage, cold chains, and reliable delivery. Regional implementation should therefore begin with a logistics assessment and realistic service areas. In remote regions, shared collection points and scheduled delivery may be more practical than individual on-demand shipping (Deichmann et al., 2016).

The study has four main limitations. Rural internet penetration is only a readiness proxy, the panel is short and incomplete for newly created regions, the composite index uses equal weights, and DalaMart has not yet been evaluated empirically. The index should therefore be treated as a screening tool rather than a definitive regional ranking.

Future research should use direct platform data on sales, delivery distances, product categories, cancellations, repeat purchases, and producer margins. Pilot evaluation should compare similar producer groups introduced at different times and measure outcomes before and after onboarding. It should also separate the effects of platform access from those of training, logistics, and payment integration before wider national support is considered.

6. CONCLUSION

This study assessed agricultural e-commerce in Kazakhstan through regional readiness rather than direct transaction performance. The results reveal substantial territorial inequality, with leading regions averaging 0.714 on the composite readiness index compared with 0.424 among lagging regions. Digital literacy was positively associated with rural internet penetration, while the significant time trend reflected broader nationwide digital diffusion. Although infrastructure variables were not statistically significant within regions, they remain essential for territorial accessibility, logistics, and reliable order fulfilment.

The main policy implication is that agricultural e-commerce should not be treated simply as a matter of connectivity or platform registration. Regions require different combinations of digital access, producer capabilities, transaction support, logistics infrastructure, and performance monitoring. DalaMart is proposed as an interoperable pilot platform linking these functions, but its effectiveness should be tested through phased implementation and direct transaction-level evidence before national expansion. Success should be evaluated through completed orders, delivery reliability, producer margins, and repeat demand rather than the number of registered users alone.

REFERENCES

Akerlof, G. A. (1970). The market for 'lemons': Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics*, 84(3), 488-500. https://doi.org/10.2307/1879431

Akilzhanova, L., Zhanseitov, A., Belgibayeva, K., Kuttybayeva, N., & Alimbayeva, L. (2025). State governance of information processes in Kazakhstan's regions: A sectoral case study of agriculture in the digital economy. *Research on World Agricultural Economy*, 6(4), 784-797. https://doi.org/10.36956/rwae.v6i4.2832

Aumeboonsuke, V., & Caplanova, A. (2026). Determinants of the Digital Gap: A Comparative Analysis of Central Europe and Southeast Asia, 2002–2024. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 309-332. https://doi.org/10.2478/eoik-2026-0038

Barska, A., & Wojciechowska-Solis, J. (2020). E-consumers and local food products: A perspective for developing online shopping for local goods in Poland. *Sustainability*, 12(12), 4958. https://doi.org/10.3390/su12124958

Bureau of National Statistics of the Republic of Kazakhstan. (2025a). Digital literacy of the population: Regional statistics 2018-2024. Astana: BNS. https://stat.gov.kz/en/industries/economy/local-market/publications/488906/

Dauliyeva, G. R., Yerezhepova, A. A., & Bakytzhan, S. S. (2022). Digital systems as a vector of success in agriculture of the Republic of Kazakhstan. *Problems of AgriMarket*, 2, 56-63. https://doi.org/10.46666/2022-2.27

Dayioglu, M. A., & Turker, U. (2021). Digital transformation for a sustainable future: Agriculture 4.0. Tarim Bilimleri Dergisi. https://doi.org/10.15832/ankutbd.986431

Deichmann, U., Goyal, A., & Mishra, D. (2016). Will digital technologies transform agriculture in developing countries? *Agricultural Economics*, 47(S1), 21-33. https://doi.org/10.1111/agec.12300

Garcia-Gallego, J. M., Chamorro-Mera, A., Valero-Amaro, V., Martinez-Jimenez, M., Romero, P., Miranda, M. T., & Rubio, S. (2025). Agri-food e-marketplaces as new business models for smallholders: A case analysis in Spain. *New Medit,* 24(1). https://doi.org/10.3390/agriculture15171806

Government of the Republic of Kazakhstan. (2021). Concept for the development of the agro-industrial complex of the Republic of Kazakhstan for 2021-2030. Resolution No. 960 of 30 December 2021. https://primeminister.kz/en/news/reviews/itogi-razvitiya-sfery-selskogo-hozyaystva-za-2021-god-i-plany-na-predstoyashchiy-period-22422

He, C., Hao, H., Su, Y., & Yang, J. (2024). Factors influencing farmers' adoption of e-commerce for agricultural products: Evidence from Wuchang City. *Sustainability*, 16(21), 9496. https://doi.org/10.3390/su16219496

Hendricks, S., & Mwapwele, S. D. (2024). A systematic literature review on the factors influencing e-commerce adoption in developing countries. *Data and Information Management*, 8(1), 100045. https://doi.org/10.1016/j.dim.2023.100045

Jahan, E., Moniruzzaman, M., Yasmin, S., & Islam, A. H. M. S. (2025). E-commerce and consumer satisfaction: Empirical evidence from the digital marketing system of mango in Bangladesh. *Journal of Agriculture and Food Research*, 20, 101867. https://doi.org/10.1016/j.jafr.2025.102456

Liu, Z., Jia, S., Wang, Z., Guo, C., & Niu, Y. (2022). Coordinated development of rural e-commerce logistics and agricultural modernisation. *Sustainability*, 14(21), 13758. https://doi.org/10.3390/su142113758

Lubag, M., Bonifacio, J., Tan, J. M., Concepcion, R., Mababangloob, G. R., Galang, J. G., & Maniquiz-Redillas, M. (2023). Diversified impacts of a technology-intensified agricultural supply chain on rural quality of life. *Sustainability,* 15(6), 5264. https://doi.org/10.3390/su151712809

Mayorga-Abril, C., Vanegas-López, J. G., Ruiz-Guajala, M., Tamayo-Vásquez, M., & Santana-Mayorga, R. (2026). Gender Discrimination and Women's Decision-Making in Sustainable Agriculture: Evidence from Ecuador. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 53-66. https://doi.org/10.2478/eoik-2026-0025

Ministry of Agriculture of the Republic of Kazakhstan. (2026). Formation of a unified digital e-APK ecosystem. Astana: Ministry of Agriculture. https://www.gov.kz/memleket/entities/moa/press/news/details/1255630?lang=en

Nguyen, D. L., Cao, H. V., Nguyen, N. A. T., Duong, V. T. T., & Nguyen, T. H. (2025). Farm size and adoption of unmanned aerial vehicles in rice production in Vietnam. *Research on World Agricultural Economy,* 6(2). https://doi.org/10.36956/rwae.v7i1.2358

Qin, T., Wang, L., Zhou, Y., & others. (2022). Digital technology-and-services-driven sustainable transformation of agriculture: Cases of China and the EU. *Agriculture,* 12(2), 297. https://doi.org/10.3390/agriculture12020297

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). New York: *Free Press*. https://smhp.psych.ucla.edu/pdfdocs/systemic/rogers%20diffusion.pdf

Shen, Y., Guo, X., & Zhang, X. (2023). Digital financial inclusion, land transfer and agricultural green total factor productivity. *Sustainability*, 15(8), 6436. https://doi.org/10.3390/su15086436

Shojaei, S. A., Pakgohar, A., & Tran, D. Y. V. (2026). Green Deliveries on a Budget: How Sustainability and Cost Shape Vietnamese E-Commerce Consumer Choices. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 67-86. https://doi.org/10.2478/eoik-2026-0026

Sun, C., & Yu, C. (2025). Enhancing consumers' purchase intention in e-commerce agricultural products. *British Food Journal*, 127(6), 2015-2034. https://doi.org/10.1108/BFJ-09-2024-0952

Tombe, R., & Smuts, H. (2023). Agricultural social networks: A value-chain-based digitalisation framework for an inclusive digital economy. *Applied Sciences,* 13(11), 6382. https://doi.org/10.3390/app13116382

Wei, D., Syed, O. R., & Hong, G. (2026). Digital transformation and green agricultural development: Evidence from agricultural value chain integration in China. *Research on World Agricultural Economy,* 7(2), 1-22. https://doi.org/10.36956/rwae.v7i2.2728

Wei, X., & Ruan, J. (2022). Government policies, farmer cognition and participation in e-commerce interest-linkage mechanisms. Agriculture, 12(11), 1841. https://doi.org/10.3390/agriculture12111841

Williamson, O. E. (1985). The economic institutions of capitalism. New York: *Free Press*.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming: A review. *Agricultural Systems*, 153, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Yessengeldin, B. S., Tasmaganbetov, A. B., & Abildina, M. K. (2026a). Features of the use of e-commerce in the sale of farmers' products in Kazakhstan. *Economic Series of the Bulletin of L. N. Gumilyov Eurasian National University,* 1, 86-101. https://doi.org/10.32523/2789-4320-2026-1-86-101

Yessengeldin, B., Zhanseitov, A., & Abildina, M. (2026b). Institutional mechanisms of state regulation of electronic commerce in the Republic of Kazakhstan. *International Journal of Economics and Project Management,* (2), 75–86. https://doi.org/10.66608/2617-085X.2026.2.2.006

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

ARTIFICIAL INTELLIGENCE, ALGORITHMIC GOVERNANCE AND CULTURAL VALUE IN THE DIGITAL ECONOMY: TRANSFORMING CREATIVE LABOR AND CINEMA

Yelda Özkoçak[1*]

Received 20.03.2026. | Send to review 07.04.2026. | Accepted 17.08.2026.

Original Article

[1] Doğuş University, Faculty of Economics, Administrative and Social Sciences, Istanbul, Turkey

***Corresponding Author:**
Yelda Özkoçak

Email:
yozkocak@dogus.edu.tr

JEL Classification:
Z11, Z10, L82, O33, L86

Doi: 10.61432/CPNE04012410

UDK: 339.5(4-672EU):004.738.5

ABSTRACT

This study develops an original analytical framework that systematically conceptualizes the role of artificial intelligence in the cinema industry through the lens of algorithmic governance. The framework comprises four dimensions: visibility management, value attribution, labor management, and predictive management. It is applied to examine how AI technologies, including platform recommendation algorithms, generative visual systems, and data driven script evaluation tools, are reshaping film production and distribution.

Drawing on media studies, cultural political economy, and critical algorithm studies, the paper employs a hybrid deductive and inductive thematic analysis of 19 open access studies published between 2023 and 2026. The sample includes 14 peer reviewed articles, four preprints, and one repository paper, with 15 studies published in 2025 or 2026. The analysis is supplemented by publicly available platform policies and documentary evidence concerning industry disputes and litigation.

The findings indicate that algorithmic systems improve production efficiency but may also reduce cultural diversity, increase the precarity of creative labor, and intensify unresolved tensions concerning intellectual property and creative authorship. The paper concludes with policy recommendations on algorithmic transparency and cultural diversity, drawing on the European Union Artificial Intelligence Act, the Digital Services Act, and existing European and East Asian content promotion frameworks.

Keywords: *Cinema, Artificial Intelligence, Digital Economy, Creative Labor, Algorithmic Culture, Platform Economy, Cultural Value*

1. INTRODUCTION

The digital economy has transformed artificial intelligence from a supportive technology in the cultural and creative industries into a central force shaping production, distribution, and value creation. Cinema represents one of the most visible and contested areas of this transformation, where the economic, aesthetic and cultural consequences of technological innovation converge. Recent research indicates that AI challenges not only established production practices but also fundamental concepts in film theory, including the notion of the creative auteur (Uddin et al., 2025).

Although AI has long been used in cinema, the development of generative AI has produced a qualitative shift in its role. AI tools are now integrated into nearly every stage of filmmaking, including screenwriting, visual effects, editing, content evaluation, and audience recommendation. Inie et al. (2023) highlight both the expectations and concerns of creative professionals, emphasizing that generative AI no longer merely analyzes human created works but can also produce original content. This development requires a reconsideration of cultural value, creativity, and labor within the digital economy.

This article conceptualizes AI in cinema not merely as a production tool but as a mechanism of algorithmic governance that reorganizes creative processes, market structures, and the production of cultural meaning. Drawing on media studies, cultural political economy, and critical algorithm studies, it examines how generative visual systems, editing technologies, and platform recommendation algorithms are transforming film production and distribution. The central argument is that algorithmic systems may improve efficiency while simultaneously reducing cultural diversity, increasing the precarity of creative labor, and intensifying unresolved tensions concerning intellectual property and authorship.

Existing research has rarely examined cinema comprehensively within the broader contexts of platform capitalism and algorithmic governance. The connection between industry reports and critical theoretical perspectives remains underdeveloped. Moreover, the literature has not provided a systematic framework for examining the four dimensions of algorithmic governance in cinema: visibility management, value attribution, labor management, and predictive management. Comparative research, particularly from the perspective of the Global South, also remains limited. This study addresses these gaps by applying a four dimensional analytical framework to the existing empirical literature and by proposing relevant policy recommendations.

2. METHOD

This study is designed within the qualitative research paradigm using an exploratory research design. By systematically examining the existing literature and secondary data relevant to the field, the study aims to explore and identify the underlying dynamics shaping the domain (Lin, 1976:137; Stebbins, 2001).

2.1. DATA SOURCES AND SAMPLE SELECTION

The study draws on academic articles, reports, policy documents, and documentary evidence identified through predefined search terms. Scopus and Web of Science served as the primary databases. Searches combined the following terms: “artificial intelligence and cinema,” “algorithmic governance and film industry,” “creative labor and platform economy,” “generative AI and cultural production,” and “streaming platforms and cultural diversity.” These searches were supplemented by targeted queries in arXiv, DOAJ, and Google Scholar.

Because much of the recent research on generative AI in film is available as open access preprints and has not yet been indexed in Scopus or Web of Science, five sources were retrieved through supplementary searches. These comprised four arXiv preprints and one repository paper, all of which are identified in the Appendix. The search process was completed on May 30, 2026.

The initial search identified 174 records. After duplicates were removed, [n1] records were screened by title and abstract, of which [n2] were excluded as irrelevant. The full texts of the remaining [n3] records were assessed, and [n4] were excluded for failing to meet one or more inclusion criteria. The final corpus consisted of 19 publications.

The inclusion criteria required that publications were written in English, openly accessible,

published between January 2023 and May 30, 2026, and substantively focused on cinema or the film and streaming industries. The year 2023 was selected as the lower boundary because the public release of large generative AI models in late 2022 marked a shift from speculative discussion to direct scholarly examination of their application in the film industry.

The corpus is dominated by recent publications. It includes one publication from 2023, three from 2024, eleven from 2025, and four from 2026. Fourteen sources are peer reviewed journal articles, four are arXiv preprints, and one is a repository paper. One peer reviewed publication, Thomas and Johnson (2026), is an opinion article rather than an empirical study. The preprints and the opinion article are identified in the Appendix and are treated in Section 4 as contributions to the broader debate rather than as independent empirical evidence.

This selection criterion replaces the formulation "published after 2025," which appeared in an earlier version of the article but did not accurately reflect the analyzed corpus. Earlier foundational studies, including Hallinan and Striphas (2016), Gaw (2022), and Lotz (2022), were not included in the coded corpus. They are used exclusively as theoretical sources in Section 3.

Purposive sampling was applied to identify publications that were recent, accessible, and directly relevant to the research question. This approach facilitated the selection of information rich sources appropriate for qualitative analysis (Patton, 2015). Criterion sampling was also employed, meaning that all publications satisfying the predefined inclusion criteria were included in the final corpus.

In addition to the academic corpus, the study examines publicly available corporate documents issued by major streaming platforms. Official support, developer, and partner portals were systematically searched for content, delivery, and metadata policies. The search covered six leading subscription video on demand services operating in European and North American markets: Netflix, Amazon Prime Video, Disney+, Apple TV+, Max and Paramount+.

Only Amazon Prime Video and Apple TV+ provided publicly accessible documents of this type. Table 3 reports both the available documents and the negative search results, since the absence of public documentation may itself indicate limited transparency in algorithmic governance.

These materials are treated as an illustrative corpus of platform self representation rather than as coded data. They were interpreted in relation to the four dimensions of the analytical framework but were not included in the thematic coding process. No finding presented in Section 4 is based solely on these documents.

The Apple TV+ document is a style and metadata standards guide. It specifies how titles, credits, and descriptive metadata should be structured but provides no information about ranking or recommendation systems. Its inclusion is justified by the role of metadata standardization in algorithmic sorting. Content must be described in a structured and machine- readable form before it can be classified, matched, ranked, or presented to users. The document therefore illustrates the infrastructural basis of visibility management rather than the operation of recommendation algorithms. No conclusion regarding Apple's recommendation system is derived from this source.

The study also considers documentary evidence concerning the 2023 Hollywood labor disputes, the collective agreements that followed, litigation related to the use of copyrighted works in AI model training, and documented applications of AI in individual film productions.

This evidence was collected through targeted searches corresponding to the five coding themes. Three categories of sources were examined. The first included official websites and published agreements of relevant professional organizations, including the Writers Guild of America, SAG AFTRA, the International Alliance of Theatrical Stage Employees, and the Directors Guild of America.

The second category comprised official legal and policy documents issued by EUR Lex, the European Commission, the European Audiovisual Observatory, and the Korean Film Council. The third included established litigation trackers and specialized trade publications reporting on production related cases.

Primary and official sources were used whenever available. Press reports were consulted only when no primary source could be identified, and information was accepted only when confirmed by at least two independent outlets. These materials provide contextual and illustrative support for arguments derived from the coded academic corpus. They are analyzed separately, do not form part of the coding framework, and are not included among the 19 publications.

2.2. DATA COLLECTION AND ANALYSIS

The collected data were analyzed using thematic analysis following Braun and Clarke (2006). The analysis focused on five main themes: algorithmic governance, creative labor, economic value, cultural diversity, and ethical and regulatory issues. The findings were subsequently interpreted in relation to the relevant theoretical literature.

The study adopted a hybrid deductive and inductive approach based on Fereday and Muir Cochrane (2006). The five main themes were defined in advance and derived from the conceptual framework. Four operationalize the dimensions of algorithmic governance presented in Section 3.1, while the fifth captures the ethical and regulatory implications associated with these dimensions.

Coding nevertheless began inductively. Each article was read in full and divided into meaning units. Open codes were generated using the terminology and concepts found in the sources rather than those imposed by the analytical framework. This procedure allowed the evidence to challenge or extend the predefined framework. In the second stage, the open codes were compared with the five predefined themes and refined into themes and subthemes according to their similarities and differences.

Codes corresponding to an existing theme were incorporated as subthemes. Codes that did not fit the predefined structure were retained as candidate themes and reassessed across the full corpus. Two notable cases emerged. The first concerned unequal access to AI infrastructure among large studios, independent producers, and producers in the Global South. As these codes did not fit the four dimensions of algorithmic governance, they were retained under cultural diversity as the subtheme of marginalization. The second concerned the attribution of authorship in human and machine collaboration. Because these codes intersected two areas, they were coded under both creative labor and ethical and regulatory issues.

Table 2 presents the relationship between the 19 sources and the final thematic structure, allowing the contribution of each publication to the findings to be traced.

2.3. VALIDITY AND RELIABILITY OF THE RESEARCH

The thematic analysis of the 19 articles was conducted by a single researcher. To assess coding stability and reduce potential subjectivity, intra coder reliability was evaluated following Miles and Huberman (1994). Ten articles, representing all five themes and publication years, were re coded after a two week interval without reference to the initial coding.

The coding unit was the meaning unit, defined as a passage ranging from one sentence to one paragraph that expressed a single analytically relevant proposition. Before coding, a written codebook was developed for each of the five main themes, including definitions, inclusion and exclusion criteria, and illustrative examples from the corpus.

Agreement was calculated as the proportion of meaning units assigned to the same main

theme in both coding rounds. Of 212 meaning units, 191 were coded identically, resulting in an agreement rate of 90.1 percent.

The 21 discrepancies were concentrated in two areas. Fourteen involved the distinction between predictive algorithmic governance and platform based economic value creation, particularly in passages concerning box office forecasting and demand prediction. Five concerned the overlap between creative labor and ethical or regulatory issues in discussions of authorship. The remaining two reflected inconsistent application of the codebook.

The codebook was subsequently revised. Passages describing how predictive systems operate were assigned to algorithmic governance, whereas those emphasizing the financial rationale for their use were assigned to economic value. Double coding was permitted where authorship issues overlapped with both creative labor and ethics and regulation. The full corpus was then re coded using these revised rules.

This procedure has two limitations. First, percentage agreement does not correct for chance. Since the analysis involved one researcher, inter coder statistics such as Cohen's kappa were not applicable. The reported figure therefore measures coding stability over time rather than intersubjective reliability. Second, coding consistency does not demonstrate that another researcher would adopt the same interpretive framework. As Braun and Clarke (2021) emphasize, reliability measures cannot replace transparency in interpretive analysis. Accordingly, the codebook structure and source to theme mapping presented in Table 2 allow the analytical reasoning to be examined and critically assessed.

Overall, this procedure strengthens the consistency and transparency of the thematic analysis and remains compatible with the approach developed by Braun and Clarke (2006).

2.4. ETHICS AND LIMITATIONS

As the study relies exclusively on secondary and publicly available data, formal ethical approval was not required. Nevertheless, the proprietary nature of platform algorithms and the resulting lack of transparency represent important limitations. The analysis is restricted to publicly accessible documents and therefore cannot examine the internal operation of closed algorithmic systems directly.

The findings are also limited to the selected corpus and are not intended to support statistical generalization. However, the depth and contextual detail of the analysis allow for analytical generalization to comparable settings.

2.5. RESEARCH QUESTIONS

RQ_1: *How do platform-based algorithmic governance mechanisms produce structural effects on cultural visibility, content diversity and creative labor in the film industry, and how do these effects deepen the tension between economic value production and cultural autonomy?*

RQ_2: *How does the integration of artificial intelligence technologies into film production and distribution processes transform creative labor practices, intellectual property regimes, and safeguards for cultural diversity and what ethical and regulatory mechanisms are required to govern this transformation?*

3.CONCEPTUAL FRAMEWORK

3.1. ALGORITHMIC GOVERNANCE AND DATA-DRIVEN CULTURAL PRODUCTION

The concept of algorithmic governance refers to institutional arrangements in which decision making is increasingly shaped by data and automated systems rather than by human actors alone (Kitchin, 2017). In cultural production, this shift means that creative

and commercial decisions are progressively informed by audience data, predictive models, and performance metrics.

Gillespie (2014) argues that algorithms are not neutral technical instruments but sociotechnical systems that embody particular norms, assumptions and values. Similarly, Beer (2017) conceptualizes algorithms as forms of social power that influence visibility, ranking, classification, and value attribution.

Building on the approaches of Kitchin (2017) and Beer (2017), algorithmic governance in cinema can be examined through four interrelated dimensions:

Table 1. Algorithmic governance in the context of cinema

Category	Description	Cinema Context
Visibility Management	Algorithms determine which content is made prominent	Recommendation systems, platform homepage curation
Value Attribution Management	Algorithmic metrics define cultural value	View counts, engagement rates, completion rates
Labor Management	Algorithms organize and regulate creative processes	Automated editing tools, data-driven script evaluation
Predictive Management	Algorithms forecast future preferences	Box office prediction systems

Source: Adapted to the context of cinema based on the conceptualizations presented in Kitchin (2017) and Beer (2017)

The literature on creative labor identifies precarity as a structural feature of the cultural industries (Hesmondhalgh & Baker, 2011). Digitalization and AI driven automation have further expanded project based employment, freelance work, and forms of invisible labor. Wood et al. (2019) show that algorithmic control can intensify work processes and create new forms of dependency that challenge claims of worker autonomy.

The reorganization of cultural production through digital platforms has also become central to research on platform capitalism. Srnicek (2017) demonstrates how platforms place data collection and analysis at the core of economic value creation, while Faraoun (2024) extends this perspective to creative labor. In the film industry, platform companies often finance production while simultaneously controlling distribution. As a result, decisions about which stories are produced and which formats are prioritized are increasingly shaped by data analytics.

Gaw (2022) argues that Netflix's recommendation system does not simply reflect audience preferences but actively contributes to their formation. This has important implications for the political economy of culture, since algorithmic design can obscure the influence of commercial interests on cultural visibility and diversity. Similarly, Thuillas and Wiart (2024) show how Netflix incorporates diversity into its corporate strategy through three partly contradictory dimensions: algorithmic diversity, globalized diversity and inclusive diversity.

In a systematic review of AI in the cultural and creative industries, Gürel (2025) finds that Industry 5.0 requires the cultural sector to balance tradition and innovation, although this balance often favors commercial interests. While AI can enhance cultural experiences and audience engagement, it may also weaken spaces for authentic and diverse cultural expression.

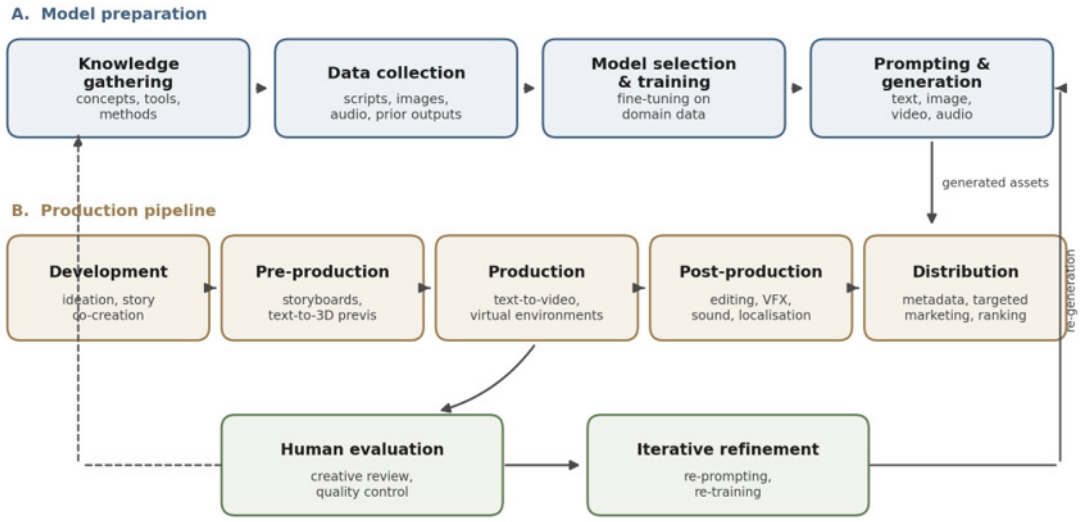
3.2. ARTIFICIAL INTELLIGENCE IN CINEMA: THE TRANSFORMATION OF PRODUCTION PROCESSES

The use of artificial intelligence in cinema is rapidly expanding through applications of generative AI, machine learning, and deep learning. Visual effects production, editing, sound design, and even screenplay drafts are increasingly supported by these technolo-

gies. Manovich (2019) addresses this transformation through the concept of "AI aesthetics," arguing that aesthetic decisions are partially delegated to algorithmic systems.

In their study titled *"Innovations and Challenges of AI in Film: A Methodological Framework for Future Exploration,"* Uddin et al. (2025) emphasize the importance of finding a balance between technological innovation and artistic integrity, while also visualizing the fundamental workflow of AI-assisted filmmaking.

Figure 1. The workflow of AI-assisted filmmaking



Source: Redrawn and adapted by the author from Uddin et al. (2025)

Debates on algorithmic creativity challenge conventional distinctions between human creativity and machine generated output. Boden (2016) argues that AI does not merely imitate human creativity but reshapes how creativity itself is understood. In cinema, this development requires a reconsideration of authorship, originality and artistic responsibility.

Recent industry reports and academic studies indicate that the global film industry is being reorganized within platform based digital economies. Streaming services such as Netflix and Amazon Prime Video influence not only content distribution but also production priorities, narrative formats, and systems of cultural valuation. Through data driven decision making and AI supported algorithms, these platforms continuously measure and classify audience behavior to reduce investment risk. This process may encourage content standardization, genre convergence, and market oriented storytelling (Srnicek, 2017; van Dijck, Poell, & de Waal, 2018).

Algorithmic governance provides a central framework for understanding this transformation. Gillespie (2014) and Kitchin (2017) emphasize that algorithms are not neutral technical instruments but normative systems that shape visibility, value attribution, and power relations. In cinema, recommendation systems therefore influence which films reach audiences and which remain less visible. Netflix engineering and research publications identify personalized recommendation as a central component of the platform's competitive strategy, illustrating the close relationship between algorithmic visibility and economic value (Netflix Research, 2025). However, as corporate publications, these sources represent the platform's own account of its technological infrastructure and do not independently establish its broader cultural effects.

The integration of AI into film production has also renewed debates concerning creative labor and authorship. Automated editing, generative visual systems, and data driven

script development can accelerate production while redistributing creative authority between human workers and technological systems (Manovich, 2019; Boden, 2016). Research on creative labor suggests that these developments may intensify precarity and transfer decision making power toward centralized platform actors (Hesmondhalgh & Baker, 2011; Wood et al., 2019). Cinema is therefore increasingly constituted not only as a field of aesthetic expression but also as a domain of algorithmic governance in which economic and cultural value intersect.

Taken together, the literature moves beyond narratives of technological innovation and highlights the need to examine AI in cinema through the perspectives of cultural diversity, ethical governance, and sustainable creative ecosystems. The frameworks of platform capitalism, algorithmic governance, and creative labor demonstrate that digital platforms are no longer merely distribution channels. They have become influential actors in shaping cultural value, aesthetic norms, audience visibility, and labor relations. Nevertheless, existing research has not sufficiently integrated industry evidence with critical theoretical approaches.

3.2.1. PRE-PRODUCTION AND SCREENWRITING

The use of AI in screenwriting is expanding rapidly. Mirowski et al. (2023), in a study presented at the CHI Conference, examine the use of language models in screenplay and theatrical writing through evaluations by industry professionals. Their findings indicate that AI can support routine writing tasks and function as a collaborative tool, but remains limited in areas requiring dramatic originality, contextual sensitivity, and cultural depth. Systems such as ScriptBook can also analyze screenplays and predict box office performance, thereby linking production decisions more closely to algorithmic assessments of commercial risk.

These developments challenge the traditional concept of the creative auteur. Whereas auteur theory identifies the director as the principal creative force behind a film, AI assisted production distributes creative authority across directors, data scientists, software engineers, and algorithmic systems. Uddin et al. (2025) show that algorithms can influence visual style, narrative development, and casting decisions, while Moruzzi (2022) argues that agency and creativity must be reconsidered in relation to both human and artificial systems.

3.2.2. POST-PRODUCTION PROCESSES AND VISUAL EFFECTS

One of the most visible effects of AI in film production can be observed in postproduction. AI assisted editing, color correction, noise reduction, sound design, and synthetic media tools can shorten production cycles and reduce costs. Runway ML and Adobe Sensei illustrate the growing integration of automated systems into these processes.

The production of *Avatar: The Way of Water* (2022), for example, relied on specialized performance capture and simulation pipelines to combine footage recorded above and below water. Although industry accounts often refer to this case in discussions of machine learning assisted visual effects, the specific techniques have not been documented in peer reviewed research. It is therefore presented as an illustrative example rather than as empirical evidence.

These efficiency gains may nevertheless disrupt established forms of skilled labor. Animators, visual effects specialists, and editing assistants are among the groups most exposed to automation pressures. Inie et al. (2023) document concerns among creative professionals that AI may weaken recognition of human contribution and diminish creative control. Deepfake and digital replication technologies also raise ethical questions concerning the future of acting, consent, and the commercial use of performers' digital identities.

3.3. DISTRIBUTION AND RECOMMENDATION ALGORITHMS

Perhaps the most influential application of AI in cinema is found in platform based distribution. Services such as Netflix, Amazon Prime Video and Disney+ use recommendation systems to analyze viewing behavior, preferences, and user data. These systems influence not only which content becomes visible but also which types of content are commissioned and produced.

Gaw (2022) shows how Netflix's recommendation system contributes to the construction of cultural taste through commercial and industrial logics. The personalization of promotional images according to inferred user characteristics has generated concerns about manipulation and the algorithmic shaping of audience preferences. Similarly, Thuillas and Wiart (2024) argue that Netflix may use diversity as part of its corporate positioning rather than as a consistent cultural commitment.

Lotz (2022) further demonstrates that platform metrics can influence narrative structure, including episode endings and pacing, in order to improve audience retention. Such data driven intervention may encourage greater standardization in content production. Research on music and video streaming also suggests that recommendation systems can marginalize minority content and reinforce feedback loops that repeatedly expose users to similar material.

3.4. THE PRECARIZATION OF CREATIVE LABOR

AI based tools increasingly support data driven assessments of the economic potential of film projects. Box office forecasts, audience analytics, and platform performance metrics enable the commercial value of films to be calculated with greater precision. However, reliance on such systems may discourage creative risk taking and contribute to genre homogenization.

The literature identifies two competing perspectives on the implications of AI for creative labor. Some scholars argue that AI can democratize creative production by expanding access to advanced tools and lowering technical barriers (Manovich, 2019). Critical approaches, however, emphasize its potential to intensify precarity, strengthen algorithmic control, and weaken worker autonomy (Hesmondhalgh & Baker, 2011; Wood et al., 2019). Faraoun (2024) situates these developments within the broader historical restructuring of labor under platform capitalism.

The 2023 Writers Guild of America and SAG AFTRA strikes provide a prominent example of collective resistance to the use of AI in cultural production. Writers sought restrictions on the use of AI in script development, while actors demanded protections against the unauthorized replication and commercial use of their digital likenesses. These disputes illustrate the broader tension between automation and human creative agency. As Mirowski et al. (2023) suggest, AI can assist with particular creative tasks but remains unable to reproduce the full range of human originality, judgment, and cultural understanding.

Precarity extends beyond employment insecurity to include threats to professional identity and creative autonomy. Inie et al. (2023) report that many creative professionals fear that AI may obscure or diminish their individual contributions. This concern is closely connected to the unresolved question of authorship. Moruzzi (2022) argues that agency and creativity must be reconsidered in relation to both human and artificial systems. In practice, this raises difficult questions about the attribution of authorship when AI contributes to screenwriting, editing, or other creative decisions.

A qualitative study of Latin American filmmakers by Burkhardt (2026) adds an important Global South perspective. Participants tended to view AI less as a creative collaborator than as a technology associated with surveillance, social control, and labor exploitation.

3.5. INTELLECTUAL PROPERTY, TRANSPARENCY ISSUES, AND ETHICAL CONCERNS

The integration of generative AI into cinema presents significant challenges to existing copyright frameworks. Mazzi (2024) examines originality and authorship in AI generated works, showing that legal systems based on human authorship are difficult to apply to machine generated outputs.

A related issue concerns the copyrighted material used to train AI systems. Geiger and Iaia (2024) examine the tension between copyright protection and text and data mining exceptions, while Tyagi (2024) analyzes the use of copyrighted works in generative AI training and the resulting claims of infringement. AI models may be trained on extensive datasets containing film frames, visual effects, and cinematographic styles, raising unresolved questions concerning consent, compensation, and lawful use.

Copyright litigation against generative AI developers expanded rapidly after 2023. Independent trackers reported more than 80 AI related copyright cases in the United States by early 2026, alongside proceedings in Germany, Italy, India, and the United Kingdom (Copyright Alliance, 2026; ChatGPT Is Eating the World, 2026). These figures change frequently and should therefore be interpreted as approximate. Most cases concern text, image, and music generation rather than film specifically, and relatively few have reached final judgment. Nevertheless, they illustrate the legal uncertainty surrounding AI based cultural production.

AI recommendation systems also redistribute cultural visibility by promoting certain narratives and aesthetic forms while marginalizing others. Their use therefore raises broader ethical and regulatory concerns regarding cultural diversity, fair representation, and access to audiences.

Transparency presents an additional challenge. Studios and filmmakers do not always disclose their use of AI, partly because of anticipated public criticism. A notable example arose during the production of *The Brutalist*. Editor Dávid Jancsó stated that Respeecher voice cloning technology had been used to refine the Hungarian pronunciation of the lead actors and that generative tools had contributed to a sequence of architectural images. The disclosure generated controversy during the awards season, after which director Brady Corbet clarified that the performances had not been altered and that no English language dialogue had been modified (Variety, 2025). Although the intervention was limited, the case is significant because disclosure came from a technician rather than the production itself and was treated as a scandal rather than as routine postproduction information.

Liu et al. (2023) further emphasize that the absence of clear ethical standards creates uncertainty regarding responsibility, attribution, and creative integrity in AI assisted media production. Limited transparency may also affect the preservation of cultural heritage and the reliability of the historical record.

Finally, access to AI driven innovation is uneven. Major studios and established platforms possess financial and technological resources that remain unavailable to many independent producers. This disparity may reinforce existing inequalities and further concentrate decision making power within the film industry.

4.FINDINGS AND DISCUSSION

The nineteen open-access, English-language articles published between 2023 and 2026 that make up the coded corpus were analyzed using the thematic analysis method (Braun & Clarke, 2006). During the analysis process, coding was conducted around the main themes of “algorithmic governance,” “creative labor,” “economic value,” “cultural diversity,” and “ethical/regulatory issues.” As set out in the Method section, the publicly available policy documents of digital platforms (Amazon Prime Video and Apple TV+) were read against the

four dimensions of the analytical framework. They were not subjected to the coding procedure. They are reported separately in Table 3, and no finding below rests on them alone.

Table 2. Thematic Analysis and Coding

Main theme	Sub-themes	Sources in the coded corpus contributing to the theme
Algorithmic governance	Visibility management; value attribution management; labor management; predictive management	Chapman & Abraham (2025); Gao & Lin (2025); Lai et al. (2025); Sun et al. (2024); Thomas & Johnson (2026); Tsiavos & Kitsios (2025); Zeng & Zhang (2023); Zhang (2025) [n = 8]
Platform economy / economic value	Data monopoly; content investment; market concentration	Kim (2025); Tsiavos & Kitsios (2025); Xu (2025); Zeng & Zhang (2023); Zhang (2025) [n = 5]
Creative labor	Precarization; loss of autonomy; invisible labor; distributed authorship	Burkhardt (2026); Masai et al. (2026); Swarnakar (2024); Uddin et al. (2025); Xu (2025); Yousefimehr et al. (2026) [n = 6]
Cultural diversity	Homogenization; genre convergence; marginalization; representation	Burkhardt (2026); Chapman & Abraham (2025); Gürel (2025); Ocal (2025); Tores et al. (2024); Zhang (2025) [n = 6]
Ethics and regulation	Transparency; intellectual property; accountability; evaluation standards	Gürel (2025); Masai et al. (2026); Swarnakar (2024); Tian & Lee (2025); Tores et al. (2024); Uddin et al. (2025); Yousefimehr et al. (2026) [n = 7]

Source: Author's coding of the 19-article corpus listed in the Appendix. Themes are not mutually exclusive. Several articles contribute to more than one theme, so the column totals exceed 19. Full bibliographic details of the coded sources are given in the Appendix and in the reference list

One item in the corpus (Thomas and Johnson, 2026) is an opinion article and four are preprints. These are identified in the Appendix and are weighted accordingly in the discussion below.

The five themes are presented sequentially below, with direct reference to the studies supporting each one. Given the limited size and heterogeneous composition of the corpus, the purpose is to identify convergence across studies rather than to aggregate their findings. The evidential basis of each theme is therefore assessed separately.

Algorithmic governance. Eight of the 19 studies directly examine recommendation systems. They can be divided into two groups that are seldom considered together. The first is technical. Gao and Lin (2025) and Lai et al. (2025) develop and assess recommender architectures for film, while Sun et al. (2024) reconsider the evaluation problem by asking what deep learning movie recommendation systems are actually designed to optimize. From the perspective of the framework proposed in this study, the main significance of these contributions lies less in their engineering outcomes than in what their objective functions reveal. Visibility is treated as an optimization problem, and cultural considerations can influence the system only when they are translated into measurable targets.

The second group adopts a critical perspective. Chapman and Abraham (2025) investigate the effects of streaming recommendation systems on aesthetic choice, while Zhang (2025) interprets streaming platforms as a redistribution of power within the film and television industries. Thomas and Johnson (2026) extend this argument to predictive systems, suggesting that the anticipation of audience response influences prevailing definitions of cinematic authenticity. As this contribution is an opinion article rather than an empirical study, it is treated as a position within the wider debate. Tsiavos and Kitsios (2025) and Zeng and Zhang (2023) place both technical and critical approaches within

the broader industrial transformation of film distribution. While one body of research explains the mechanism, the other identifies its cultural implications. Their convergence supports the interpretation of recommendation systems as instruments of governance rather than neutral tools for matching content with audiences.

Platform economy and economic value. Kim (2025) examines whether platform series are displacing cinema as a cultural form. Tsiavos and Kitsios (2025) analyze the digital transformation of the film industry as an industrial process, while Zeng and Zhang (2023) focus on AI based distribution practices. Xu (2025) considers the balance between creativity and automation in production and dissemination, and Zhang (2025) examines the associated redistribution of power.

Together, these studies suggest that the economic significance of AI lies primarily in the reorganization of distribution rather than solely in reductions in production costs. The ability to direct and allocate audience attention becomes a scarce economic resource. Through vertical integration across financing, production, and distribution, platforms are able to capture the returns generated by this capacity. In the context of film, this interpretation is consistent with Srnicek's (2017) broader theory of platform capitalism. However, none of the studies included in the corpus tests this relationship econometrically. The argument should therefore be understood as qualitative evidence based on convergence rather than as proof of causality.

Creative labour. The corpus provides relatively limited direct empirical evidence concerning labor, and this imbalance is itself an important finding. Burkhardt (2026) offers the strongest evidence through interviews with practicing filmmakers. Masai et al. (2026) examine the incorporation of generative AI into filmmaking as a transition from collaborative creativity to distributed creativity, with direct implications for the attribution of authorship. Uddin et al. (2025) and Yousefimehr et al. (2026) document the spread of AI and deep learning technologies across different stages of production but do not assess employment effects. Swarnakar (2024) and Xu (2025) discuss professional consequences more generally.

No study in the reviewed corpus measures employment levels, earnings, or contractual conditions in film occupations affected by AI. The argument that AI intensifies the precarity of creative labor therefore derives more strongly from the wider literature on creative work (Hesmondhalgh & Baker, 2011; Wood et al., 2019) and from the industrial record of the 2023 labor disputes than from recent film specific research. This limitation is explicitly acknowledged in the present study.

Cultural diversity and perspectives from the Global South. The theme of cultural diversity is the area in which evidence from outside dominant metropolitan centers makes its most significant contribution. Burkhardt's (2026) interview study includes 11 filmmakers from six Latin American countries and finds that their representations of AI differ systematically from those prevalent in Western science fiction. Rather than imagining AI primarily as autonomous machine intelligence, participants associate it with surveillance, social control, labor exploitation, data colonialism, and the concentration of power in governments and corporations.

Burkhardt further argues that these perspectives are rooted in participants' lived experiences and material production conditions rather than in abstract academic or technological debates. Aesthetic strategies such as retrofuturism are adopted partly in response to financial constraints and structural inequalities in cultural visibility.

Viewed through the framework adopted here, these findings extend beyond differences in thematic preference. First, they qualify the dimension of visibility. When filmmakers outside dominant production centers experience platforms primarily as barriers to recognition, the composition of catalogues becomes an inadequate measure of cultural pluralism.

This interpretation is consistent with Thuillas and Wiart's (2024) claim that Netflix uses diversity discourse as a source of corporate legitimacy.

Second, the findings relate to value attribution. Representations of AI centered on surveillance and data extraction raise the question of who controls the infrastructure through which cultural value is measured. They therefore echo Srnicek's (2017) account of data as a central asset of platform capitalism, but from the perspective of those whose data and cultural production are subject to extraction.

Third, they relate to labor. In these accounts, exploitation is not presented as a future consequence of automation but as an existing condition of transnational cultural production. The current debate on precarity in the Global North may therefore describe the spread of conditions that have long characterized production elsewhere. This inference must nevertheless be treated cautiously. It is based on a single exploratory study involving 11 participants and cannot be generalized to the Global South as a whole. Its value lies in challenging the implicit universalism of theories developed mainly from North American and European cases and in identifying the need for further comparative research.

Two additional studies examine diversity through representation rather than distribution. Tores et al. (2024) conceptualize visual objectification in film as a computer vision task, while Ocal (2025) models the relationship between screenplay content and audience emotion. Both illustrate a methodological shift with important governance implications. Features of film that were traditionally interpreted through qualitative criticism are increasingly being converted into machine readable variables. This development may improve accountability by enabling large scale measurement of representational patterns, but it may also extend optimization into the sphere of cultural representation. The present corpus does not provide sufficient evidence to resolve this tension.

Ethics and regulation. The literature on ethics and regulation is primarily programmatic. Gürel's (2025) systematic review identifies tensions between innovation and tradition in the cultural and creative industries under Industry 5.0 but does not assess particular regulatory mechanisms. Uddin et al. (2025) and Swarnakar (2024) call for rules governing the responsible use of AI without specifying their institutional form. Masai et al. (2026) raise questions concerning authorship under conditions of distributed creativity. Tian and Lee (2025) examine the aesthetic evaluation of AI generated short films but leave unresolved the standards by which such works should be judged.

None of the studies in the corpus analyzes the application of a binding regulatory instrument to the film sector. The policy proposals presented in the Conclusion are therefore based on primary legal sources rather than on the reviewed academic literature. They should be understood as recommendations derived from the analysis, not as findings directly established by the corpus.

Overall, these themes are consistent with the wider literature on the transformation of cultural industries through platformization. Srnicek (2017) and Nieborg and Poell (2018) argue that platforms reorganize economic value creation through data extraction and algorithmic governance. Studies of cinema similarly suggest that digital platforms are weakening established relationships between production and distribution.

The findings also correspond with research on algorithmic culture and filter bubbles. Gillespie (2014) and Bucher (2018) conceptualize algorithms not as neutral technical systems but as mechanisms of cultural selection and curation. Research on Netflix, including Hallinan and Striphas (2016), demonstrates that algorithmic personalization exerts a normative influence on audience preferences. Although algorithmic systems may accelerate production and reduce costs, they may also restrict creative autonomy and complicate established understandings of authorship.

These developments are likewise consistent with the literature on creative labor and digital capitalism. Existing studies identify precarity as a structural feature of cultural production, while research on AI and creative work suggests that algorithmic systems increasingly treat labor as an input that can be measured, monitored and optimized.

Table 3. Publicly Available Policy Documents of Digital Platforms

Platform	Document / Source	About the Content	Link
Amazon Prime Video	Content Policy and Technical Guidelines	Rules forming the basis of the content strategy. Details include which types of content are accepted/rejected, quality standards, and the possibility of content removal based on audience engagement (e.g., completion rates).	Video Central Documents
Apple TV+	TV Style and Data Standards Guide	A strategic document defining titling, metadata, and technical standards for content published on the platform. Focuses more on standardization of content presentation than on algorithms.	Apple TV Style Guide
Netflix	No publicly available official document	Netflix does not publicly share detailed technical documentation regarding its content strategy or algorithms (e.g., recommendation systems).	—
Paramount+	No publicly available official document	No detailed public technical documentation regarding content strategy or algorithmic governance has been identified.	—
Disney+	No publicly available official document	No public technical documentation is available regarding the platform's content management or recommendation systems.	—
Max	No publicly available official document	No such documentation has been found for Max, the platform of Warner Bros. Discovery.	—

Source: Compiled by the author from the official support, developer and partner portals of the listed platforms. A dash (—) indicates that no such document is publicly available.

The rapid growth of content investment by digital streaming platforms indicates that value creation in the film industry is increasingly shaped by data driven and algorithmic decision making. AI supported predictive systems are now used not only to analyze audiences but also to guide content development, production, and distribution.

Taken together, the findings show that AI in cinema has developed from a production aid into a broader mechanism of governance that restructures cultural value creation. This transformation generates three interconnected tensions.

The first is between efficiency and creative originality. Although AI can accelerate production, data driven decision making may encourage standardized narrative forms. As Lotz (2022) suggests, algorithmic systems prioritize audience retention, often at the expense of broader cultural meaning and artistic experimentation.

The second tension concerns global reach and cultural diversity. Thuillas and Wiart (2024) show that, despite their commitment to diversity, streaming platforms often adapt content to the demands of global markets. This may promote the diffusion of dominant, particularly Western centered, aesthetic norms and intensify concerns about cultural homogenization.

The third tension lies between technological democratization and market concentration. AI tools may broaden access to advanced production capabilities for independent filmmakers. At the same time, platforms continue to strengthen their market position through algorithmic control over visibility, discovery, and audience access.

Digital platforms should therefore be understood not merely as distribution channels but as algorithmically organized centers of cultural production. Their growing influence re-

distributes economic power in the film industry and aligns creative decisions more closely with market priorities. Recommendation systems do not simply reflect audience preferences. They also function as cultural filters that determine which narratives gain visibility and which remain marginalized.

Ultimately, AI based systems in cinema operate not only as technical instruments but also as governance mechanisms that shape economic value, cultural visibility, and creative labor. Cinema has therefore become an important cultural and political field of contestation within platformized digital economies.

5. CONCLUSION

This study demonstrates that the transformation of cinema through artificial intelligence extends beyond technological innovation. AI based systems increasingly function as mechanisms of algorithmic governance that shape creative production, economic value, cultural visibility, and labor relations. Within platformized digital economies, streaming services no longer operate solely as distribution channels but increasingly influence which films are financed, produced, recommended, and ultimately seen. The findings reveal several interconnected tensions. AI tools can improve efficiency, reduce production costs, and expand opportunities in screenwriting, visual effects, editing, and postproduction. At the same time, data driven decision making may encourage narrative standardization, reduce creative risk taking, and align production more closely with predicted audience behavior. Similarly, although streaming platforms provide global access to diverse content, their recommendation systems may reinforce dominant preferences and limit the visibility of minority, regional, and independent productions. The democratizing potential of AI is therefore accompanied by increasing market concentration and platform control over cultural circulation.

The analysis also shows that AI is transforming creative labor and established understandings of authorship. Generative systems redistribute creative authority among writers, directors, technical specialists, software developers, and algorithmic systems, while raising concerns about employment security, compensation, consent, digital replicas, and the use of copyrighted works in model training. Existing agreements developed by organizations such as the Writers Guild of America, SAG AFTRA, and IATSE provide important safeguards, but their applicability remains limited in industries with weaker collective bargaining structures.

These challenges require a regulatory approach that combines algorithmic transparency, cultural diversity protection, labor safeguards, and fair access for independent producers. The transparency provisions of the European Union Artificial Intelligence Act and the Digital Services Act offer useful foundations, although recommendation systems used by subscription video on demand services remain insufficiently regulated. Similarly, catalogue quotas under the Audiovisual Media Services Directive should be complemented by effective prominence requirements, since regulating what is available does not necessarily determine what audiences are able to discover. The introduction of cultural diversity criteria into recommendation systems may offer a possible response, but such mechanisms require careful design. Any cultural value translated into a measurable ranking parameter may itself become subject to optimization and standardization. Cultural diversity weighting should therefore be treated as an area for regulatory experimentation and further research rather than as a fully developed policy instrument.

Overall, AI in cinema should not be understood merely as a collection of production technologies. It is a structural force through which economic power, cultural value, creative autonomy, and visibility are increasingly negotiated. Governing this transformation re-

quires a multidimensional approach based on transparency, cultural sustainability, ethical responsibility, labour protection and social justice. Such an approach is essential if cinema is to retain its cultural diversity and artistic autonomy while benefiting from the opportunities created by digital transformation.

REFERENCES

Beer, D. (2017). The social power of algorithms. *Information, Communication & Society*, 20(1), 1–13. https://doi.org/10.1080/1369118X.2016.1216147

Boden, M. A. (2016). AI: Its nature and future. *Oxford University Press*. https://archive.org/details/boden-ai-its-nature-and-future-2016

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Braun, V., & Clarke, V. (2021). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, 18(3), 328–352. https://doi.org/10.1080/14780887.2020.1769238

Bucher, T. (2018). If... then: Algorithmic power and politics. *Oxford University Press*. https://doi.org/10.1093/oso/9780190493028.001.0001

Burkhardt, A. (2026). Artificial intelligence in the work and view of Latin American filmmakers: Insights from a qualitative interview study. *AI & Society*, 41(2), 969–987. https://doi.org/10.1007/s00146-025-02577-3

Chapman, H. E., & Abraham, A. (2025). Because you watched: How do streaming services' recommender systems influence aesthetic choice? *Behavioral Sciences*, 15(11), 1544. https://doi.org/10.3390/bs15111544

ChatGPT Is Eating the World. (2026, April 9). AI copyright case tracker. https://chatgptiseatingtheworld.com/2026/04/09/todays-launch-of-new-ai-copyright-case-tracker-via-chatgpt-is-eating-the-world/

Copyright Alliance. (2026, March 4). Top noteworthy copyright stories from February 2026. https://copyrightalliance.org/copyright-stories-february-2026/

Directive (EU) 2018/1808 of the European Parliament and of the Council of 14 November 2018 amending Directive 2010/13/EU (Audiovisual Media Services Directive). *Official Journal of the European Union,* L 303, 69–92. https://eur-lex.europa.eu/eli/dir/2018/1808/oj

European Commission. (2024). Report on the application of Articles 13, 16 and 17 of the Audiovisual Media Services Directive (COM(2024) 261 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2024:261:FIN

European Commission. (2026). Draft guidelines on the transparency obligations under Article 50 of Regulation (EU) 2024/1689. https://digital-strategy.ec.europa.eu/en/policies/code-practice-ai-generated-content

Faraoun, A. (2024). Theorizing labor in the platform economy: Labor restructuring in historical perspective. *Sociology Compass*, 18(11), e70018. https://doi.org/10.1111/soc4.70018

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods*, 5(1), 80–92. https://doi.org/10.1177/160940690600500107

Gao, Y., & Lin, Z. (2025). The movie recommendation algorithm based on the TransD model and AIGC empowerment and its application effectiveness analysis. *PLoS ONE*, 20(11), e0333607. https://doi.org/10.1371/journal.pone.0333607

Gaw, F. (2022). Algorithmic logics and the construction of cultural taste of the Netflix recommender system. *Media, Culture & Society*, 44(4), 706–725. https://doi.org/10.1177/01634437211053767

Geiger, C., & Iaia, V. (2024). The forgotten creator: Towards a statutory remuneration right for machine learning of generative AI. *Computer Law & Security Review*, 52, 105925. https://doi.org/10.1016/j.clsr.2023.105925

Gillespie, T. (2014). The relevance of algorithms. In T. Gillespie, P. J. Boczkowski, & K. A. Foot (Eds.), *Media technologies* (pp. 167–194). MIT Press. https://doi.org/10.7551/mitpress/9780262525374.003.0009

Gürel, E. (2025). AI-driven experiences in cultural and creative industries: A review of literature and development of a multifaceted framework. *The Service Industries Journal,* 1–40. https://doi.org/10.1080/02642069.2025.2542822

Hallinan, B., & Striphas, T. (2016). Recommended for you: The Netflix Prize and the production of algorithmic culture. *New Media & Society,* 18(1), 117–137. https://doi.org/10.1177/1461444814538646

Hesmondhalgh, D., & Baker, S. (2011). Creative labour: Media work in three cultural industries. *Routledge*. https://doi.org/10.4324/9780203855881

IATSE. (2023, July 5). Core principles for applications of artificial intelligence and machine learning technology. International Alliance of Theatrical Stage Employees. https://iatse.net/wp-content/uploads/2023/07/2023-07-05-AI-Core-Principles-FINAL.pdf

Inie, N., Falk, J., & Tanimoto, S. (2023). Designing participatory AI: Creative professionals' worries and expectations about generative AI. Extended abstracts of the CHI Conference on Human Factors in Computing Systems (pp. 1–8). ACM. https://doi.org/10.48550/arXiv.2303.08931

Kim, J.-G. (2025). Deconstructing the screen: Are platform series replacing cinema? *Journal of Digital Contents Society*, 26(11), 2981 https://doi.org/10.9728/dcs.2025.26.11.2981

Kitchin, R. (2017). Thinking critically about and researching algorithms. *Information, Communication & Society*, 20(1), 14–29. https://doi.org/10.1080/1369118X.2016.1154087

Korean Film Council. (2006). Announcement on the reduction of the screen quota. http://www.koreanfilm.or.kr/eng/news/news.jsp?mode=VIEW&blbdComCd=601006&pageRowSize=10&seq=344

Lai, C.-Y., Hashim, N., & Krisnawati, L. D. (2025). Hybrid-based movie recommender system: Techniques, case studies, evaluation metrics, and future trends. *Journal of Informatics and Web Engineering*. https://doaj.org/article/a5be3016c79a4b76a62e1d512485e816

Lin, N. (1976). Foundations for social research. *McGraw-Hill*. https://uk.sagepub.com/sites/default/files/upm-assets/123956_book_item_123956.pdf

Liu, J., Niu, Y., Jia, Z., & Wang, R. (2023). Assessing the ethical implications of artificial intelligence integration in media production and its impact on the creative industry. *MEDAAD*, 2023, 32–38. https://doi.org/10.70470/MEDAAD/2023/005

Lotz, A. D. (2022). Netflix and streaming video: The business of subscriber-funded video on demand. *Polity Press*. https://content.e-bookshelf.de/media/reading/L-18549931-dd1c01173e.pdf

Manovich, L. (2019). AI aesthetics. *Strelka Press*. https://monoskop.org/images/6/66/Manovich_Lev_AI_Aesthetics_2018.pdf

Masai, P., Carta, L., & Lis, M. M. (2026). Integrating GenAI in filmmaking: From co-creativity to distributed creativity [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2603.23415

Mazzi, F. (2024). Authorship in artificial intelligence-generated works: Exploring originality in text prompts and artificial intelligence outputs through philosophical foundations of copyright and collage protection. T*he Journal of World Intellectual Property*, 27(3), 410–427. https://doi.org/10.1111/jwip.12310

Miles, M. B., & Huberman, A. M. (1994). Qualitative data analysis: An expanded sourcebook. Sage. https://vivauniversity.wordpress.com/wp-content/uploads/2013/11/milesandhuberman1994.pdf

Mirowski, P. W., Mathewson, K. W., Pittman, J., & Evans, R. (2023). Co-writing screenplays and theatre scripts with language models: Evaluation by industry professionals. Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems. https://doi.org/10.1145/3544548.3581225

Moruzzi, C. (2022). Creative agents: Rethinking agency and creativity in human and artificial systems. *Journal of Aesthetics and Phenomenology*, 9(2), 245–268. https://doi.org/10.1080/20539320.2022.2150470

Netflix Technology Blog. (2025). Recommendations. Netflix Research. https://netflixtechblog.com/

Nieborg, D. B., & Poell, T. (2018). The platformization of cultural production: Theorizing the contingent cultural commodity. *New Media & Society,* 20(11), 4275–4292. https://doi.org/10.1177/1461444818769694

Ocal, A. (2025). Cinematic narratives as socio-technical systems: Emotion mining and script–audience emotional fidelity. *Systems,* 13(11), 994. https://doi.org/10.3390/systems13110994

Patton, M. Q. (2015). Qualitative research & evaluation methods: Integrating theory and practice (4th ed.). Sage. https://ia800500.us.archive.org/30/items/michael-quinn-patton-qualitative-research-evaluation-methods-integrating-theory-/Michael%20Quinn%20Patton%20-%20Qualitative%20Research%20&%20Evaluation%20Methods_%20Integrating%20Theory%20and%20Practice-Sage%20Publications,%20Inc%20(2014).pdf

Regulation (EU) 2022/2065 of the European Parliament and of the Council of 19 October 2022 on a Single Market for Digital Services (Digital Services Act). *Official Journal of the European Union*, L 277, 1–102. https://eur-lex.europa.eu/eli/reg/2022/2065/oj

Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence (Artificial Intelligence Act). *Official Journal of the European Union,* L, 2024/1689. https://eur-lex.europa.eu/eli/reg/2024/1689/oj

SAG-AFTRA. (2023). 2023 TV/theatrical contracts: Artificial intelligence resources. https://www.sagaftra.org/contracts-industry-resources/contracts/2023-tvtheatrical-contracts/artificial-intelligence-resources

Srnicek, N. (2017). Platform capitalism. *Polity Press*. https://mudancatecnologicaedinamicacapitalista.wordpress.com/wp-content/uploads/2019/02/platform-capitalism.pdf

Stebbins, R. A. (2001). Exploratory research in the social sciences. *Sage*. https://doi.org/10.4135/9781412984249

Sun, R., Wu, X., Akella, A., Kong, R., Knijnenburg, B., & Konstan, J. A. (2024). What are we optimizing for? A human-centric evaluation of deep learning-based movie recommenders [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2401.11632

Swarnakar, S. (2024). Artificial intelligence and cinema: Exploring the implications of artificial intelligence in cinema https://www.researchgate.net/publication/382692930_Artificial_Intelligence_and_Cinema_-_Exploring_the_Implications_of_Artificial_Intelligence_in_Cinema

Thomas, S., & Johnson, J. (2026). Rewriting authenticity: Cinema in the grip of digital prediction [Opinion article]. *Frontiers in Communication,* 11, 1687526. https://doi.org/10.3389/fcomm.2026.1687526

Thuillas, O., & Wiart, L. (2024). Cultural diversity according to Netflix: A means of legitimizing an industrial strategy? *Online Media and Global Communication*, 3(2), 290–306. https://doi.org/10.1515/omgc-2024-0015

Tian, Y., & Lee, S. (2025). Aesthetic evaluation of visual perception in AI-generated short films via integrated support vector machine and attention mechanism. *IEEE Access*, 13, 162144–162155. https://doi.org/10.1109/ACCESS.2025.3607486

Tores, J., Sassatelli, L., Wu, H., Bergman, C., Andolfi, L., Ecrement, V., Precioso, F., Devars, T., Guaresi, M., Julliard, V., & Lecossais, S. (2024). Visual objectification in films: Towards a new AI task for video interpretation [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2401.13296

Tsiavos, V., & Kitsios, F. (2025). The digital transformation of the film industry: How artificial intelligence is changing the seventh art. *Telecommunications Policy*, 103021. https://doi.org/10.1016/j.telpol.2025.103021

Tyagi, K. (2024). Copyright, text and data mining and the innovation dimension of generative AI. *Journal of Intellectual Property Law & Practice*, 19(7), 557–570. https://doi.org/10.1093/jiplp/jpae028

Uddin, S. M. I., Sumon, R. I., Mozumder, M. A. I., Chowdhury, M. K. H., Armand, T. P. T., & Kim, H. C. (2025). Innovations and challenges of AI in film: A methodological framework for future exploration. *ACM Transactions on Multimedia Computing, Communications and Applications*, 21(7), Article 199. https://doi.org/10.1145/3736724

van Dijck, J., Poell, T., & de Waal, M. (2018). The platform society: Public values in a connective world. *Oxford University Press*. https://doi.org/10.1093/oso/9780190889760.001.0001

Variety. (2025, January 20). 'The Brutalist' sparks backlash after editor reveals use of AI in dialogue and buildings. https://variety.com/2025/film/global/the-brutalist-ai-dialogue-drawings-backlash-1236279361/

Wood, A. J., Graham, M., Lehdonvirta, V., & Hjorth, I. (2019). Good gig, bad gig: Autonomy and algorithmic control in the global gig economy. *Work, Employment and Society*, 33(1), 56–75. https://doi.org/10.1177/0950017018785616

Writers Guild of America. (2023). 2023 Minimum Basic Agreement: Artificial intelligence provisions. https://www.wga.org/contracts/know-your-rights/artificial-intelligence

Xu, Y. (2025). Balancing creativity and automation: The influence of AI on modern film production and dissemination [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2504.19275

Yousefimehr, B., Ghatee, M., Ghaffari, S., Arasteh, A., Ahmadi, P., Ghane, A., & Esnaasharieh, S. (2026). A systematic review for 2019–2025 on deep learning models in the film production industry. *Entertainment Computing,* 52, 101076. https://doi.org/10.1016/j.entcom.2025.101076

Zeng, R., & Zhang, H. (2023). Analysis of film distribution methods based on artificial intelligence technology. *Applied Mathematics and Nonlinear Sciences*. https://www.researchgate.net/publication/375084572_Analysis_of_film_distribution_methods_based_on_artificial_intelligence_technology

Zhang, R. (2025). Algorithms as a cage and creative freedom: How streaming platforms reshape the power landscape of the film and television industry. A*dvances in Social Science, Education and Humanities Research*. https://doi.org/10.2991/978-2-38476-432-7_58

Appendix: Articles included in the coded corpus (n = 19)

1. Burkhardt, A. (2026). Artificial intelligence in the work and view of Latin American filmmakers. AI & Society, 41(2), 969–987.
2. Chapman, H. E., & Abraham, A. (2025). Because you watched. Behavioral Sciences, 15(11), 1544.
3. Gao, Y., & Lin, Z. (2025). The movie recommendation algorithm based on the TransD model. PLoS ONE, 20(11), e0333607.
4. Gürel, E. (2025). AI-driven experiences in cultural and creative industries. The Service Industries Journal.
5. Kim, J.-G. (2025). Deconstructing the screen. Journal of Digital Contents Society, 26(11).
6. Lai, C.-Y., Hashim, N., & Krisnawati, L. D. (2025). Hybrid-based movie recommender system. Journal of Informatics and Web Engineering.
7. Masai, P., Carta, L., & Lis, M. M. (2026). Integrating GenAI in filmmaking. arXiv. [Preprint]
8. Ocal, A. (2025). Cinematic narratives as socio-technical systems. Systems, 13(11), 994.
9. Sun, R., Wu, X., Akella, A., Kong, R., Knijnenburg, B., & Konstan, J. A. (2024). What are we optimizing for? arXiv. [Preprint]
10. Swarnakar, S. (2024). Artificial intelligence and cinema. ResearchGate. [Preprint]
11. Thomas, S., & Johnson, J. (2026). Rewriting authenticity. Frontiers in Communication, 11, 1687526. [Opinion article]
12. Tian, Y., & Lee, S. (2025). Aesthetic evaluation of visual perception in AI-generated short films. IEEE Access, 13, 162144–162155.
13. Tores, J., Sassatelli, L., Wu, H., Bergman, C., Andolfi, L., Ecrement, V., Precioso, F., Devars, T., Guaresi, M., Julliard, V., & Lecossais, S. (2024). Visual objectification in films. arXiv. [Preprint]
14. Tsiavos, V., & Kitsios, F. (2025). The digital transformation of the film industry. Telecommunications Policy, 103021.
15. Uddin, S. M. I., Sumon, R. I., Mozumder, M. A. I., Chowdhury, M. K. H., Armand, T. P. T., & Kim, H. C. (2025). Innovations and challenges of AI in film. ACM TOMM, 21(7), Article 199.
16. Xu, Y. (2025). Balancing creativity and automation. arXiv. [Preprint]
17. Yousefimehr, B., Ghatee, M., Ghaffari, S., Arasteh, A., Ahmadi, P., Ghane, A., & Esnaasharieh, S. (2026). A systematic review for 2019–2025 on deep learning models in the film production industry. Entertainment Computing, 101076.
18. Zeng, R., & Zhang, H. (2023). Analysis of film distribution methods based on artificial intelligence technology. Applied Mathematics and Nonlinear Sciences.
19. Zhang, R. (2025). Algorithms as a cage and creative freedom. Advances in Social Science, Education and Humanities Research.

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

REIMAGINING CAREER GUIDANCE IN BOSNIA AND HERZEGOVINA: ALIGNING NATIONAL POLICIES WITH THE REALITIES OF THE GLOBAL DIGITAL ECONOMY

Andrijana Mrkaić Ateljević[1], Anđelka Štilić[2], Sara Drakul[3]

Received 12.03.2026. | Send to review 29.03.2026. | Accepted 29.08.2026.

Original Article

CC BY NC ND

[1] College of Tourism and Hotel Management Trebinje, Bosnia and Herzegovina

[2] College of Tourism Belgrade; Academy of Professional Studies, Belgrade, Republic of Serbia

[3] Faculty of Technical Sciences, University of Novi Sad

***Corresponding Author:**
Andrijana Mrkaić Ateljević

Email:
andrijanamrkaic@gmail.com

JEL Classification:
Q01, Q56, L83, Z32, C51

Doi: 10.61432/CPNE0401261a

UDK: 331.548:005.591.5(497.6)

ABSTRACT

This paper investigates the divergence between traditional career guidance models in Bosnia and Herzegovina (BiH) and the dynamics of the digital economy, conceptualized as a distinct outcome of specific socio-economic conditions. The study examines the drivers of youth "digital emigration," analyzes the underlying structural interests of global digital platforms, and explores how these factors redefine contemporary career trajectories. The objective is to theoretically framework digital labor as an adaptive strategy for mitigating domestic systemic anomalies, while simultaneously delineating the structural differences between conventional and digital employment. Furthermore, the paper analyzes the working conditions of digital workers operating within Bosnia and Herzegovina, who concurrently navigate a pronounced deficit in institutional support. Utilizing multiple regression analysis, this study evaluates the impact of the independent variables "Average Monthly Net Wage in BiH" and "Above Basic Digital Skills" on the dependent variable "Hourly Wage of Digital Workers," thereby empirically validating the formulated research hypotheses. The paper concludes that the career development of digital workers is decoupled from the conditions of the domestic traditional economy, macro-dependant instead on the global economic landscape and the proficiency of their digital skills.

Keywords: *Career Guidance, Digital Economy, Bosnia and Herzegovina, Digital Enclosure, Social Justice*

1. INTRODUCTION

Within this new economic order, traditional concepts of linear career development and institutionally mediated employment are rapidly giving way to flexible, yet highly precarious, forms of remote work (Standing, 2011). While developed economies integrate these changes through proactive digital transformation strategies, post-socialist and post-conflict societies on the geopolitical periphery of Europe, such as Bosnia and Herzegovina (BH), face a unique socio-technical paradox. While national policies and institutional models of career guidance in BH remain firmly rooted in a rigid, industrial paradigm, a significant portion of the young and highly skilled workforce is undergoing processes of autonomous integration into global value chains, creating a phenomenon defined in the literature as "digital emigration" (Graham et al., 2017). The contemporary discourse on human resource development and macroeconomic stability is increasingly articulated through the prism of the Fourth

Industrial Revolution, within which technological advancements radically reconfigure the global division of labor (Schwab, 2016). Traditional postulates of industrial economies, relying on stable labor relations and predictable institutional frameworks within national borders, are rapidly retreating before the expansion of platform-based business models. In such an environment, the concept of a career loses its historical characteristics of static nature and linear progression, transforming into highly dynamic, fluid, and individualized socio-technical trajectories (Bridstock, 2019). For developed Western democracies, these processes represent an avenue for planned digital transition and the implementation of innovative lifelong learning strategies, based on the establishment of the European Qualifications Framework for lifelong learning - EQF (European Commission, 2020). Conversely, for transition countries and post-conflict societies, the digital space becomes an alternative, parallel, and often unregulated market operating beyond the reach of state control mechanisms and social protection (Heeks, 2017). In this context, Bosnia and Herzegovina stands out as a specific area of pronounced socio-economic contrasts and structural anomalies. While the domestic institutional system, including the education sector and public employment services, suffers from chronic inertia and rigidity, the youth population autonomously finds channels for economic integration at the global level (World Bank, 2021). Official data and international indexes recognize BH and the Western Balkans region as one of the leading zones per capita regarding participation in the global online workforce (Stephany et al., 2021). This phenomenon of mass engagement on foreign platforms does not represent mere technical progress or a reflection of high digital literacy, but rather a reflection of deep social circumstances (Graham et al., 2017). However, this spontaneous integration into global economic flows takes place within a complete institutional vacuum, which constitutes the central research problem of this paper. Current legislative and strategic frameworks in BH treat digital labor in a fragmented manner—primarily through the lens of taxation and foreign currency inflows—while the labor-legal status, social security, and systemic support for these workers are entirely neglected. Career guidance, as a public policy intended to direct, empower, and protect human capital, remains focused in BiH on traditional mediation within the domestic labor market. Aligning national strategies with the demands of digital transformation is crucial for labor market sustainability, which is further confirmed by regional studies focused on innovative economic policies in the Western Balkans. According to the findings of Stojanović, investing in innovative activities and digital technologies represents a fundamental prerequisite for raising the competitiveness of Western Balkan countries in the global market. Through the application of a multi-criteria SMART approach (CRITIC and CRADIS methods), the authors demonstrate that pronounced disparities regarding innovative characteristics exist within this region, which necessitates a redefinition of national strategies and a shift toward stabilizing decision-making models in developing economies (Stojanović et al., 2022).

The scientific contribution of this paper lies in its endeavor to deconstruct the sharp disconnection between static national policies and the dynamic digital reality in which workers from BH operate on a daily basis. Instead of a reactive approach limited to the administrative registration of the unemployed, this paper advocates for a proactive transformation of public policies toward developing digital agility, legal literacy, and protecting the dignity of labor within the global economy (Wood et al., 2019). Following the introductory considerations, the paper provides a critical review of global literature on the platform economy, with a special emphasis on changes in the structure of occupations and skills. The central part of the paper is dedicated to the methodological framework, which combines desk research and available statistical indicators on trends within the digital labor market in BH. The conclusion of the paper summarizes the key theses and defines directions for future empirical research in this field.

2.THEORETICAL RECONFIGURATION OF CAREER DEVELOPMENT: TRADITIONAL VERSUS PLATFORM PARADIGM

2.1. PERVIOUS RESEARCH

The global labor market is undergoing a profound transformation driven by the expansion of the digital economy and the proliferation of labor platforms, which redefines traditional concepts of employment and career development (Srnicek, 2017). The beginnings of the digital economy's development date back to the 1990s and the emergence of the internet, which laid the foundation for its subsequent growth (Bukht & Heeks, 2017). The tethering of workers to the physical location of the production process has drastically decreased over the years. Wherever a need for new jobs emerged alongside a significant presence of digital connectivity, many individuals turned to the outsourcing of digitally mediated labor as a way to overcome certain limitations of their local labor markets (Taylor & Bain, 2017). The digital economy, driven by the rise of platform capitalism and artificial intelligence, has fundamentally redefined the nature of work, blurring traditional boundaries between the workplace and the home, as well as between the status of an employee and an entrepreneur (Srnicek, 2017). Elaborating on the same concept, Deloitte identifies four main areas of rapidly expanding digital transformation: the future of work, customer experience, the digital supply network, and the Internet of Things (2021). In the contemporary digital era, the concept of a career ceases to be a linear process within a single stable organization and transforms into the so-called "boundaryless career." Workers no longer advance through the hierarchical ladders of a single firm; instead, they manage a "portfolio career," balancing multiple distinct projects, clients, and platforms simultaneously (Bridstock, 2019). This observation aligns with Arthur's assertions, according to which the boundaryless career is characterized by mobility and flexibility (Arthur & Rousseau, 2001). The main characteristic of a career in the digital age is its foundation in technological advancement (Ha et al., 2026). Numerous platforms utilize complex algorithms for worker ranking, performance evaluation, or the hiring process. In various literature sources, the term "algorithmic management" can be found. This process implies replacing human managers with invisible software code, which often results in reduced transparency and the degradation of workers' bargaining power (Wood et al., 2019; Gandini, 2019). In such an environment, career guidance and skills development must transform radically. Traditional "hard" knowledge quickly becomes obsolete, while digital agility, the ability to manage an online reputation, and continuous learning (lifelong learning) come to the forefront (Aumeboonsuke & Caplanova, 2026). However, this transformation can cause a multitude of issues, such as income instability or a lack of social protection, which Standing (2011) defines as the emergence of a new class of workers, the so-called "precariat." Thus, it is a class that faces great freedoms, but unlike the secure (albeit partly low-paid and monotonous) jobs of the proletariat, the precariat must struggle with a whole range of new uncertainties, disadvantages, and the reduction of rights (Standing, 2014). In many transition societies, national digitalization strategies are often focused exclusively on technical infrastructure, while human capital and career guidance are left on the margins. Policies that disregard the specifics of digital labor risk creating a deep gap; on one hand, a "knowledge society" is promoted, while on the other, the growth of unprotected precarious work is tacitly permitted (Woodcock, 2021). National career guidance policies worldwide face the challenge of adapting regulatory frameworks that have been built for decades on the assumption of standard employment relations. Today, the main conflict in policy-making lies in the tension between the need for flexibility demanded by global platforms and the state's obligation to ensure social protection and labor rights in accordance with the International Labour Organization's decent work agenda (Graham

et al., 2017). Explaining the issues of labor policies in the digital era, Graham specifically highlights the so-called "digital exit strategy," which represents an individual's conscious choice to bypass systemic barriers, corruption, and nepotism in the domestic environment by redirecting their career toward global digital platforms (Anwar & Graham, 2021). This strategy allows workers to achieve economic independence and merit-based advancement without physically leaving their own country, although it simultaneously exposes them to new forms of algorithmic insecurity (Graham et al., 2017; Wood et al., 2019). Understanding these dynamics is crucial for establishing any local career guidance framework that strives for social justice and the protection of labor dignity.

2.2. THEORETICAL RECONFIGURATION OF CAREER DEVELOPMENT: TRADITIONAL VERSUS PLATFORM CAREER

To deconstruct the structural labor market gap in BH, it is essential to contrast the traditional and emergent models of career development. Classic 20th-century models rely on a stable, predictable, and geographically bounded domestic labor market (Super, 1957). Within this paradigm, a career is a linear and vertical process within formal organizations, grounded in institutional security (permanent contracts, collective bargaining, pension systems). Public policies and employment services function reactively, serving as mere administrative intermediaries in a static local market. Conversely, global platform capitalism introduces the concepts of "boundaryless" and "portfolio" careers, erasing geographical constraints and tethering to a single employer (Arthur & Rousseau, 1996; Bridstock, 2019). Socio-technical platforms (Upwork, Fiverr, Toptal) assume the role of labor allocators, while entirely externalizing business risks onto the worker (Srnicek, 2017). Career development becomes a permanent process of individual project and online reputation management (Gandini, 2016), subjected to asymmetric "algorithmic management" (Wood et al., 2019). In reality, the proclaimed autonomy and flexibility are inextricably linked to a high degree of precariousness, income instability, and the erosion of labor rights (Standing, 2011). These global asymmetries are specifically refracted through regional and gender inequalities. The largest gender pay gap is recorded precisely in Bosnia and Herzegovina, where women earn only 38.9% of men's wages. Concurrently, across almost all observed occupational groups, platform workers from European Union countries such as Hungary, Croatia, Bulgaria, and Romania achieve significantly higher hourly rates compared to their counterparts from BH.

Table 1. Comparative analysis of traditional and digital platform career development

Dimension of Comparison	Traditional Career Development	Digital Platform Career Development
Career Paradigm	Organizational / Hierarchical	Boundaryless
Nature of Career Path	Linear, vertical, spatially bounded	Non-linear, fluid, cross-border, networked
Primary Management Actor	Human Resources (HR)	Algorithmic management
Degree and Nature of Autonomy	Limited by formal contract and working hours	Nominally high ("Gig freedom" and flexibility)
Regulatory Status of Worker	Standard employment relationship (Labor contract)	Legal vacuum / Precarious status
Performance Evaluation Mechanism	Transparent internal corporate appraisal	Non-transparent algorithmic reputation systems
Social and Labor Security	Integrated (Sick leave, years of service, pension funds)	Total insecurity / Complete vulnerability
Main Motivational Factor	Striving for stability	Digital exit strategy Meritocracy
Main Forms of Vulnerability	Mobbing, political clientelism, nepotism	Digital enclosure / Algorithmic bias
Required Career Competencies	Specialized formal and technical knowledge	Digital agility, self-branding, lifelong learning

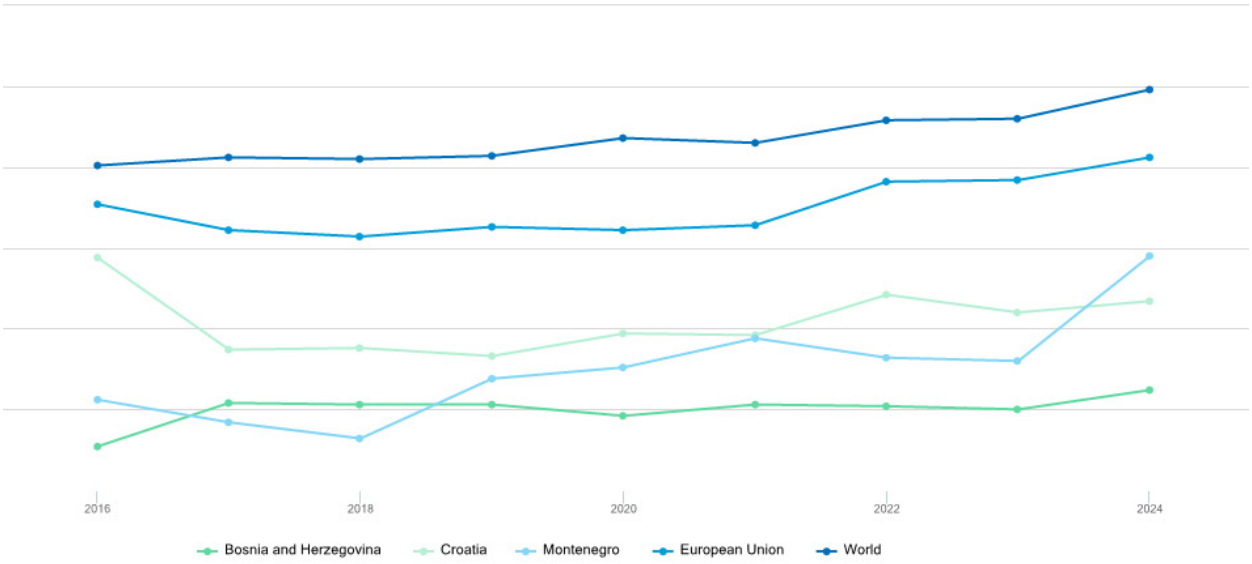
Source: Author's own work

As shown in Table 1, the transformation of the career paradigm from traditional to digital platform brings a radical turn in the structure of power and control. While the traditional model in Bosnia and Herzegovina suffers from local anomalies such as nepotism, the transition to a platform model creates the appearance of an absolute meritocracy. However, this transition simultaneously introduces workers to a state of systemic vulnerability under the influence of algorithmic management, where the lack of national policies and adequate career guidance leaves the digital workforce without basic labor-legal protection.

3. CAREER ANALYSIS OF DIGITAL WORKERS IN BOSNIA AND HERZEGOVINA

The contemporary labor market in Bosnia and Herzegovina is characterized by a profound structural dualism, manifested through a sharp mismatch between rigid, locally grounded traditional forms of employment and the fluid expansion of the global digital economy. While traditional career models progressively lose economic competitiveness and innovative potential, digital career development is articulated as an informal strategy of economic resistance and merit-based advancement for the youth population. Within this nascent digital segment, the workforce in Bosnia and Herzegovina is essentially divided into three key categories: classic freelancers, who independently secure foreign clients via project-based platforms; online workers, who establish longer-term contractual relations with a single foreign company with fixed monthly incomes (Oruč & Kurta, 2023); and location-based platform workers, such as drivers and delivery couriers, whose labor is digitally mediated by algorithms but physically executed within the local market (Center for Public Policy Research, 2022). In contrast to the dynamism of this digital sphere, the country's traditional sector which primarily encompasses public administration, traditional retail, manufacturing, and construction remains deeply burdened by systemic dysfunctions that generate high rates of unemployment and economic inactivity (BHAS, 2025). To better understand the state of careers within the digital economy, the indicator "High-technology exports (% of manufactured exports)" can be observed within the context of Bosnia and Herzegovina. The value of this indicator for BH is traditionally among the lowest in Europe hovering below 5% which demonstrates that the domestic traditional industry fails to generate a sufficient number of high-technology and well-paid digital jobs. Concurrently, this indicator stands at 25% globally and at 21% within the European Union. This very inability of the domestic system to provide avenues for advanced career development drives young and educated individuals into the gig economy and freelance work for foreign markets. Consequently, the low macroeconomic values of this indicator in Bosnia and Herzegovina directly stimulate the growth of remote digital workers, who develop their careers entirely independent of the technological underdevelopment characterizing the domestic economy. The following chart provides a comparative overview of this indicator for Bosnia and Herzegovina and its neighboring countries.

Chart 1. High-technology exports (% of manufactured exports), Bosnia and Herzegovina and other countries



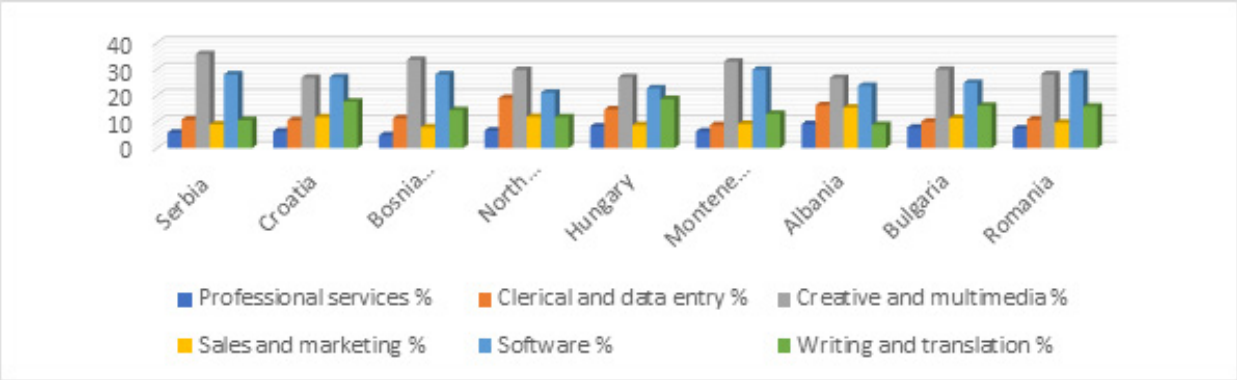
Source: https://databank.worldbank.org/reports.aspx?source=2&series=TX.VAL.TECH.MF.ZS&country=BIH,HRV,MNE,SRB,EUU,WLD , downloaded 15.05.2026.

Workers in Bosnia and Herzegovina are massively developing new career imaginaries, escaping local frameworks into the sphere of the global digital world. In contemporary literature, this specific form of economic mobility is defined as digital emigration, whereby the working-age population, instead of physically crossing the geographical borders of the state, emigrates into the online space (Oruč & Kurta, 2021). These individuals remain spatially located in their home country, directly contributing to local consumption, while exporting their services in software development, graphic design, digital marketing, and translation to wealthy Western markets through global labor platforms. According to regional empirical research conducted by the Gigmetar platform, Bosnia and Herzegovina has positioned itself as one of the leading countries in the Southeast Europe region regarding the number of digital workers per capita. The key driver of this structural transition is algorithmic meritocracy, given that traditional barriers lose relevance on global platforms, and clients select collaborators solely based on publicly available portfolios, technical skills, and digital ratings. Beyond a sense of fairness, this engagement yields direct material benefits, as reports indicate that the average hourly rate in the digital economy multiple times exceeds the equivalent hourly wage in the domestic traditional market, thereby generating a significant economic premium.

Aligning national policies with the reality of the digital economy in BH is exceptionally slow, leaving workers in a legal and institutional vacuum. The country faces a pronounced deficit in regulations regarding digital rights, which directly jeopardizes online workers and slows down the development and competitiveness of the domestic digital market (Zečević et al., 2024). Entity-level income tax laws (such as the Law on Income Tax of the FBH) recognize these workers exclusively through their tax obligations—specifically a 10% tax and a 4% health insurance contribution. However, this income is treated as "casual independent activity," which legally deprives them of the right to actual health insurance coverage, pension years, paid sick leave, or maternity leave. In addition to domestic institutional vulnerability, digital workers are simultaneously exposed to the asymmetric power of global platforms and non-transparent algorithmic management. An algorithmic modification or a unilateral profile suspension means an overnight loss of entire career capital without any right to legal remedy. Thus, transitioning to digital careers simultane-

ously offers an avenue for meritocratic salvation while opening up unprecedented forms of precarization and existential insecurity (Gigmetar, 2022). This career is predominantly realized on global platforms such as Guru, Freelancer, and Upwork, with the latter hosting as many as 56.01% of digital workers. While more developed, conventional markets with greater local business opportunities (such as Hungary, Romania, Bulgaria, and Croatia) register an average of 61 gig workers per 100,000 inhabitants, Bosnia and Herzegovina records a significantly higher concentration of 100.6 gig workers per 100,000 inhabitants (Gigmetar, 2026). Nevertheless, Gigmetar data indicate that during 2025, there was a contraction in the digital labor supply in BH, specifically at a rate of 6.1%. Despite this, BH continuously maintains a comparative advantage in regional career development, particularly in the fields of creative services and multimedia, administrative services, and software development. The following chart illustrates the regional representation of specific sectors, with percentage breakdowns for all observed countries.

Chart 2. Regional gig workers by country and profession



Source: Author's own work

Older data suggest that during 2023, Bosnia and Herzegovina recorded stable indicators in the domain of digital skills development, with an internet usage rate of 83% fully following the average of the Western Balkan countries. Also, in 2021, ICT graduates accounted for more than 5% of all graduated students, while that percentage in 2019 was 4.6% (EU DESI).

4. RESEARCH METHODOLOGY AND SPECIFICATION OF THE REGRESSION MODEL

In order to empirically demonstrate the gap between institutional support and the economic reality of workers in Bosnia and Herzegovina, this paper applies a multiple linear regression model based on annual time series for the period from 2022 to 2025. The focus of this model is not only on establishing a correlation, but on mathematically testing the thesis that digital career development in BiH occurs autonomously and completely isolated from national economic trends and official educational policies. The objective is to test the following hypotheses:

H_0: Workers' digital skills influence the hourly wage of digital workers;

H_1: Digital career development and the labor price of digital workers in BiH occur autonomously and completely isolated from the movements of the average monthly net wage in BiH as a key indicator of national economic trends.

The specification of the multiple linear regression model follows the standard econometric methodology of time series analysis (Wooldridge, 2020). The application of this formula allows for the isolation of the individual impacts of independent factors on digital career development in Bosnia and Herzegovina.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (1)$$

Y – dependent variable,

X – independent variable;

β_0 - the model constant (Intercept) which represents the theoretical starting point;

β_1- measures the change in Y with respect to X_1, holding other factors fixed;

β_2 - measures the change in Y with respect to X_2, holding other factors fixed;

ε – random disturbance, error.

The dependent variable in the regression model is the „Hourly price of digital workers“ expressed in US dollars, and the data is taken from the official regional reports of the Gigmetar platform. This variable shows the financial attractiveness of the global online market, which serves as a mechanism for autonomous career development and meritocratic advancement for workers. The first independent variable is „Above basic digital skills“, as one of the indicators of the DESI (Digital Economy and Society Index). Established by the European Commission in 2014, DESI measures four major indicators as a percentage of the total index in a given country: digitally skilled population and highly skilled digital professionals, secure and sustainable digital infrastructures, digital transformation of businesses, and digitalisation of public services. The “Above basic digital skills” indicator reflects the population’s digital literacy that exceeds the basic level. The data for this variable is sourced from the DESI reports for the Western Balkans, published by the Regional Cooperation Council (RCC). Its primary role is to test whether the digital skills possessed by workers in Bosnia and Herzegovina in any way track, generate, or direct earnings. The second independent variable is the „Average monthly neto wage in BH“ (expressed in BAM), with data retrieved from the official annual releases and bulletins of the Agency for Statistics of Bosnia and Herzegovina (BHAS). This variable measures the economic standard within the country’s traditional sector, demonstrating the extent to which unattractive wages incentivize the workforce to abandon conventional business models and enter the digital economy.

Given that the data are expressed in different units, the first step is to reduce the data to the same, standardized value (Z-score), because in this way the influence of different units is removed and comparability and interpretation are facilitated. The Z-score calculation is achieved using the formula (Mrkaić Ateljević, 2025):

$$Z = \frac{X - \mu}{\sigma} \quad (2)$$

X = value for the indicator/year,

μ = average value of the entire series – arithmetic mean,

σ = standard deviation

For the purpose of standardization, the arithmetic mean was first calculated in Excel using the statistical formula (Gravetter, 2017, p. 76):

$$\mu = \frac{1}{n} \sum_{i=1}^{n} x_i \quad (3)$$

x_i = individual value (observation)

n = number of observations

The sample standard deviation (S) is calculated using the following formula (Gravetter, 2017, p. 113):

$$S = \sqrt{\frac{SS}{n-1}}, \; SS = \sum_{i=1}^{n} (x_i - \mu)^2 \quad (4)$$

Table 2. Input data before standardization

Year	2022	2023	2024	2025
Hourly rates in US$	17.4	19.3	21.7	20.9
Above basic digital skills %	5	5.4	6.9	6.9
Average salary BAM	1100	1263	1381	1570

Source: www.bhas.org , https://gigmetar.repeople.rs/ , https://desi.rcc.int/docs_archive, downloaded 18.05.2026.

After obtaining the standardized values, a regression analysis was performed, the results of which are shown in the following figure.

Table 3. Results of correlation and regression analysis of the relationship

Regression Statistics								
Multiple R	0.917097869							
R Square	0.841068501							
Adjusted R Square	0.523205502							
Standard Error	0.690503076							
Observations	4							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	2.523205502	1.261603	2.646009	0.398662137			
Residual	1	0.476794498	0.476794					
Total	3	3						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.15198427	0.38201383	0.39785	0.758943	-4.701961662	5.005930203	-4.70196166	5.0059302
X -Above basic digital s	1.494209255	1.60753531	0.929503	0.523249	-18.93146352	21.91988203	-18.9314635	21.919882
X- Average salary	-0.453538323	1.446484815	-0.31355	0.806572	-18.83287053	17.92579389	-18.8328705	17.925794

Source: Author's own work

$$Y = 0.152 + 1.494\ X_1 - 0.453\ X_2 \qquad (5)$$

The obtained econometric results of the multiple regression analysis provide a critical empirical insight into the structural specificities through which digital career development is channeled in Bosnia and Herzegovina. The regression analysis reveals a high multiple correlation coefficient (Multiple R = 0.91), indicating an exceptionally strong linear relationship between the observed independent variables and the dependent variable. Furthermore, the coefficient of determination (R Square = 0.84) confirms that the model successfully explains 84% of the variations in the observed trends. A one-unit increase in the *Above basic digital skills* variable leads to an increase in the *Hourly wage of digital workers* by approximately 1.49 units, ceteris paribus. Conversely, a one-unit increase in the *Average monthly net wage* leads to a decrease in the *Hourly wage of digital workers* by about 0.45 units. This negative slope coefficient β_2= -0.45 indicates an inverse (negative) relationship between the *Average net wage* in Bosnia and Herzegovina and the *Hourly wage of digital workers*. This result directly demonstrates the existence of a deep gap between the domestic economic reality and the digital sector. The cause of this negative coefficient is neither an internal shift in the labor force nor a decline in interest in digital jobs within BH. While wages in the domestic (traditional) market grew under the pressure of local inflation and administrative minimum wage adjustments, the hourly wage of digital workers declined due to the global recession in the IT sector and rising competition on global platforms. The digital worker in BH is isolated from the domestic economy they share the fate of the global digital market while simultaneously bearing the costs of local inflation.

5. CONCLUSION

The empirical analysis conducted in this study provides critical insights into the factors generating labor value within the digital sphere, thereby offering a robust scientific foundation for evaluating the formulated research hypotheses. The multiple regression results indicate that the average monthly net wage in Bosnia and Herzegovina exerts no statistically significant impact on the determination of digital workers' hourly rates. This finding directly and fully validates the research hypothesis H1, demonstrating that digital career development and labor pricing within this sector operate autonomously and in isolation from traditional national macroeconomic trajectories. The primary driver of this structural decoupling lies in the absolute orientation of digital workers toward the global labor market. The professional advancement of this demographic is independent of conventional progression phases within the domestic economic framework; instead, it is primarily channeled through international platform ecosystems.

Conversely, the analysis established a statistically significant impact of the advanced digital competencies variable on the dependent variable, thereby successfully verifying the research hypothesis H0, which posits that workers' digital skills directly determine their hourly wage. Their labor pricing dynamics and transition into higher income brackets are strictly contingent upon building a globally competitive portfolio, acquiring international client reviews, and rigidly adapting to the standards of developed Western economies.

The statistical model's failure to identify a stable linear relationship between domestic macroeconomic parameters and platform reality scientifically substantiates that internet-based career development occurs within a complete regulatory and institutional vacuum. The deficit of systemic support and adequate legal frameworks in Bosnia and Herzegovina directly induces a process of "digital enclosure," leaving the labor force in a state of high precarity—a finding that aligns with existing scientific literature. Workers deploying the strategy of "digital emigration" attain a semblance of meritocratic salvation; however, their subsequent career trajectory remains structurally vulnerable due to unresolved foundational social rights, such as healthcare and pension-disability insurance.

Ultimately, the empirical findings confirm that digital career development in Bosnia and Herzegovina does not replicate traditional economic cycles. Instead, it constitutes an autonomous substitute conditioned by the stagnation of the domestic labor market. Within this context, depressed wages in the traditional sector act as a primary push factor, steering workers with advanced digital proficiencies toward the more lucrative online space.

Nevertheless, interpreting these conclusions requires careful consideration of the study's methodological limitations. The primary constraint of this research stems from the small sample size, dictated by a chronic deficit of official statistical data regarding the gig economy in Bosnia and Herzegovina, which precludes a broader generalization of these economic conclusions at the macro-level.

REFERENCES

Agency for Statistics of Bosnia and Herzegovina, 2025 Labor Force Survey 2025: Working-age population by age groups, activities and gender - Annual Bulletin. Sarajevo. https://bhas.gov.ba/data/Publikacije/Saopstenja/2026/LAB_00_2025_Y1_1_BS.pdf , downloaded 12.05.2026.

Agency for Statistics of Bosnia and Herzegovina [BHAS] (2024). Average monthly paid net and gross salaries of employees in 2024: Indices of nominal and real growth by areas of activity - Annual announcement. Sarajevo: BHAS. Link: https://bhas.gov.ba/data/Publikacije/Saopstenja/2024/LAB_05_2023_H1_1_BS.pdf , downloaded 18.05.2026.

Andrejevic, M. (2007). I Spy: Surveillance and Power in the Interactive Era. University Press of Kansas. ISBN: 978-0-7006-1528-5

Andjelkovic, B., Jakobi, T., & Radonjic, L. (2024). Right before your eyes, yet unnoticed: A comparison of the growth of online labour in various countries in Southeast Europe. PRO PUBLICO BONO: MAGYAR KÖZIGAZGATÁS, *A Nemzeti Közszolgálati Egyetem Közigazgatás-Tudományi Szakmai Folyóirata*, 12(1), 145-172. https://doi.org/10.32575/ppb.2024.1.7

Arthur, M. B., & Rousseau, D. M. (Eds.). (2001). The boundaryless career: A new employment principle for a new organizational era. Oxford University Press. ISBN: 9780195100143

Anwar, M. A., & Graham, M. (2021). Between a rock and a hard place: Freedom, flexibility, precarity and vulnerability in the gig economy in Africa. *Competition & Change,* 25(2), 237-258. https://doi.org/10.1177/1024529420914473

Ateljević, A. M. (2025). Bibliometric analysis as a basis for research on sustainability in tourism in Bosnia and Herzegovina. *Collection of papers new economy,* 3(1), 57-70. https://doi.org/10.61432/CPNE0301057

Aumeboonsuke, V., & Caplanova, A. (2026). Determinants of the Digital Gap: A Comparative Analysis of Central Europe and Southeast Asia, 2002–2024. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 309-332. https://doi.org/10.2478/eoik-2026-0038

Bridgstock, R. (2019). Graduate employability 2.0: Learning for life and work in a socially networked world. *In Education for Employability* (Volume 1) (pp. 97-106). Brill. https://doi.org/10.1163/9789004400832_008

Bukht, R., & Heeks, R. (2017). Defining, conceptualising and measuring the digital economy. *Development Informatics working paper,* (68). Link: https://hummedia.manchester.ac.uk/institutes/gdi/publications/workingpapers/di/di_wp68.pdf

Center for Public Policy Research. (2022). The vulnerability of workers in the gig economy of the Western Balkans and the risk of algorithmic management. *Center for Public Policy Research*. Link: https://gigmetar.publicpolicy.rs/region-2022-2/

Deloitte, n.d. What is Digital Economy? New York, NY. Link: https://www2.deloitte.com/mt/en/pages/technology/articles/mt-what-is-digital-economy.html

European Commission. (2020). European Skills Agenda for sustainable competitiveness, social fairness and resilience. Brussels. Link: https://eur-lex.europa.eu/legal-content/HR/TXT/PDF/?uri=CELEX:52016DC0381

International Labour Organization. (2021). The role of digital labour platforms in transforming the world of work. World Employment and Social Outlook 2021: The role of digital labour platforms in transforming the world of work.

International Labour Organization (ILO). Employment and Labour Market Trends in Bosnia and Herzegovina. Geneva. Link: https://national-policies.eacea.ec.europa.eu/youthwiki/chapters/bosnia-and-herzegovina/36-integration-of-young-people-in-the-labour-market , downloaded 12.05.2026.

Graham, M., & Woodcock, J. (2019). The gig economy: a critical introduction. *Polity*, 54. Link: http://oro.open.ac.uk/68716/

Gandini, A. (2019). Labour process theory and the gig economy. *Human relations*, 72(6), 1039-1056. https://doi.org/10.1177/0018726718790002

Gandini, A. (2016). The reputation economy: Understanding knowledge work in digital society. *Springer*. https://doi.org/10.1057/978-1-137-56107-7

Graham, M., Hjorth, I., & Lehdonvirta, V. (2017). Digital labour and development: impacts of global digital labour platforms and the gig economy on worker livelihoods. *Transfer: European review of labour and research,* 23(2), 135-162. https://doi.org/10.1177/1024258916687250

Gravetter Frederick J and Larry B. Walnau, 2017, Statistics for the Behavioral Sciences, 10 edition, The College at Brockport, State University of New York. Link: http://ndl.ethernet.edu.et/bitstream/123456789/29095/1/Frederick%20J%20Gravetter_2017.pdf

Ha, T. M. (2026). How Digital Capabilities Drive Innovation in Banking: Extending the Resource-Based View in the Era of Digital Transformation. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 353-373. https://doi.org/10.2478/eoik-2026-0040

Heeks, R. (2017). Information and communication technology for development (ICT4D). Routledge. ISBN (Print) 9781138101814.

Taylor, P., & Bain, P. (2008). United by a common language? Trade union responses in the UK and India to call centre offshoring. *Antipode,* 40(1), 131-154. https://doi.org/10.1111/j.1467-8330.2008.00567

Oruč, N., & Kurta, A. (2021). The impact of digital platform work on labor migration migration trajectories in the Western Balkans. Sarajevo: Centre for Development Evaluation and Social Research (CREDI). Link: https://credi.ba/en/category/publication/page/8/ downloaded 21.05.2026.

Srnicek, N. (2017). Platform Capitalism. Polity Press, Cambridge Malden, MA. https://doi.org/10.20396/rbi.v18i2.8654960

Standing, G. (2011). The precariat: The new dangerous class (p. 208). Bloomsbury academic. ISBN:978-1-4725-36167 Link: https://library.oapen.org/viewer/web/viewer.html?file=/bitstream/handle/20.500.12657/58691/9781849664547.pdf?sequence=1&isAllowed=y

Standing, G. (2014). The precariat-the new dangerous class. *Amalgam*, 6 (6-7), 115-119. https://hrcak.srce.hr/file/198908

Stojanović, I., Puška, A., & Selaković, M. (2022). A multi-criteria approach to the comparative analysis of the global innovation index on the example of the Western Balkan countries. *Economics,* 10(2), 9-26. https://doi.org/10.2478/eoik-2022-0019

Schwab, K. (2016). The fourth industrial revolution. *In World Economic Forum* (Vol. 12). Link: https://cormolenaar.nl/wp-content/uploads/2020/09/The-fourth-industrial-revolution.pdf

Zečević Z., Raković S., Zagajac J., 2024., "Guide on labor and digital rights in Bosnia and Herzegovina" European Union - LIR Evolution. Link: https://nestovise.org/wp-content/uploads/2023/08/Vodi%C4%8D-o-radnim-i-digitalnim-pravima.pdf, downloaded 22.05.2026.

Wood, A. J., Graham, M., Lehdonvirta, V., & Hjorth, I. (2019). Good gig, bad gig: autonomy and algorithmic control in the global gig economy. *Work, employment and society,* 33(1), 56-75. https://doi.org/10.1177/0950017018785616

Wooldridge, J. M. (2016). Introductory econometrics a modern approach. South-Western cengage learning Link: https://www.kufunda.net/publicdocs/Wooldridge-Introductory-Econometrics_-A-Modern-Approach-6th-Edition-c2016.pdf , downloaded 15.04.2026.

Stephany, F., Kässi, O., Rani, U., & Lehdonvirta, V. (2021). Online Labour Index 2020: New ways to measure the world's remote freelancing market. *Big Data & Society,* 8(2). https://doi.org/10.1177/20539517211043240

World Bank. 2021. Western Balkans Regular Economic Report, No. 20, Fall 2021: Greening the Recovery. *Western Balkans Regular Economic Report*, 20. World Bank. http://hdl.handle.net/10986/36402

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

DIGITAL TWIN RESILIENCE IN PORTUGUESE ATLANTIC CORRIDOR PORTS: A STAKEHOLDER STUDY

Carlos Batista[1*], Ana Barroso[2], Tiago Pinho[3]

Received 09.03.2026. | Send to review 27.03.2026. | Accepted 23.08.2026.

Original Article

CC BY NC ND

[1] Polytechnic University of Setúbal, School of Business and Administration, Setúbal, Portugal

[2] UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Caparica, Portugal, Laboratório Associado de Sistemas Inteligentes, LASI, Guimarães, Portugal

[3] Polytechnic University of Setúbal, School of Business and Administration, Setúbal, Portugal, UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Caparica, Portugal

***Corresponding Author:**
Carlos Batista

Email:
carlos.batista@esce.ips.pt

JEL Classification:
L91, O33, R41, L98

Doi: 10.61432/CPNE0401273b

UDK: 351.778.5:711.417.4(469)

ABSTRACT

Digital transformation (DTx) has become a key driver of competitiveness, sustainability, and operational performance in modern ports, where increasingly complex supply chains require resilient information management. Among emerging digital technologies, the Digital Twin (DT) has gained attention as a cyber-physical solution that strengthens information flow resilience and supports smarter port operations.

In line with Portugal's Ports 5+ Strategy, which promotes digitalization and automation as pillars of port modernization, this study examines the potential of DT solutions in Portuguese core ports within the Atlantic Corridor of the Trans-European Transport Network (TEN-T), recognizing information as a strategic operational asset.

The study adopts an exploratory qualitative design based on semi-structured interviews with ten key stakeholders from a core Atlantic Corridor port. The interview protocol focused on two dimensions: (i) information flow resilience and (ii) the continuity and sustainability of port and logistics operations.

The findings indicate that stakeholders perceive DT solutions as having significant potential to improve logistics resilience by reducing vulnerabilities, anticipating disruptions, and maintaining operational continuity during technological failures, congestion, and other unexpected events. However, the study also identifies important research gaps. Existing literature lacks an integrated framework connecting DT with port resilience, interoperability, and logistics continuity, while empirical evidence remains largely limited to major high-tech terminals, with insufficient attention to medium-sized ports and their regional and organizational contexts, such as those in Portugal.

Keywords: *Digital Twin, Information Flow Resilience, Port Operations, Atlantic Corridor, Portuguese Ports, Stakeholder Analysis, Maritime Logistics Continuity*

1. INTRODUCTION

Seaports are strategic components of the global economy, serving as key hubs for maritime and inland freight transport. As nearly 90% of global trade is carried by sea, ports are essential to the functioning and stability of modern supply chains. Their role in facilitating intermodal transport means that changes in port efficiency can generate significant effects across the entire value chain.

Ports also contribute to regional and national economic development (Valenzuela-Silva et al., 2025). Improved port performance can create economies of scale, reduce emissions, and lower transportation costs for businesses (Klar et al., 2023). Moreover, ports constitute critical national infrastructure because they support the continuous supply of essential goods (Epiphaniou et al., 2023).

Port resilience is therefore crucial to overall supply chain resilience. It refers to the ability of ports to anticipate, prepare for, respond to, and recover from disruptions, including natural disasters, public health crises, and technological failures, while maintaining essential operations. Given the highly interconnected nature of maritime logistics, disruptions at a single port can rapidly produce cascading effects throughout the wider supply chain (Tsoulfas, 2025).

1.1. SEAPORT DIGITAL TRANSFORMATION

Digital transformation (DTx), within the Industry 4.0 and 5.0 paradigms, can strengthen port resilience by replacing reactive governance with proactive, data-driven decision-making and predictive intelligence. This shift enables ports to adapt to changing conditions while minimizing severe operational disruptions. In this context, the Digital Twin (DT) has emerged as a cyber-physical solution capable of improving the resilience of information flows in port operations (Guizzardi et al., 2025; Zhou et al., 2021).

DTx involves a systemic transformation of the organization, coordination, and governance of maritime trade and supply chain operations. It integrates technologies such as the Internet of Things (IoT), machine learning (ML), artificial intelligence (AI), and DTs with data-driven management practices. These technologies aim to improve operational efficiency, reduce bottlenecks, strengthen resilience, and support sustainability and decarbonization objectives (González-Cancelas et al., 2025). DTx also repositions ports as coordinators of collaborative networks connecting shipping companies, terminal operators, freight forwarders, customs authorities, and inland transport providers within data-centric ecosystems.

Information therefore represents a strategic operational asset and an intangible infrastructure supporting port resilience and competitiveness (Su, 2026). However, port ecosystems comprise complex and interdependent groups of operational, regulatory, and socioeconomic stakeholders (Cai et al., 2022). Differences in their priorities and perspectives may create conflicting objectives and hinder the implementation of advanced technologies (Homayouni et al., 2025).

In Portugal, port digitalization has progressed through the continuous development of information systems, particularly the Single Logistics Window (JUL). This platform has improved interoperability, simplified procedures, replaced paper-based processes, and extended digital integration across the intermodal logistics chain. It enables authorities and operators to exchange data in real time, reducing administrative burdens and aligning national procedures with European standards (Presidência do Conselho de Ministros, 2019).

More recently, the NEXUS Innovation Pact, funded through Portugal's Recovery and Resilience Plan and led by APS Administração dos Portos de Sines e do Algarve, S.A., introduced improvements to JUL, cybersecurity systems, and autonomous operational capabilities (APS Administração dos Portos de Sines e Algarve, 2022). This process continues under the Ports 5+ Strategy for 2025–2035 (Table 1), which provides €70 million for advanced digital technologies and the full automation of administrative procedures through JUL 5+. The strategy seeks to strengthen maritime and intermodal integration across regional, national, and European logistics networks (Presidência do Conselho de Ministros, 2025).

Table 1. Strategic Objectives of the Ports 5+ Strategy

Strategic objectives	Detailed description
More Investment and Growth	Focus on strengthening private investment to accelerate the increase in port capacity, productivity, and competitiveness. Aims to grow the movement of ships, passengers, and cargo (especially exports), prioritizing the concession model for the private construction and operation of terminals.
More Decarbonization and Sustainability	Focus on the energy transition with public and private investment in electrification (Onshore Power Supply), the supply of green fuels (LNG and hydrogen), and offshore wind energy. Sustainability goals include protecting ecosystems and reducing emissions, integrating circular economy industries.
More Intermodality and Connectivity	Focus on logistics integration to increase rail participation and improve land connections. The investment aims at linking with dry ports and logistics platforms (TEN-T Networks), promoting advances in the fluidity of sustainable flows and reducing the environmental impact on local communities.
More Digitization and Automation	Focus on technological advancements through the evolution of the Single Logistics Window (JUL 5+), artificial intelligence, and terminal automation. The investment in digitalization aims for total interoperability between ships, ports, and land transport, optimizing operational efficiency and data security.
More Integration and Security	Focus on the symbiotic Port-City relationship through the transfer of non-operational areas to municipal management and joint planning. This includes strengthening security against illicit trade through technological investment and fostering strategic cooperation with local communities.

Source: (Presidência do Conselho de Ministros, 2025)

1.2. SEAPORT DIGITAL TWIN

The literature defines a Digital Twin (DT) as a virtual representation of a physical system, process, or object that remains continuously synchronized with its physical counterpart through bidirectional data flows (Guizzardi et al., 2025; Klar et al., 2023; Neugebauer et al., 2024). Within industrial engineering, a DT extends beyond three-dimensional modelling and functions as a dynamic decision-support system that integrates historical data, real-time sensor inputs, and analytical models to predict system behaviour and optimize operations (Fonseca et al., 2023; Giering & Dyck, 2021; Homayouni et al., 2025).

In this study, a port logistics DT is conceptualized as a dynamic and interoperable digital system that maintains continuous bidirectional synchronization with the port ecosystem and its stakeholder network. Through real-time data flows, it supports simulation, prediction, and coordinated decision-making across operational levels.

This definition distinguishes DTs from conventional Port Community Systems (PCS) and platforms such as Portugal's Single Logistics Window (JUL) in three respects. First, while PCS and JUL primarily support data exchange and administrative processing, a DT integrates heterogeneous sources, including Internet of Things sensor data, operational logs, and interorganizational transactions, into a continuously updated virtual model. Second, unlike static or event-triggered reporting tools, a DT incorporates predictive analytics and simulation capabilities, enabling proactive scenario planning. Third, it functions as a decision-support layer that models the interdependencies among physical assets, information flows, and stakeholder interactions, which are not fully represented in the current JUL infrastructure.

Because no operational DT has yet been implemented in the Portuguese Atlantic Corridor ports, this study evaluates its potential through stakeholder perceptions. These perceptions are treated as informed anticipatory judgments based on stakeholders' direct experience with existing digital systems and their knowledge of emerging technological capabilities.

Despite growing interest in DTs, research on their adoption in ports and maritime terminals remains limited and fragmented. While some ports are still developing basic digital capabilities, larger and more technologically advanced ports have begun implementing DT solutions. Their application in small and medium-sized ports remains particularly underexplored (Neugebauer et al., 2024). Four major research gaps can therefore be identified:

- **Theoretical gap:** The literature proposes numerous component-level architectures and models, but lacks an integrated framework linking DTs with port resilience, interoperability, and logistics continuity (Ding et al., 2023; Eom et al., 2023; González-Cancelas et al., 2025; Hakimi et al., 2025; Neugebauer et al., 2023; Zavvos et al., 2024).
- **Practical gap:** Empirical implementations are concentrated in large and often highly automated terminals, leaving unresolved questions concerning adoption, standardization, scalability, and return on investment (Ding et al., 2023; Eom et al., 2023; Hakimi et al., 2025; Neugebauer et al., 2023; Paredis et al., 2024; Yao et al., 2021).
- **Methodological gap:** Existing studies rely heavily on prototypes and isolated demonstrations, with limited use of comparative, longitudinal, or causally oriented research designs (Bao et al., 2024; González-Cancelas et al., 2025; Neugebauer et al., 2023; Yao et al., 2021).
- **Contextual gap:** Most evidence relates to large, technologically advanced terminals in Europe and East Asia, while Portuguese ports, small and medium-sized enterprises, and regional and organizational specificities remain insufficiently examined (Bao et al., 2024; Ding et al., 2023; González-Cancelas et al., 2025; Neugebauer et al., 2023; Paredis et al., 2024; Zavvos et al., 2024).

In line with the strategic priorities of the Portuguese Government, this study examines stakeholder perceptions of the potential of DT solutions in a core Portuguese port located within the Atlantic Corridor of the Trans-European Transport Network (TEN-T). Although the empirical analysis focuses on a single port, the case shares important institutional and operational characteristics with other Portuguese Atlantic Corridor core ports. These include integration into the TEN-T core network, use of the national JUL platform, alignment with the Ports 5+ Strategy for 2025–2035, and the presence of a comparable multi-stakeholder logistics ecosystem. These common features enhance the analytical relevance of the findings beyond the selected case.

Given the complexity of port ecosystems and the divergent operational, regulatory, and strategic priorities of their stakeholders, semi-structured interviews were used to capture heterogeneous views on DT adoption.

The study addresses the following research question:

To what extent do port ecosystem stakeholders perceive Digital Twin solutions as capable of strengthening information flow resilience and operational continuity in medium-sized Atlantic Corridor ports?

The interview data were examined using thematic analysis, which provides a structured yet flexible method for identifying, interpreting, and reporting recurring patterns within qualitative datasets (Ahmed et al., 2025; Braun & Clarke, 2022).

The study contributes to the broader debate on the digital economy by examining DT technology as a practical response to the operational, coordination, and resilience challenges facing maritime logistics in an increasingly uncertain global environment.

The analytical model conceptualizes the DT as a socio-technical system operating within the port logistics ecosystem through two interdependent dimensions (Fig. 1).

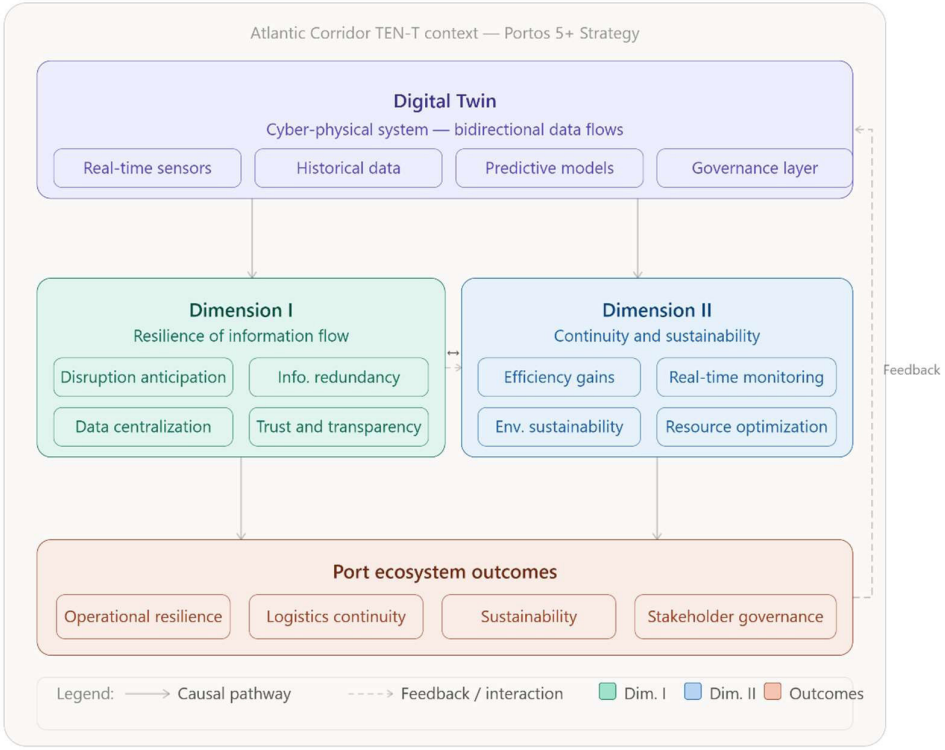
The first dimension concerns **information flow resilience**. DT solutions can support disruption anticipation, information redundancy, the integration of fragmented data, and

greater trust and transparency among stakeholders.

The second dimension concerns **the continuity and sustainability of port and logistics operations**. DTs can enable real-time monitoring, improve operational efficiency, optimize resource use, and support environmental sustainability measures.

These dimensions are mutually reinforcing. Resilient information flows are a prerequisite for operational continuity, while sustained operational performance generates feedback that improves the DT's predictive and coordination capabilities. Together, they may produce system-level outcomes such as operational resilience, logistics continuity, environmental sustainability, and collaborative stakeholder governance. These outcomes are consistent with the priorities of the Ports 5+ Strategy and the TEN-T Atlantic Corridor framework.

Figure 1. Conceptual framework: Digital Twin as a sociotechnical enabler of port resilience and operational continuity



Source: Authors

The article is structured as follows: after the introduction, section 2 details the methodology adopted, highlighting the research model, the method, and the sample; section 3 addresses the results and discussion; and finally, the conclusions are presented.

2. METHODS

The study adopts an exploratory qualitative design based on semi-structured interviews with ten key stakeholder representatives. Participants were selected through purposive, expert-based sampling to capture informed perspectives from actors directly involved in port logistics, information exchange, and coordination within the Portuguese Atlantic Corridor port ecosystem. Rather than seeking statistical representativeness, the sampling strategy emphasized informational richness, functional relevance, and stakeholder diversity, in line with exploratory qualitative research.

The participants represented different functional layers of the port-logistics ecosystem, allowing the study to capture heterogeneous views on information flow resilience, oper-

ational continuity, digital coordination, and the potential adoption of Digital Twin solutions. Selection criteria included: (a) direct involvement in port-related logistics activities; (b) substantial experience in coordination or decision-making roles; (c) practical knowledge of digital information systems and interorganizational processes; (d) regular interaction with port authorities or Port Community Systems; and (e) strategic or operational responsibility within the participant's organization.

Interviewees occupied senior coordination or management positions and had an average of approximately 20 years of professional experience. Their backgrounds provided substantial knowledge of logistics operations, digital infrastructure, stakeholder coordination, and port-related business processes. Selection also considered participants' operational integration and established collaborative relationships within the port ecosystem. Although access and availability influenced recruitment, the interviews generated detailed operational and strategic insights into resilience, interoperability, governance, sustainability, and disruption management.

The data were analyzed through thematic analysis following Braun and Clarke (2022). The process involved data familiarization, repeated reading, analytical note-taking, initial coding, theme development, theme review, and final theme definition. Codes were grouped into candidate themes based on recurring patterns of meaning, after which themes were assessed for internal coherence, distinctiveness, and consistency with the dataset. Themes were merged, divided, refined, or discarded where necessary.

Data collection continued until thematic recurrence and analytical convergence were observed across the main research dimensions. The final two interviews produced no substantive new themes or perspectives, while the thematic categories associated with both analytical dimensions were consistently supported across different stakeholder types. This indicated an acceptable level of thematic saturation for the exploratory purpose of the study (Guest et al., 2006).

The reporting stage combined illustrative interview excerpts, researcher interpretation, and relevant literature to develop an evidence-based response to the research question. Researcher reflexivity was maintained throughout the analysis, recognizing that themes are interpretively constructed rather than mechanically extracted from the data.

The interview guide was structured around two dimensions: (i) information flow resilience and (ii) the continuity and sustainability of port and logistics operations. To protect confidentiality, participants were coded according to stakeholder typology, as shown in Table 2. Interviews lasted approximately 45 minutes on average, were transcribed, and underwent content clarification and linguistic cleaning while preserving their original semantic meaning. Thematic analysis was then used to identify and organize the principal research themes (Jović et al., 2022).

Before each interview, participants received a brief explanation of the Digital Twin concept as operationalized in this study. The explanation distinguished Digital Twins from existing Port Community Systems and administrative platforms, ensuring a shared conceptual basis for the discussion.

Table 2. Stakeholder codification

Typology	n	Code	Functional Role in the Port Ecosystem
Importer	1	A1	Coordination of cargo reception, customs-related processes, and inbound logistics operations
Exporter	1	B1	Coordination of export logistics operations and international shipment flows
Logistics operator	1	C1	Coordination of logistics activities and collaborative supply chain operations
Logistics operator	1	C2	Strategic logistics and transport management across integrated logistics networks
Land transporter	1	D1	Coordination of inland freight transportation and operational traffic management
Land transporter	1	D2	Management of road transport operations and logistics execution activities
Customs Broker	1	E1	Coordination of freight forwarding, customs procedures, transport logistics, and import/export documentation flows
Customs Agent	1	F1	Coordination of customs clearance procedures and regulatory compliance within import logistics operations
Intermodal Platform	1	G1	Management of rail freight transport, inland terminal operations, and intermodal cargo coordination
Port Dimension	1	H1	Strategic planning, port governance, infrastructure development, tariff management, and innovation oversight

Source: Authors

3. RESULTS AND DISCUSSION

3.1. CASE STUDY

The Trans-European Transport Network (TEN-T) is a European Union policy (Regulation (EU) 2024/1679) that aims to establish a single, high-quality multimodal transport network across Europe. This network comprises infrastructure for rail, road, air, sea and inland waterway transport, as well as associated information and communication technology (ICT) systems and measures to promote the efficiency and sustainability of services. The Core Network (Fig. 2) encompasses the strategically most important parts of the network, focusing on connecting the core ports on the Atlantic coast (Sines, Lisbon/Setúbal and Leixões) to the interior of the Iberian Peninsula and Central Europe.

Figure 2. Map of the Atlantic Corridor (TEN-T)



Source: (Infraestruturas de Portugal, 2021)

The study focused on a Portuguese Atlantic seaport located in southern Europe, recognized for its high cargo throughput, strong international connectivity, and increasing digital maturity. The port plays a strategic role in multimodal logistics chains, exhibiting high levels of technological integration and operational interoperability, thus constituting a relevant context for analyzing the resilience of information flow in complex port-logistics ecosystems.

3.2. ANALYTICAL DIMENSION I- RESILIENCE OF INFORMATION FLOW

An in-depth examination of the responses indicates that DT can greatly enhance the resilience of the logistics ecosystem. This improvement is accomplished by addressing vulnerabilities, anticipating disruptions, and maintaining seamless operations even amidst technological breakdowns, traffic jams, or unforeseen incidents (Table 3).

Table 3. Analytical Dimension I - Main Themes Identified

Themes	Thematic Descriptions
Anticipating Disruptions and Proactive Planning	• Access to statistical and operational data allows for the identification of work peaks, average waiting times, and equipment availability (E1). • Data sharing allows for anticipating problems before they cause greater damage (C1). • Information on congestion, weather, or operational failures allows for rapid reaction and the development of action plans (A1). • Possibility of immediate replanning in the event of a disruption (B1).
Operational Continuity and Information Redundancy	• When systems such as the Automated Customs Declaration Processing System, JUL, or Terminal fail, all stakeholders are left "blind" (F1). • A DT can function as a backup to ensure continuity of information management (F1). • It reduces dependence on individual contacts in the field, making information more reliable and less vulnerable (D2). • Paper is still seen as a contingency, but a robust platform can replace this weakness (F1).
Centralization and Elimination of Fragmentation	• Data sharing eliminates the need to consult multiple platforms and reduces information duplication (D1). • An integrated view improves fluidity and reduces inconsistencies between sources (D1). • It facilitates coordination between dispersed stakeholders (H1).
Strengthening Trust and Transparency	• Shared information builds trust among stakeholders and with customers (C1). • Transparency about the state of operations reduces uncertainty and increases predictability (H1). • Trust is seen as a critical asset in disruptive contexts (C1).
Organizational Commitment and Governance	• Resilience depends on the ongoing commitment of all stakeholders (C2). • Need to designate internal managers to ensure continuity and reliability of information (H1). • Risk of loss of continuity if there is no adequate project management (H1). • The DT must be accompanied by a clear organizational culture and processes (C2).
Responsiveness to Unforeseen Events	• Allows for earlier responses to projects, delays, and other unforeseen events (D2). • Facilitates rapid and coordinated communication between stakeholders. • Reduces the impact of unexpected events by allowing for immediate adjustments (A1).

Source: Authors

Digital Twin solutions can strengthen information flow resilience in several interconnected ways. The most frequently identified benefit is the ability to anticipate disruptions through real-time and historical data. As one participant explained, "Data sharing alone

can give us indicators of peak workloads. It can give us average wait times, equipment availability, etc." (E1). Another noted that "information regarding traffic congestion, weather conditions, or failures would allow for a faster response from the various stakeholders and the development of action plans" (A1).

Participants also emphasized the importance of operational continuity during failures of critical information systems. One stakeholder suggested that "it would make sense to have a backup system for information management, because when one fails, the other will 'protect' me" (F1). DT solutions could also improve information consistency by centralizing data and reducing fragmentation and duplication. According to one participant, "Data available on a single platform would eliminate the need to access multiple platforms and prevent the duplication of information" (D1).

A further benefit concerns trust and crisis response. One stakeholder stated that "customers and partners trust us because we strive to capture all the data to provide an information service. Therefore, a system for updating and sharing information is crucial, especially in a crisis context" (C1). Participants also stressed that technological reliability depends on organizational responsibility and collective involvement: "A project like this requires the involvement of all participants. I believe there should be someone designated within the companies to be responsible for ensuring that there is no loss of continuity and reliability of the necessary information" (H1). Information resilience should therefore be understood not only as a technological capability but also as an organizational, collaborative, and strategic capacity.

The findings from Dimension I are broadly consistent with the literature on DT-enabled resilience in maritime environments, while extending it to the context of medium-sized ports. The theme of disruption anticipation and proactive planning supports the proposition by Zhou et al. (2021) that DT systems can function as decision-support mechanisms by combining real-time monitoring with resource optimization. However, this study shows that, in medium-sized Atlantic Corridor ports, anticipatory capacity is perceived less as a product of highly automated terminal intelligence, as observed in large-scale applications such as Yangshan Port (Ding et al., 2023), and more as an outcome of collaborative data sharing among heterogeneous stakeholders operating across fragmented information systems.

The theme of operational continuity and information redundancy reveals a vulnerability that differs from those commonly discussed in technologically advanced terminals. Existing DT applications in large automated ports primarily focus on equipment scheduling, throughput optimization, and dynamic operational control (Bao et al., 2024; Ding et al., 2023). By contrast, participants in this study emphasized the loss of visibility and coordination caused by failures in administrative platforms, including JUL and customs-processing systems. This finding is consistent with Homayouni et al. (2025), who identify data quality and availability as major barriers to sustainable DT implementation. It further suggests that, in medium-sized ports, DT-enabled information redundancy and backup capabilities may represent a more immediate resilience priority than advanced operational optimization.

Finally, the theme of organizational commitment and governance introduces a dimension that remains underdeveloped in predominantly technical DT frameworks (Klar et al., 2023; Neugebauer et al., 2024). Although existing models emphasize sensors, bidirectional data flows, system integration, and predictive analytics, the present findings indicate that information resilience also depends on clear governance structures, assigned responsibilities, stakeholder commitment, and mutual trust. This result supports Homayouni et al. (2025), who identify conflicting stakeholder priorities as a major implementation

barrier, but extends their argument by framing organizational governance not merely as a constraint, but as an active enabler of DT-supported resilience.

3.3. ANALYTICAL DIMENSION II- CONTINUITY AND SUSTAINABILITY OF PORT AND LOGISTICS OPERATIONS

Thematic analysis of the interview data reveals that DT can be crucial for ensuring operational continuity, increasing efficiency, reducing risks, supporting environmental sustainability, and encouraging innovation (Table 4).

Table 4. Analytical Dimension II - Main Themes Identified

Themes	Thematic Descriptions
Acceleration, Efficiency, and Continuous Improvement	• Makes operations faster, more reliable, and less error-prone (E1). • Reduces unnecessary steps and simplifies processes, increasing overall efficiency (E1). • Eliminates manual processes and associated errors (B1). • Enables optimization of empty container pick-ups and deliveries (F1). • Paperless processes make operations more sustainable and consistent (G1).
Real-Time Monitoring and Anticipation of Disruptions	• Continuous monitoring of flows allows for anticipating disruptions and adjusting operations (A1). • Real-time data allows for correcting the course of projects and processes (H1). • Management of disruption scenarios becomes more effective with shared data (B1). • Better transportation planning reduces unnecessary and inefficient trips (D2).
Operational Continuity and Risk Reduction	• Reduces dependence on manual processes, but paper is still seen as a contingency (F1). • Data sharing increases resilience by allowing all stakeholders to maintain visibility even in technological failures (H1). • Well-designed digital processes ensure continuity and stability (G1).
Environmental Sustainability and Carbon Footprint Reduction	• Optimization of truck entry/exit times reduces waiting times and emissions (F1). • Emissions monitoring and environmental control become more rigorous (B1). • Sustainability is addressed through three pillars: warehousing, transportation, and carbon footprint reduction (C2). • More efficient flows reduce energy consumption and waste (C2).
Innovation, Competitiveness, and New Business Models	• Promotes innovation and competitiveness (A1). • Collaborative data allows for the development of new solutions and business models (A1). • Data sharing supports strategic decisions and increases adaptability (H1).
Resource Optimization and Loss Minimization	• Allows for better resource allocation and reduction of operational losses (D2). • Optimization of human resources, equipment, and infrastructure (B1). • More efficient processes reduce costs and increase economic sustainability (A1).

Source: Authors

Thematic analysis indicates that the main perceived benefits of DT are greater operational efficiency, improved real-time monitoring, and stronger environmental sustainability. Participants reported that automation would reduce manual intervention, errors, truck waiting times, and container-handling delays, thereby increasing terminal productivity: “The flow of incoming and outgoing containers should be automated at the gates when passage doesn’t require human intervention” (G1). “Continuity and sustainability can be ensured through better management of disruption scenarios, and regular operational control” (B1). “We believe that having a system with information to allocate carbon con-

sumption to each of our expeditions, for example, is a way to work with clients to define more efficient flows and schedules" (C2). "Data sharing is essential to ensure the continuity and sustainability of port and logistics operations, by accelerating administrative and customs processes, reducing both waiting times and costs" (A1). The findings for Dimension II are broadly consistent with the DT literature but also reveal patterns specific to medium-sized Atlantic Corridor ports. Real-time monitoring supports operational continuity, as shown by Ding et al. (2023) and Wang et al. (2024). However, participants emphasized its role in improving interorganizational coordination and reducing information asymmetries rather than enabling fully automated operational control.

The environmental sustainability theme also aligns with Eom et al. (2023) and Zavvos et al. (2024). In the present study, stakeholders focused mainly on indirect sustainability measures, including shorter truck dwell times, fewer empty-container movements, and improved flow coordination. Unlike technologically advanced terminals that use direct emissions-monitoring systems, medium-sized ports may achieve decarbonisation primarily through logistics efficiency.

Finally, the theme of innovation, competitiveness, and new business models reflects the broader strategic role of DT. This aligns with the systematic review by Nurrosyidah et al. (2026), which identified prediction and data-driven decision-making as the second most prominent driver of DT adoption in smart ports, after operational performance. In the present study, stakeholders viewed DT not only as an operational tool but also as a platform for collaborative coordination and adaptive business models. This perspective extends DT beyond individual terminals to the wider port-logistics ecosystem, in line with Cai et al. (2022).

4. CONCLUSIONS

This study examined how Digital Twin (DT) can strengthen information-flow resilience and support the continuity and sustainability of port-logistics operations in the Portuguese Atlantic Corridor. Based on an exploratory qualitative analysis of stakeholders from different functional areas, the findings indicate that operational resilience is perceived as increasingly dependent on real-time visibility, interoperability, collaborative coordination, and predictive decision-making across interconnected actors and digital infrastructures.

The study contributes to the literature by moving beyond a purely technological understanding of DT and positioning it as a sociotechnical enabler of resilience, operational continuity, and collaborative governance. From the stakeholders' perspective, resilient port operations depend on the quality, accessibility, integration, and synchronization of information flows. Shared and interoperable digital infrastructures are therefore perceived as essential for coordinated responses to operational disruptions.

The findings also contribute to research at the intersection of digital transformation, supply chain resilience, and smart port ecosystems. DT-enabled visibility and data integration are perceived as key mechanisms for adaptive decision-making and coordinated disruption management. This extends existing technical frameworks by emphasizing governance, stakeholder alignment, and interorganizational collaboration.

Several practical implications follow. Port authorities and managers should strengthen integration among Port Community Systems, customs platforms, transport operators, and logistics stakeholders to reduce information fragmentation and operational inefficiencies. Investments should prioritize interoperable infrastructures that enable real-time data exchange, predictive analytics, and collaborative decision-making. DT initiatives should also be supported by governance arrangements, organizational capability development, and stakeholder coordination rather than treated solely as technology-modernization projects.

For policymakers, the findings highlight the importance of interoperability standards, integrated logistics platforms, and collaborative innovation ecosystems aligned with the Portuguese Ports 5+ Strategy. Public investment and regulatory support may also facilitate the transition toward smarter, more sustainable, and resilient port infrastructures.

The study has several limitations. Its purposive and partly convenience-based sample involved a limited number of stakeholders closely connected to the selected port ecosystem, restricting the generalisability of the findings. The single-port exploratory design also prevents comparison across different institutional, operational, and technological contexts. Furthermore, the cross-sectional qualitative approach does not capture the long-term evolution or effects of DT implementation.

Future research should compare multiple ports within the Atlantic Corridor and other European logistics corridors. Longitudinal studies could examine how digital resilience capabilities develop over time, while mixed-method research combining stakeholder perceptions with operational and performance indicators could provide stronger evidence of the relationship between digitalization, interoperability, and resilience.

Overall, the findings suggest that the future resilience of port-logistics ecosystems will increasingly depend on integrated digital infrastructures, synchronized information flows, and collaborative decision-making. Within the scope of this exploratory study, DT is therefore perceived not merely as a technological tool but as a strategic enabler of more resilient, sustainable, and adaptive port ecosystems.

Funding

This work was developed within the scope of the Agenda "NEXUS – Pacto de Inovação: Transição Verde e Digital para Transportes, Logística e Mobilidade," financed by the Portuguese Recovery and Resilience Plan under project no. C645112083-00000059, investment project no. 53.

Ana Barroso acknowledges the Portuguese Fundação para a Ciência e a Tecnologia (FCT) for its financial support via the project UID/00667/2025 (UNIDEMI).

REFERENCES

Ahmed, S. K., Mohammed, R. A., Nashwan, A. J., Ibrahim, R. H., Abdalla, A. Q., M. Ameen, B. M., & Khdhir, R. M. (2025). Using thematic analysis in qualitative research. *Journal of Medicine, Surgery, and Public Health,* 6, 100198. https://doi.org/10.1016/j.glmedi.2025.100198

APS—Administração dos Portos de Sines e Algarve, S. A. (2022, April). Innovation Agenda for Digital and Green Transition. https://nexuslab.pt

Bao, X., Jia, F., Zhong, J., Zhang, L., Liu, C., Chen, L., & Zheng, Y. (2024). Digital twin system for automated container terminal and a case study. *IEEE International Conference on Automation Science and Engineering*, 142–147. https://doi.org/10.1109/CASE59546.2024.10711351

Braun, Virginia., & Clarke, Victoria. (2022). Thematic analysis: a practical guide. SAGE.

Cai, J., Li, G., & Zhang, L. (2022). Study on the Construction of Digital Twin- Oriented Operation Ecosystem Model of Large-Scale Comprehensive Port. *Advances in Transdisciplinary Engineering,* 31, 1280–1285. https://doi.org/10.3233/ATDE220998

Ding, Y., Zhang, Z., Chen, K., Ding, H., Voss, S., Heilig, L., Chen, Y., & Chen, X. (2023). Real-Time Monitoring and Optimal Resource Allocation for Automated Container Terminals: A Digital Twin Application at the Yangshan Port. *Journal of Advanced Transportation*, 2023, 1–12. https://doi.org/10.1155/2023/6909801

Eom, J. O., Yoon, J. H., Yeon, J. H., & Kim, S. W. (2023). Port Digital Twin Development for Decarbonization: A Case Study Using the Pusan Newport International Terminal. *Journal of Marine Science and Engineering,* 11(9). https://doi.org/10.3390/jmse11091777

Epiphaniou, G., Hammoudeh, M., Yuan, H., Maple, C., & Ani, U. (2023). Digital twins in cyber effects modelling of IoT/CPS points of low resilience. *Simulation Modelling Practice and Theory*, 125. https://doi.org/10.1016/j.simpat.2023.102744

Fonseca, A., de Oliveira, F. F., & Gaspar, H. M. (2023). Open Framework for Digital Twin Ship Data: Case Studies on Handling of Multiple Taxonomies and Navigation Simulation. Transactions of the Royal Institution of Naval Architects Part A: *International Journal of Maritime Engineering*, 165(1), A23–A42. https://doi.org/10.5750/ijme.v165iA1.813

Giering, J. E., & Dyck, A. (2021). Maritime Digital Twin architecture A concept for holistic Digital Twin application for shipbuilding and shipping. *At-Automatisierungstechnik*, 69(12), 1081–1095. https://doi.org/10.1515/auto-2021-0082

González-Cancelas, N., Martínez Martínez, P., Vaca-Cabrero, J., & Camarero-Orive, A. (2025). Optimization of Port Asset Management Using Digital Twin and BIM/GIS in the Context of Industry 4.0: A Case Study of Spanish Ports. Processes, 13(3). https://doi.org/10.3390/pr13030705

Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. Field Methods, 18(1), 59–82. https://doi.org/10.1177/1525822X05279903

Guizzardi, R., Piest, J. P. S., Akyazi, A., Ariji, S., Tao, T., Bastani, M., Scheijgrond, A.-R., Kromanis, R., Vahdatikhaki, F., Hüllmann, J. A., & Mes, M. (2025). Requirements Analysis for a Digital Twin to Increase the Resilience of Multimodal Corridors: A Case Study in the Twente Region (pp. 219–230). https://doi.org/10.1007/978-3-031-94931-9_18

Hakimi, F., Khaled, T., Al-Kharaz, M., Gouabou, A. C. F., & Amzil, K. (2025). Towards a Digital Twin Modeling Method for Container Terminal Port. https://doi.org/10.1016/j.procs.2024.09.361

Homayouni, S. M., Pinho de Sousa, J., & Moreira Marques, C. (2025). Unlocking the potential of digital twins to achieve sustainability in seaports: the state of practice and future outlook. *WMU Journal of Maritime Affairs*, 24(1), 59–98. https://doi.org/10.1007/s13437-024-00349-2

Infraestruturas de Portugal. (2021). Corredor Atlântico. Infraestruturas de Portugal. https://servicos.infraestruturasdeportugal.pt/pt-pt/parceiros/corredor-atlantico/corredor-atlantico-ips

Jović, M., Tijan, E., Brčić, D., & Pucihar, A. (2022). Digitalization in Maritime Transport and Seaports: Bibliometric, Content and Thematic Analysis. *In Journal of Marine Science and Engineering* (Vol. 10, Number 4). MDPI. https://doi.org/10.3390/jmse10040486

Klar, R., Fredriksson, A., & Angelakis, V. (2023). Digital Twins for Ports: Derived From Smart City and Supply Chain Twinning Experience. *IEEE Access*, 11, 71777–71799. https://doi.org/10.1109/ACCESS.2023.3295495

Neugebauer, J., Heilig, L., & Voß, S. (2023). Digital Twins in Seaports: Current and Future Applications (pp. 202–218). https://doi.org/10.1007/978-3-031-43612-3_12

Neugebauer, J., Heilig, L., & Voß, S. (2024). Digital Twins in the Context of Seaports and Terminal Facilities. *Flexible Services and Manufacturing Journal,* 36(3), 821–917. https://doi.org/10.1007/s10696-023-09515-9

Nurrosyidah, A., Gohari, A., Mokhtar, K., Rachmannullah, A. F., Mhd Ruslan, S. M., Oloruntobi, O., Mohammed Gismalla, M. S., Isiacik Colak, A. T., Abd Manan, T. S., Latip, A. S. A., & Nugroho, A. (2026). Drivers of digital twin adoption in smart ports: a systematic review of empirical evidence. *Australian Journal of Maritime and Ocean Affairs*. https://doi.org/10.1080/18366503.2026.2644703

Paredis, R., Vangheluwe, H., & Albertins, P. A. R. (2024). COOCK project Smart Port 2025 D3.2: "Variability in Twinning Architectures." http://arxiv.org/abs/2409.01859

Presidência do Conselho de Ministros. (2019). Diário da República, 1.ª série Presidência do Conselho de Ministros: Cria a Janela Única Logística, transpondo a Diretiva n.º 2010/65/UE. https://diariodarepublica.pt/dr/detalhe/decreto-lei/158-2019-125560577

Presidência do Conselho de Ministros. (2025). Resolução do Conselho de Ministros n.º 119/2025: Aprova a Estratégia para os Portos Comerciais do Continente 2025-2035 — PORTOS 5+. Diário da República: 1.ª série, n.º 154. https://files.diariodarepublica.pt/1s/2025/08/15400/0001400035.pdf

Su, Z. (2026). Digital Transformation in Port Logistics. Encyclopedia, 6(1), 28. https://doi.org/10.3390/encyclopedia6010028

Tsoulfas, G. T. (2025). Port resilience: a systematic literature review. Maritime Economics and Logistics. https://doi.org/10.1057/s41278-025-00326-3

Valenzuela-Silva, L., Muñoz, M., Lagos, C., Sepúlveda-Rojas, J. P., & Carrasco, R. (2025). Assessment of Differences Between the Ports of Rotterdam, Valparaíso and San Antonio Towards Smart Ports, Emphasising Digital Technologies. *Journal of Marine Science and Engineering*, 13(12). https://doi.org/10.3390/jmse13122220

Wang, K., Xu, H., Wang, H., Qiu, R., Hu, Q., & Liu, X. (2024). Digital twin-driven safety management and decision support approach for port operations and logistics. *Frontiers in Marine Science*, 11. https://doi.org/10.3389/fmars.2024.1455522

Yao, H., Wang, D., Su, M., & Qi, Y. (2021). Application of Digital Twins in Port System. *Journal of Physics: Conference Series,* 1846(1). https://doi.org/10.1088/1742-6596/1846/1/012008

Zavvos, E., Zavitsas, K., Latinopoulos, C., Leemen, V., & Halatsis, A. (2024). Digital Twins for Synchronized Port-Centric Optimization Enabling Shipping Emissions Reduction (pp. 137–160). https://doi.org/10.4018/978-1-6684-9848-4.ch007

Zhou, C., Xu, J., Miller-Hooks, E., Zhou, W., Chen, C. H., Lee, L. H., Chew, E. P., & Li, H. (2021). Analytics with digital-twinning: A decision support system for maintaining a resilient port. *Decision Support Systems,* 143. https://doi.org/10.1016/j.dss.2021.113496

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

BLOCKCHAIN IN THE AGENT ECONOMY: IDENTITY, AUTHORIZATION, AND MACHINE-TO-MACHINE SETTLEMENT

Krzysztof Bochenek[1*], Jarosław Bochenek[1]

Received 02.03.2026. | Send to review 03.04.2026. | Accepted 13.08.2026.

Original Article

[1] Wyższa Szkoła Biznesu – National-Louis University (WSB-NLU), Nowy Sącz, Poland

***Corresponding Author:**
Krzysztof Bochenek

Email:
krzysztof.bochenek94@gmail.com

JEL Classification:
D23, E42, O33

Doi: 10.61432/CPNE0401287b

UDK: 316.422-027.511:004.652.4

ABSTRACT
Autonomous AI agents increasingly conduct economic transactions on behalf of individuals and organizations. This paper examines which payment architecture is most suitable for such transactions. Using a conceptual research design grounded in transaction cost economics, it separates agent based payments into three functions: identity, authorization, and settlement. It then compares delegated fiat, managed on chain, and native on chain architectures. The analysis shows that identity and authorization do not inherently require blockchain technology. Its distinctive contribution lies in enabling settlement through a shared ledger that is not controlled by a single institution. This feature is most valuable when multiple parties lack mutual trust and access to a common intermediary, when value can remain on chain, and when limited recourse is acceptable.A full cost comparison also challenges simple claims that blockchain settlement is inexpensive. Although public network fees may be low, total costs can be dominated by access, compliance, currency conversion, custody, liquidity and expected fraud losses. Evidence available through July 2026 remains promising but limited. Amazon Bedrock AgentCore Payments is still in preview, while x402 activity remains concentrated among a small number of facilitators and stablecoins. The most plausible institutional outcome is therefore the coexistence of conventional payment systems, managed blockchain services, native on chain settlement, and central bank digital currencies. The paper contributes a decision framework and research agenda rather than an empirical estimate of adoption.
Keywords: *agent economy, blockchain, transaction-cost economics, machine-to-machine settlement, stablecoins, central bank digital currency (CBDC), AI agents*

1. INTRODUCTION

Autonomous AI agents are software systems that plan and act in digital environments to achieve goals defined by human or organizational principals. They increasingly call external tools, purchase data or computational resources, and initiate economic transactions. Although these actions may be automated, their legal and economic consequences remain attributable to principals and service providers rather than to software as an independent legal entity. Rothschild et al. (2025) argue that the broader economic significance of this development may lie not only in productivity gains but also in reducing communication frictions among economic actors.

This development raises an institutional question that is often framed primarily as a technical one. AI agents can already make payments by using a principal's credentials within intermediated payment systems. The central issue is therefore not whether agents can pay, but which payment architecture is most appropriate for transactions that may be continuous, low value, executed at machine speed, and conducted between parties without a shared provider or prior relationship.

This paper does not argue that blockchain is necessary for agent mediated payments. Cards, bank transfers, stored value accounts, and instant payment systems will remain efficient for many transactions. The narrower claim is that permissionless blockchain provides a distinct institutional option: settlement through a shared ledger that is not controlled by a single bank, platform, or state issuer. Bitcoin demonstrated the feasibility of maintaining such a ledger over time (Nakamoto, 2008), while smart contract networks and stablecoins have expanded the scope for programmable payments. The economic value of this feature depends on the characteristics of the transaction rather than on the technology itself.

The analysis draws on transaction cost economics and institutional approaches to blockchain. Catalini and Gans (2020) conceptualize blockchain as a mechanism for reducing verification and networking costs, while Davidson, De Filippi, and Potts (2018) examine it as a form of governance technology. Nguyen Thanh, Son, and Vo (2024) consider blockchain as an institutional infrastructure for autonomous AI, and more recent studies address the emerging agent economy and its associated risks (Rothschild et al., 2025; Marino & Juels, 2025; Romandini et al., 2025).

The paper contributes a functional distinction among identity, authorization, and settlement and uses it to compare three payment architectures. Its central theoretical implication is that blockchain relevance is neither universal nor binary. Rather, it depends on the governance requirements, trust structure, and full transaction costs associated with a particular exchange.

The study combines conceptual analysis with a time specific assessment of early implementations. The evidence covers authorization protocols, the x402 payment stack, Amazon Bedrock AgentCore payments, public fee schedules, and independent security and transaction analyses. These examples demonstrate technical and institutional feasibility but should not be interpreted as evidence of representative adoption. The following section explains the research design and source selection process.

2. ANALYTICAL APPROACH AND SCOPE

Following Jaakkola's (2020) guidance that conceptual research should clearly define its theoretical foundation and analytical design, this study applies transaction cost economics to payments initiated by AI agents and synthesizes relevant institutional and technical evidence. Transaction cost economics provides the main explanatory framework by enabling payment architectures to be compared according to the costs of coordinating, verifying, executing, and governing exchange. The unit of analysis is a payment initiated or executed by an AI agent on behalf of a principal. Identity, authorization, and settlement are examined separately to prevent the characteristics of one function from being incorrectly attributed to another.

The analysis proceeds in four stages. First, it identifies the institution responsible for each payment function. Second, it classifies the payment architecture as delegated, managed on chain, or native on chain. Third, it compares total transaction costs across access, processing, liquidity, custody, compliance, and recourse rather than focusing solely on ledger fees. Fourth, it examines public implementations and fee schedules to assess whether the predicted tradeoffs are observable in practice. The resulting framework is conditional and does not seek to establish a universal ranking of payment architectures.

Cases were selected purposively to ensure analytical coverage and source verifiability. Visa, Mastercard, ACP, and AP2 represent delegated authorization models, while Amazon Bedrock AgentCore payments and x402 illustrate managed stablecoin settlement. Public blockchain documentation is used to identify the fee structures and control characteristics of native on chain systems. FedNow, FedACH, and TIPS demonstrate that conventional payment infrastructure can also provide rapid and low cost settlement.

The evidence therefore covers all three payment architectures and includes both private and public sector sources. The evidence cutoff date was July 25, 2026. Because the study does not use an original dataset, the cases establish technical feasibility and boundary conditions rather than representativeness, causal effects, adoption rates, or market share.

3. WHY INTERMEDIARIES EXIST, AND WHAT AGENTS CHANGE

Payment intermediaries exist because market exchange is costly. Coase (1937) identified the costs of discovering prices and negotiating and concluding contracts, while Williamson (1985) linked governance choice to transaction characteristics such as frequency, uncertainty, and asset specificity. In payment systems, intermediaries authenticate account holders, authorize instructions, verify funds, route messages, manage liquidity, allocate fraud losses, and provide recourse. Catalini and Gans (2020) describe part of this burden as verification cost, namely the cost of confirming the facts on which exchange depends.

In conventional commerce, a bundled merchant fee is often modest relative to the transaction value and covers more than settlement alone. Stripe, for example, publicly lists a United States domestic card processing fee of 2.9 percent plus USD 0.30. This is a merchant facing processing price rather than the marginal cost of the underlying settlement infrastructure (Stripe, 2026). Public infrastructure fees are much lower. In 2026, the Federal Reserve lists USD 0.045 for a FedNow customer credit transfer and USD 0.0035 for a standard FedACH origination item, while the Eurosystem lists EUR 0.002 for a TIPS instant payment, excluding participant systems and customer services (Federal Reserve Financial Services, 2026a, 2026b; European Central Bank, 2026b). These services are not directly available to retail users or AI agents. Access is limited to eligible institutions and qualifying payment service providers, so agents generally reach them through banks or other intermediaries (Federal Reserve Financial Services, 2026c; European Central Bank, 2024). Conventional settlement infrastructure can therefore be rapid and inexpensive even when access and retail services remain costly.

Agent activity changes the relevant transaction structure. Payments may occur repeatedly for individual API calls, be too small to absorb fixed merchant fees, and involve providers that do not share an account system. Conventional systems can address these conditions through batching, netting, prepaid balances, subscriptions, and instant payment rails. Such arrangements may be efficient when a platform can hold balances and allocate risk. The more difficult case arises when no platform connects all participants, cross border onboarding is costly, or parties do not wish to rely on a single operator as the universal gatekeeper.

4. THREE FUNCTIONS, AND WHERE BLOCKCHAIN CONTRIBUTES

The concept of agent payment combines at least three distinct functions: identity, authorization, and settlement. Identity establishes which technical or legal principal is acting. Authorization defines what that principal permits the agent to do. Settlement changes the monetary positions of the parties. Cryptography can support all three functions, but it is not synonymous with blockchain. A blockchain is one institutional arrangement for maintaining a shared state through distributed validation and consensus. The relevant question is therefore not whether cryptography is involved, but whether a particular function benefits from this form of shared ledger.

Identity does not generally require blockchain infrastructure. An agent can hold a cryptographic key pair and prove control of it without using a shared ledger, just as users and servers already authenticate themselves online. The W3C decentralized identifier standard likewise supports ledger based, web based, peer based, and key based methods (World Wide Web Consortium, 2022). More importantly, a cryptographic key or identifier authenticates a technical controller but does not independently establish legal identity, accountability, or the individual or organization that bears liability. These relationships usually depend on contracts, registries, and governance arrangements outside the ledger.

Authorization can also be implemented without blockchain. Visa Intelligent Commerce, Mastercard Agent Pay, the Agentic Commerce Protocol, and Google's Agent Payments Protocol describe mechanisms such as scoped mandates, evidence of buyer intent, and revocable permissions operating through conventional payment systems (Visa, 2025; Mastercard, 2025; Stripe & OpenAI, 2025; Google, 2025). Because these initiatives were announced or introduced during 2025, they should be regarded as emerging infrastructure rather than mature empirical benchmarks. Nevertheless, they demonstrate that enabling an agent to spend within the limits established by a principal is fundamentally an authorization problem and does not logically require on chain settlement.

Settlement is the function for which a permissionless ledger offers the most distinctive institutional arrangement. However, transfer, clearing, and settlement must be distinguished. Transfer refers to the payment instruction, clearing determines the resulting obligations, and settlement discharges those obligations. Banks and central bank payment systems perform all three functions without blockchain. A permissionless blockchain differs by maintaining the settlement state according to protocol rules rather than on the books of a single institution.

Control of a private key may allow an agent to sign transactions from an address, but it does not imply that the agent legally owns assets in its own name or possesses independent legal personality. Stablecoins also introduce an additional governance layer. USDC, for example, represents a liability of its issuer, while Circle retains the authority to block addresses and freeze or restrict redemption under specified conditions (Circle, 2026). Consequently, the underlying ledger may be permissionless even when the asset, wallet, sequencer, facilitator, or fiat gateway remains subject to centralized control.

Blockchain's specific contribution is therefore operator independent recordkeeping at the settlement layer. It does not inherently provide legal identity, authorization, monetary denomination, regulatory compliance, or recourse. This settlement property may nevertheless be valuable when participants can change wallets, facilitators, or service providers while continuing to transact through a common ledger. It should not, however, be interpreted as eliminating all intermediaries or all institutional points of control.

5. WHEN ON-CHAIN SETTLEMENT IS ADVANTAGEOUS

An AI agent can access a payment rail through three stylized architectures. Under delegated settlement, the agent acts within a principal's mandate while an intermediary debits a card, bank account, or stored value balance. Under managed on chain settlement, a wallet provider, custodian, or payment facilitator controls transaction execution and settles a stablecoin on a blockchain. Under native on chain settlement, software controls the signing key subject to policies established by the principal and submits transactions without relying on a custodial facilitator. These categories represent governance arrangements rather than sequential stages of technological development, and practical systems may combine elements of more than one architecture.

Two variables organize the central comparison: the number of transacting parties and

the availability of a common trusted intermediary. These variables are not sufficient by themselves. Architecture choice also depends on transaction frequency and value, jurisdiction, onboarding requirements, liquidity and foreign exchange needs, confidentiality, liability allocation, and the importance of ex post recourse. When relatively few parties transact through a trusted operator, delegated payment will often minimize total cost. As the number and heterogeneity of participants increase, and as reliance on a common operator becomes difficult or undesirable, managed or native on chain settlement becomes a plausible alternative rather than an automatic default.

The comparison must therefore consider the cost of the complete transaction rather than settlement fees alone. In this study, total transaction cost includes access and onboarding, identity and authorization, payment processing, clearing and settlement, liquidity, foreign exchange and fiat conversion, custody and key security, compliance and reporting, and expected losses arising from fraud, error, disputes, and limited recourse. A low network fee addresses only one part of this cost structure. Conversely, card and managed payment prices may bundle several services that a native wallet must obtain separately. Protocol openness also does not eliminate the need for regulated onboarding through an exchange, stablecoin issuer, wallet provider, or merchant.

Table 1. Conceptual transaction-cost decision framework for agent-payment architectures

Dimension	Delegated payment	Managed on-chain	Native on-chain
Access	Principal and merchant use a bank, card, or platform relationship	Provider supplies wallet, policy, and settlement access	Principal provisions a software-controlled key or smart account; RPC or paymaster services may remain
Authorization	Mandate enforced by issuer, network, merchant, or platform	Mandate enforced by agent platform and wallet/facilitator	Mandate enforced in software, smart account, or contract policy
Settlement control	Bank, network, or platform ledger and governance	Public ledger underneath; provider controls custody, transaction submission, or access policy	Public ledger; no custodial facilitator is required, although RPC, paymaster, or sequencer services may remain
Recourse	Potential disputes, reversals, and allocated liability	Service-level limits or remedies; ledger transfer usually final	Limited ledger-level recourse; principal bears key and policy risk
Best fit	Known parties, common intermediary, fiat endpoints, high value of recourse	Cross-platform programmatic payment needing enterprise controls	Many parties without common operator; value stays on-chain; recourse less valuable
Main hidden cost	Onboarding, merchant pricing, cross-border reach, platform lock-in	Custody, screening, conversion, provider concentration, issuer control	Key security, infrastructure dependencies, compliance, liquidity, privacy, error and fraud losses

Note: The columns are ideal types. Actual systems may combine elements of more than one architecture

Source: Authors' own elaboration

Table 2 does not compare interchangeable end-to-end agent-payment products. It decomposes public prices at different layers of the payment stack. Stripe lists 1.5 percent for stablecoin checkout and explicitly includes fiat conversion, wallet and anti-money-laundering screening, fraud prevention, and gas sponsorship (Stripe, 2026). An agent cannot connect directly to FedNow, FedACH, or TIPS and must use an eligible institution or payment service provider. Conversely, protocol access on Base, Solana, or Ethereum does not supply compliance, stablecoin issuance, custody, conversion, or recourse. In a managed on-chain system, wallet and facilitator costs sit above gas, just as bank or payment-service-provider costs sit above central-bank settlement. At the protocol layer, Base

charges an L2 execution fee plus an L1 security fee; Solana charges 5,000 lamports, equal to 0.000005 SOL, per signature plus an optional priority fee; and Ethereum fees vary with gas used and network demand (Base, 2026; Solana Foundation, 2026; CoinCodex, 2026; Ethereum Foundation, 2026). These figures are dated parameters or public list prices, not evidence that every user can achieve them end to end.

Table 2. Illustrative public prices and access conditions at different payment-stack layers, July 2026

Example	Published price or parameter	What the figure covers	Direct access / eligibility
Stripe domestic card (US)	2.9% + USD 0.30 per successful domestic-card transaction	Merchant-facing processing product; includes more than the underlying settlement rail.	Merchants and platforms through Stripe's API; an agent acts through an authorized customer or merchant integration.
Stripe stablecoin checkout	1.5% of the USD transaction amount	Includes fiat conversion, wallet/AML screening, fraud prevention, and gas sponsorship.	Eligible merchants through Stripe; a managed service, not native protocol access.
FedNow / FedACH	FedNow: USD 0.045 per credit transfer, offset for the first 2,500 monthly transfers in 2026. FedACH: USD 0.0035 per standard origination item.	Central infrastructure or operator-to-participant prices; exclude participant systems, customer service, and integration.	Eligible institutions, or service providers acting for them; no direct agent or retail access.
TIPS	EUR 0.002 per instant transaction, shared between sending and receiving participants	Central-bank infrastructure price; monthly account-holder charges also apply.	Eligible credit institutions and qualifying PSPs; agents and merchants use a bank or PSP interface.
Base	Minimum L2 base fee: 0.005 gwei. Base illustrates about USD 0.002 for 200,000 gas at ETH = USD 2,000, plus the L1 security fee.	Network execution and data/security components only; actual price varies with gas, demand, and ETH.	Protocol-level access with a wallet or key and fee funding or sponsorship; asset, wallet, and sequencer controls may remain.
Solana / Ethereum	Solana: 5,000 lamports = 0.000005 SOL per signature, about USD 0.00037 using the July 25, 2026 daily opening price of SOL = USD 73.96, plus an optional priority fee. Ethereum: gas used × (base + priority fee).	Protocol fees only; USD cost varies with SOL/ETH and demand; excludes wallet, stablecoin, conversion, compliance, and recourse.	Protocol-level access with a key and fee funding or sponsorship; service and asset controls may remain.

Note: The rows are not interchangeable end-to-end alternatives. They decompose prices at different layers of the payment stack. Central-bank fees exclude the bank or PSP interface through which an agent would gain access; blockchain protocol fees exclude wallet, stablecoin, facilitator, compliance, conversion, and recourse costs. The Solana dollar value is an illustrative calculation using CoinCodex's July 25, 2026 daily opening price and will change with SOL/USD.

Source: Authors' compilation based on Stripe (2026), Federal Reserve Financial Services (2026a, 2026b), European Central Bank (2026b), Base (2026), Solana Foundation (2026), Ethereum Foundation (2026), and CoinCodex (2026).

Recourse is the institutional counterpart of settlement finality. Delegated payment systems can offer dispute procedures, transaction reversals, and a contractual counterparty responsible for specified losses. Native on chain transfers, by contrast, are generally irreversible at the ledger level. A mistaken, deceived, or compromised agent may therefore expose its principal to losses without access to a chargeback mechanism. Managed services can introduce spending limits, transaction screening, custody controls, and contractual remedies, but these protections arise from service governance rather than from the blockchain itself. Marino and Juels (2025) similarly identify mistaken transfers, theft by malicious or mis-

aligned agents, and the irreversibility of resulting losses as important sources of harm.

On chain settlement is therefore most attractive under a specific set of conditions. It becomes more plausible when many parties lack both mutual trust and a common intermediary, when transactions are sufficiently frequent or low in value that individual onboarding and billing are costly, when value can remain on chain so that conversion costs do not dominate, when transparency and settlement finality are acceptable, and when the principal can absorb or mitigate the consequences of limited recourse.

Managed on chain settlement is likely to be more suitable for early enterprise adoption because it preserves policy controls, compliance mechanisms, and contractual accountability. Native on chain settlement provides the clearest test of blockchain's institutional value, but it also creates the greatest exposure to key management, security, operational, and liability risks.

6. EVIDENCE, LIMITATIONS, AND EARLY IMPLEMENTATIONS

The preceding sections develop a conceptual framework. Evidence available through July 2026 can demonstrate feasibility and illustrate institutional design, but it cannot establish causal cost savings or representative adoption. Vendor documentation is used to describe product architecture and public pricing, while independent research is used, where available, to assess transaction activity and security. Because the field is evolving rapidly, all implementation claims should be interpreted as a dated snapshot.

Amazon Bedrock AgentCore payments provides an instructive example of managed on chain settlement. However, it was announced in May 2026 as a preview rather than as a production system operating at established scale (Amazon Web Services, 2026). The preview supports x402 and allows users to connect Coinbase or Stripe Privy wallet infrastructure, authorize wallet access, and impose session spending limits. AWS itself acknowledges that agent payment infrastructure at scale does not yet exist. The example therefore demonstrates technical integration and governance design rather than market validation or a reliable cost benchmark.

The x402 stack also illustrates the relocation rather than elimination of intermediation (Reppel et al., 2025). A resource server issues an HTTP 402 payment request, the client submits payment authorization, and a facilitator verifies and settles the transaction according to the selected scheme. The protocol can support multiple networks and facilitators, making the access layer more contestable than a closed proprietary ledger. In practice, however, Ling et al. (2026) report that three facilitators processed approximately 71 percent of observed activity by mid May 2026. Neutral settlement at one layer can therefore coexist with concentration at another.

Claims about scale require similar caution. Ling et al. (2026) report approximately 130 million cumulative x402 transactions through May 2026. Base accounted for about 54 percent of activity, Solana for 35 percent, and Polygon for 10 percent, while USDC represented 98.8 percent of dollar denominated volume on EVM networks. Monthly transaction counts peaked in late 2025 before declining. These figures demonstrate real protocol use, but they do not reveal how much activity reflects autonomous economic demand rather than testing, incentives, bots, or other automated traffic.

At the broader stablecoin level, McKinsey and Artemis estimate approximately USD 390 billion in annualized payment activity based on December 2025 data, equivalent to about 0.02 percent of global payments (McKinsey & Company, 2026). This estimate depends partly on transaction tagging and category assumptions and is not specific to AI agents. The available evidence therefore does not support a precise estimate of the share of genuine agent initiated payments.

The infrastructure is also not secure by default. Ling et al. (2026) identify cross resource substitution, duplicate settlement races, allowance overdraft, and denial of settlement vulnerabilities across protocol, software, and deployment layers. More broadly, agents that control keys or delegated authority remain exposed to prompt injection, misdirected transfers, excessive permissions, and privacy leakage through transaction graphs (Marino & Juels, 2025; Romandini et al., 2025). Concentration among facilitators and stablecoin issuers creates further operational and governance risks even when the underlying ledger remains open.

Bitcoin based machine payments are technically feasible, although the evidence is more limited in this context. Lightning Labs' L402 combines HTTP access credentials with Bitcoin Lightning payments and is designed for APIs and digital services that software agents can purchase (Lightning Labs, 2026). Routing fees vary according to channel structure and liquidity conditions, and no comparable independent dataset establishes agent specific adoption. L402 is therefore treated as evidence of technical possibility rather than as a basis for comparative adoption claims.

Taken together, the evidence supports the feasibility of agent initiated payments and demonstrates early institutional experimentation across several architectures. It does not yet establish comparative welfare effects, causal cost advantages, representative adoption, or the emergence of a dominant payment architecture.

7. GOVERNANCE, REGULATION, AND THE CONTROL OF MONEY

Governance in agent payment systems is distributed across multiple layers. The ledger determines transaction ordering and technical finality. A stablecoin issuer governs issuance, redemption, and address restrictions. A sequencer or validator set influences transaction availability and ordering. Wallet providers and facilitators control access, policy enforcement, and transaction execution, while banks and exchanges govern entry into and exit from fiat currency. Describing a payment as on chain therefore does not identify who can exclude a participant, freeze an asset, allocate a loss, or satisfy a legal claim. These functions must be mapped separately for each payment architecture.

A digital euro would represent a different institutional arrangement, but its current design requires careful distinction. The European Central Bank states that the digital euro would operate through a centralized settlement platform rather than distributed ledger technology. It would not constitute programmable money, although conditional payments could be supported through payment service providers. The ECB aims to be prepared for a possible first issuance during 2029, subject to the adoption of the necessary legislation (European Central Bank, 2026a). Coexistence should therefore not be understood as the emergence of a single programmable settlement ledger. A more plausible outcome is a set of parallel and potentially interoperable payment rails comprising commercial bank money, central bank digital money, issuer backed stablecoins, and permissionless crypto assets, each governed by different control, access, and liability arrangements.

Regulation directly affects the transaction costs of agent payments. Know your customer and anti money laundering obligations, sanctions screening, data protection, consumer protection, licensing, tax reporting, and operational resilience requirements determine which institutions may provide wallets, payment access, and settlement services. Liability is particularly important because an AI agent normally acts as a tool of a human or organizational principal. Contracts and legal rules must therefore specify who bears losses when an agent exceeds its mandate, is manipulated, or pays a merchant that fails to deliver.

Consumer payments that require reversibility and dispute resolution may consequently need different governance arrangements from wholesale machine to machine settlement.

This paper does not attempt to resolve these legal issues. Instead, it treats them as institutional cost variables that must be incorporated into any empirical comparison of agent payment architectures.

8. CONCLUSION

This paper advances a deliberately bounded theoretical claim. Blockchain is not necessary for agent identity or authorization, nor is it inherently a superior payment technology. Its distinctive contribution lies in providing a shared settlement record that does not depend on the ledger of a single institution. This property becomes economically relevant when many heterogeneous parties lack a common trusted intermediary, value can remain on chain, and reductions in onboarding or networking costs exceed the additional costs of conversion, compliance, security, and limited recourse. Where these conditions are absent, delegated bank or card payments, or another governed payment rail, may minimize total transaction costs.

The paper's main contribution is the functional decomposition of agent payments into identity, authorization, and settlement, combined with the comparison of delegated, managed on chain, and native on chain architectures. This framework transforms the broad question of whether the agent economy requires blockchain into a sequence of analytically testable choices. These include identifying the function being performed, determining who governs each layer, distinguishing bundled from externalized costs, assessing whether participants share a trusted intermediary, establishing whether value must cross the fiat boundary, and specifying who bears losses arising from error, fraud, or manipulation.

Evidence available through July 2026 demonstrates the feasibility of managed on chain infrastructure, but it also reveals facilitator concentration, security vulnerabilities, issuer control, and insufficient data to distinguish genuine autonomous demand from testing, bots, incentives, and speculative activity. The current evidence therefore does not support claims of superior welfare, broad adoption, or the emergence of a dominant architecture.

Future research should measure complete transaction costs for comparable agent payment tasks across delegated, managed on chain, and native on chain systems. It should distinguish agent initiated commerce from automated testing and speculative traffic, examine how batching and prepaid balances affect micropayment economics, compare fraud, error, and dispute rates, and assess concentration among wallets, facilitators, sequencers, and stablecoin issuers. Legal and organizational research should also examine how mandates, accountability, and liability are allocated when agents transact across jurisdictions.

A further theoretical boundary case concerns advanced AI systems, including possible artificial general intelligence, that operate with substantially greater autonomy and cannot rely on a principal's continuously available account. Such systems could create stronger demand for native and programmable settlement, while intensifying unresolved questions concerning control, ownership, accountability, and liability. This remains a hypothesis for future research and should not be interpreted as evidence that uncontrollable artificial general intelligence exists or that blockchain would necessarily be required.

The most plausible near term outcome is therefore institutional coexistence. Delegated payment systems, managed blockchain services, native on chain settlement, and central bank digital currencies are likely to serve different transaction types. Architecture will be selected according to the governance and cost characteristics of each transaction rather than through a single technological verdict.

REFERENCES

Amazon Web Services. (2026, May 7). Agents that transact: Introducing Amazon Bedrock AgentCore payments, built with Coinbase and Stripe. *AWS Machine Learning Blog*. Retrieved July 25, 2026, from https://aws.amazon.com/blogs/machine-learning/agents-that-transact-introducing-amazon-bedrock-agentcore-payments-built-with-coinbase-and-stripe/

Base. (2026). Network fees. Base Documentation. Retrieved July 25, 2026, from https://docs.base.org/base-chain/network-information/network-fees

Catalini, C., & Gans, J. S. (2020). Some simple economics of the blockchain. *Communications of the ACM*, 63(7), 80–90. https://doi.org/10.1145/3359552

Circle Internet Group. (2026). USDC terms. Retrieved July 25, 2026, from https://www.circle.com/legal/usdc-terms

CoinCodex. (2026). Solana (SOL) historical data. Retrieved July 28, 2026, from https://coincodex.com/crypto/solana/historical-data/

Coase, R. H. (1937). The nature of the firm. Economica, 4(16), 386–405. https://doi.org/10.1111/j.1468-0335.1937.tb00002.x

Davidson, S., De Filippi, P., & Potts, J. (2018). Blockchains and the economic institutions of capitalism. *Journal of Institutional Economics,* 14(4), 639–658. https://doi.org/10.1017/S1744137417000200

Ethereum Foundation. (2026). Ethereum gas and fees: Technical overview. Retrieved July 25, 2026, from https://ethereum.org/developers/docs/gas/

European Central Bank. (2024). Policy on access by non-bank payment service providers to central bank-operated payment systems and to central bank accounts. https://www.ecb.europa.eu/paym/target/target-professional-use-documents-links/tips/shared/pdf/Eurosys_pol_on_access_to_central_bank_operated_payment_systems_by_NBPSPs.pdf

European Central Bank. (2026a). FAQs on the digital euro. Retrieved July 25, 2026, from https://www.ecb.europa.eu/euro/digital_euro/faqs/html/ecb.faq_digital_euro.en.html

European Central Bank. (2026b). What is TIPS? Retrieved July 25, 2026, from https://www.ecb.europa.eu/paym/target/tips/html/index.en.html

Federal Reserve Financial Services. (2026a). FedACH Services 2026 fee schedule. Retrieved July 25, 2026, from https://www.frbservices.org/resources/fees/ach-2026

Federal Reserve Financial Services. (2026b). FedNow Service 2026 fee schedule. Retrieved July 25, 2026, from https://www.frbservices.org/resources/fees/fednow-2026

Federal Reserve Financial Services. (2026c). Payment processors and third-party service providers. Retrieved July 25, 2026, from https://www.frbservices.org/resources/service-setup/payment-processors-third-party-service-providers

Google. (2025). Agent Payments Protocol (AP2) [GitHub repository]. Retrieved July 25, 2026, from https://github.com/google-agentic-commerce/AP2

Jaakkola, E. (2020). Designing conceptual articles: Four approaches. *AMS Review*, 10, 18–26. https://doi.org/10.1007/s13162-020-00161-0

Lightning Labs. (2026). L402: Lightning HTTP 402 protocol. Retrieved July 25, 2026, from https://docs.lightning.engineering/the-lightning-network/l402

Ling, S., Huang, Y., Du, Y., Chen, Y., Zhou, Y., Wu, L., & Wang, C. (2026). Free-riding the agentic web: A systematic security analysis of x402 payments. arXiv:2605.30998v2. https://doi.org/10.48550/arXiv.2605.30998

Marino, B., & Juels, A. (2025). Giving AI agents access to cryptocurrency and smart contracts creates new vectors of AI harm. arXiv:2507.08249. https://arxiv.org/abs/2507.08249

Mastercard. (2025, April 29). Mastercard unveils Agent Pay, pioneering agentic payments technology to power commerce in the age of AI [Press release]. Retrieved July 25, 2026, from https://www.mastercard.com/us/en/news-and-trends/press/2025/april/mastercard-unveils-agent-pay-pioneering-agentic-payments-technology-to-power-commerce-in-the-age-of-ai.html

McKinsey & Company. (2026, February 18). Stablecoins in payments: What the raw transaction numbers miss. Retrieved July 25, 2026, from https://www.mckinsey.com/industries/financial-services/our-insights/stablecoins-in-payments-what-the-raw-transaction-numbers-miss

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. https://bitcoin.org/bitcoin.pdf

Nguyen Thanh, B., Son, H. X., & Vo, D. T. H. (2024). Blockchain: The economic and financial institution for autonomous AI? *Journal of Risk and Financial Management*, 17(2), 54. https://doi.org/10.3390/jrfm17020054

Reppel, E., Caspers, R., Leffew, K., Organ, D., Kim, D., & Dalal, N. (2025). x402: An open standard for internet-native payments [Whitepaper]. Coinbase Developer Platform. https://www.x402.org/x402-whitepaper.pdf

Romandini, N., Mazzocca, C., Otsuki, K., & Montanari, R. (2025). SoK: Security and privacy of AI agents for blockchain. In 2025 7th International Conference on Blockchain Computing and Applications (BCCA) (pp. 708–720). IEEE. https://doi.org/10.1109/BCCA66705.2025.11229689

Rothschild, D. M., Mobius, M., Hofman, J. M., Dillon, E. W., Goldstein, D. G., Immorlica, N., Jaffe, S., Lucier, B., Slivkins, A., & Vogel, M. (2025). The agentic economy. arXiv:2505.15799. https://arxiv.org/abs/2505.15799

Solana Foundation. (2026). Fees. Solana Documentation. Retrieved July 25, 2026, from https://solana.com/docs/core/fees

Stripe, & OpenAI. (2025). Agentic Commerce Protocol (ACP). Retrieved July 25, 2026, from https://www.agenticcommerce.dev/

Stripe. (2026). Local payment methods pricing [United States]. Retrieved July 25, 2026, from https://stripe.com/pricing/local-payment-methods

Visa. (2025, April 30). The future is here: Visa announces new era of commerce featuring AI [Press release]. Retrieved July 25, 2026, from https://usa.visa.com/about-visa/newsroom/press-releases.releaseId.21361.html

Williamson, O. E. (1985). The economic institutions of capitalism: Firms, markets, relational contracting. Free Press. https://www.simonandschuster.com/books/The-Economic-Intstitutions-of-Capitalism/Oliver-E-Williamson/9780684863740

World Wide Web Consortium. (2022). Decentralized identifiers (DIDs) v1.0. W3C Recommendation. https://www.w3.org/TR/did-core/

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

DIGITAL TRADE, GOVERNMENT POLICY, AND ECONOMIC GROWTH: THE CASE OF AZERBAIJAN

Ramil Huseyn[1*], Aykhan Gadashov[2]

Received 09.03.2026. | Send to review 26.03.2026. | Accepted 15.08.2026.

Original Article

[1] Centre for Analysis of Economic Reforms and Communication of Azerbaijan, Baku, Azerbaijan

[2] Head of Azexport portal, Baku, Azerbaijan

***Corresponding Author:**
Aykhan Gadashov

Email:
aykhan.gadashov@ereforms.gov.az

JEL Classification:
F17, L81, O24, Q17

Doi: 10.61432/CPNE0401299h

UDK: 338.486.1.02:316.323.6

ABSTRACT
Digital platforms provide significant opportunities to expand international trade, improve market accessibility, and support the participation of small and medium-sized enterprises (SMEs) in global value chains. In 2016, the Government of Azerbaijan launched Azexport, a centralized digital platform designed to promote domestically produced goods in international markets and reduce the barriers faced by local exporters, particularly SMEs. This study examines the contribution of digital trade and e-commerce to export growth, accessibility, and inclusion in Azerbaijan's non-oil sector. It combines two complementary evaluation approaches: the six evaluation criteria of the Organisation for Economic Co-operation and Development's Development Assistance Committee (OECD/DAC) and a Social Accounting Matrix multiplier model used to estimate the platform's short-term and indirect effects on export revenues and employment. The findings indicate that Azexport has played an important role in improving access to international markets, supporting export diversification, and expanding the participation of smaller producers and vulnerable groups in digital trade. As the first platform in the South Caucasus to provide both a virtual exhibition hall and a virtual conference space, Azexport has facilitated the international promotion of Azerbaijani products and strengthened the country's digital trade infrastructure. The combined evaluation demonstrates that Azexport represents a distinctive government-led mechanism for promoting accessibility and inclusion through digital trade and e-commerce. The platform provides a relevant policy model for resource-dependent economies seeking to diversify exports, strengthen SME competitiveness, and support sustainable non-oil economic development.

Keywords: *digital trade, e-commerce, export promotion, SMEs, digital transformation, Azerbaijan*

1. INTRODUCTION

Given the dominant role of the oil sector in Azerbaijan's economy and export structure, the development of the non-oil sector has become a major government priority. Following global economic instability and the sharp decline in oil prices during 2014–2015, the Government of Azerbaijan introduced reforms aimed at reducing the economy's dependence on hydrocarbons and strengthening non-oil exports (SRM, 2016).

In 2016, Azerbaijan's exports remained heavily concentrated in oil and gas, while non-oil enterprises faced significant barriers to entering international markets. Many producers

lacked access to foreign buyers, limiting their ability to expand production. These challenges were particularly acute in agriculture, which employed approximately 36% of the national workforce. Small-scale farmers often lacked the resources, market information, and institutional support required to export their products. In response, policymakers increasingly viewed digital trade and e-commerce as instruments for reducing market-entry barriers, expanding participation, and promoting greater accessibility and inclusion in international trade.

As part of this policy agenda, the government supported the establishment of the Azexport e-commerce portal. Launched pursuant to the Presidential Order of 21 September 2016 (OoP, 2016), the platform was designed to provide comprehensive information on Azerbaijani products and facilitate their sale in domestic and international markets.

Azexport adopted an innovative product-centred approach. Rather than promoting the portal itself, it focused on increasing the international visibility of the products listed on it. The platform was therefore integrated with major global electronic marketplaces, as well as domestic and international logistics and transportation providers. Secure payment options, including Visa, Mastercard, and American Express, were also incorporated.

Azexport's electronic services draw on the European Union's Once-Only Principle, which aims to simplify administrative procedures by allowing citizens and businesses to provide information to public authorities only once. Through the Push2Export service, exporters can submit a single online application and obtain export-related documents, including permits, certificates, and customs declarations. This mechanism reduces administrative burdens and simplifies export procedures.

The platform also contributes to the implementation of Azerbaijan's national priorities for 2030 (NP, 2021) and its socio-economic development strategy for the period up to 2026 (SSED, 2022).

Against this background, the study addresses the following research question: How can government-led digital trade and e-commerce initiatives, such as Azexport, enhance export diversification, strengthen SME competitiveness, and promote accessibility and inclusion in global markets as drivers of sustainable economic growth?

The study hypothesises that government-led digital trade and e-commerce platforms can serve as effective instruments for export diversification and the integration of SMEs into international markets. By reducing transaction costs, simplifying export procedures, and providing market intelligence, such platforms can strengthen competitiveness and create new market opportunities. When designed around accessibility and inclusion, they may also enable small-scale producers and socially vulnerable groups to overcome traditional barriers and participate more actively in cross-border trade.

The remainder of the paper is structured as follows. Section 2 presents the institutional background of Azexport and the conceptual framework. Section 3 describes the data and methodology. Section 4 discusses the empirical results and key findings, while the final section presents the conclusions and policy recommendations.

2. INSTITUTIONAL BACKGROUND AND CONCEPTUAL FRAMEWORK

Since late 2014, the sharp decline and increased volatility of global oil prices have had significant consequences for Azerbaijan's economy. After approaching USD 150 per barrel in 2008, oil prices fell below USD 30 in 2016. This downturn weakened export revenues, reduced government income, intensified pressure on the current-account balance, and contributed to two devaluations of the Azerbaijani manat in 2015. Economic growth slowed to an average of 2.7% between 2010 and 2014, while unemployment increased as export activity declined (SRM, 2016).

These developments highlighted the need for a new growth model capable of addressing structural and institutional constraints, balance-of-payments pressures, the non-oil budget deficit, and vulnerabilities in the financial and banking sectors. In response, the Government of Azerbaijan introduced a broader strategy aimed at diversifying exports and strengthening the competitiveness of domestic producers (SRM, 2016).

Azexport was established within this policy context as a government-supported digital platform for promoting non-oil exports and facilitating access to international markets. One of its principal innovations was the introduction of a "reverse dropshipping" model, through which products listed on Azexport were automatically displayed on more than ten international marketplaces, including Alibaba, TradeIndia, All.biz, and Agroserver. Membership, product listing, marketing, and business-matching costs were covered by the government, allowing exporters to receive international inquiries and purchase requests without bearing the associated platform costs (Azexport, 2025a; Huseyn & Gardashov, 2019).

This model generated substantial results. The online presence of Azerbaijani products increased more than sixtyfold, over 50,000 international orders and inquiries were recorded, and the country's export reach expanded to 122 markets. Azexport consequently became an important gateway for small and medium-sized enterprises, which often lack the specialised export departments and market-access capabilities available to larger firms.

The platform has been particularly relevant to agricultural producers, given that agriculture accounts for approximately 36% of national employment (Huseyn et al., 2020). In addition to connecting producers with domestic and international buyers, Azexport provides access to export documentation through a single-window system and offers support with customs declarations and related administrative procedures.

Since 2019, the platform has expanded its activities to include the international promotion of creative products through global e-commerce channels (UNESCO, 2022). It supports the sale of textiles, paintings, decorative products, souvenirs, and other handmade goods produced by persons with disabilities and creative professionals. These initiatives have strengthened the economic inclusion of vulnerable groups while promoting Azerbaijani culture and national identity in international markets.

The platform's activities have also extended beyond physical products. Music, photography, visual art, poetry, and electronic books have been promoted internationally, while dedicated campaigns have supported the globalisation of Azerbaijani information technology services. Local IT professionals are connected with international clients through freelance and corporate projects, and their portfolios are adapted for platforms such as Upwork, Fiverr, Freelancer, and Toptal.

Azexport is also authorised to issue Free Sale Certificates, which facilitate the entry of Azerbaijani food and cosmetic products into more than thirty additional markets (DoP, 2017b). In parallel, the Digital Trade Hub of Azerbaijan was established as a broader component of the country's digital trade infrastructure (DoP, 2017a). The Hub provides business-to-business and business-to-government services, including single exporter applications, electronic customs clearance, online company registration, bank-account opening, electronic signatures, payment processing, and document management. By integrating these services, it simplifies cross-border transactions and reduces administrative burdens (DTH, 2025).

Azexport has additionally developed into a source of market intelligence. Changes in buyer inquiries can signal shifts in regional demand or emerging shortages, allowing exporters and policymakers to respond more effectively. The portal therefore performs not only a promotional function but also an informational one, providing insights that may support production planning, market regulation, and domestic price stability.

The platform has also contributed to improved export outcomes in specific sectors. For example, before cooperation with Azexport, Azerbaijani cotton fibre was reportedly exported at approximately USD 1,300-1,350 per tonne. Following the identification of new buyers through the platform, the export price increased to approximately USD 1,750 per tonne, representing an additional USD 400–450 per tonne and generating substantial additional export revenue (Azexport, 2019).

The use of Azexport's digital services increased further during the COVID-19 pandemic, which accelerated demand for digital trade solutions and highlighted their importance for agricultural modernisation and market access. By enabling producers to reach broader markets remotely, the platform contributed to the wider digital transformation of Azerbaijan's export sector.

Azexport expanded from approximately 100 participating companies in 2016 to 3,500 businesses by 2024. By 2023, it had developed a comprehensive portfolio of electronic trade services covering export documentation, product certification, digital marketing, and international business matching. According to internal data, each US dollar invested in the platform generated approximately USD 3,000 in quotations from foreign buyers.

Overall, Azexport has evolved from a product-promotion portal into a broader digital trade ecosystem. It facilitates export diversification, strengthens SME access to foreign markets, supports socially inclusive entrepreneurship, promotes creative and digital services, and provides market intelligence. Its development illustrates how a government-led platform can combine trade facilitation, digital transformation, and social inclusion to support the internationalisation of a non-oil economy.

3. DATA AND RESEARCH METHOD

3.1. DATA

The study draws on data from the State Statistical Committee of the Republic of Azerbaijan (SSC, 2023; SSC, 2024a; SSC, 2024b; SSC, 2024c; SSC, 2025) and the Azexport portal (Azexport, 2025b). Since 2017, Azexport has developed an extensive database containing information on Azerbaijani products, producers, production regions, prices, and export inquiries received from international markets.

One of the platform's most important features is its large export-related data archive, accumulated over more than nine years of activity. This database supports detailed visual analysis by country, product category, and period, as well as weekly, monthly, and quarterly export forecasting. It also facilitates the early identification of market trends and structural changes. Commercially sensitive information and data classified as business secrets were excluded from the analysis.

Additional data were obtained from the *Export Review* journal (Export Review, 2025), which is produced using market inquiries and export-related information collected through the portal. The journal functions as an important source of market intelligence and reportedly reaches more than 600,000 subscribers.

Export Review was the first publication to introduce an official monthly ranking of Azerbaijan's leading exporters. It provides product-level and country-specific analyses, enabling businesses to monitor export performance, identify potential markets, and assess changes in demand. The journal is also distributed electronically through taxpayer accounts, providing exporters with timely information on domestic market developments and economic conditions in Azerbaijan's principal trading partners.

3.2. METHODOLOGY

This case study employs a qualitative and quantitative research design based on official reports, internal key performance indicators, stakeholder interviews, user surveys, and export data. The methodology combines documentary analysis, comparative benchmarking, and performance assessment to evaluate the effectiveness, sustainability, and potential replicability of the Azexport model. The analysis also incorporates a Social Accounting Matrix approach to estimate the broader economic effects of the platform.

Assessment Based on the OECD/DAC Criteria

The study applies the six evaluation criteria developed by the Development Assistance Committee of the Organisation for Economic Co-operation and Development (OECD/DAC): relevance, coherence, effectiveness, efficiency, impact, and sustainability. These criteria provide a structured framework for evaluating policies, programmes, projects, and institutional initiatives.

In the context of this study, the criteria are used to assess the extent to which Azexport addresses the needs of Azerbaijani exporters, achieves its intended objectives, uses resources efficiently, complements broader national policies, generates economic and social effects, and produces benefits that can be sustained over time.

4. KEY FINDINGS AND ISSUES REQUIRING FURTHER ATTENTION

4.1. HOW DOES AZEXPORT ENHANCE ACCESSIBILITY AND INCLUSION THROUGH DIGITAL TRADE AND E-COMMERCE?

Azerbaijan's non-oil exports increased 2.2-fold between 2017 and 2024, reaching USD 3.357 billion. During the same period, the value of export orders received through the Azexport portal also followed a positive growth trajectory.

Export inquiries submitted through the portal are forwarded directly to producers, while Azexport does not participate in negotiations between buyers and sellers. When both parties agree to proceed with a transaction, the platform supports exporters in obtaining the required certificates and documentation. Initial contacts may subsequently develop into long-term commercial relationships; however, such follow-up transactions are not included in the data presented in Figure 1. The reported figures therefore reflect only initial orders submitted by verified potential buyers.

The products most frequently ordered through the portal in 2024 included raw cotton, cottonseed oil, dates, hazelnuts, tomatoes, apples, wine, chicken meat, pomegranate juice, clinker, cement, and aluminium alloys.

The geographical distribution of portal-based export orders in 2024 was as follows:

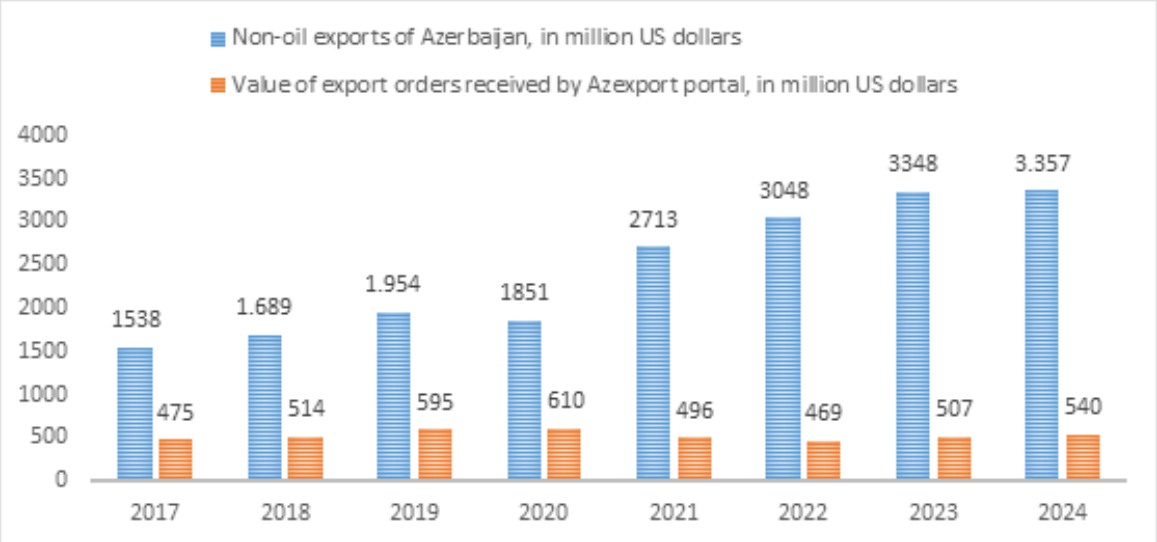
- Russia: 34.5%;
- Türkiye: 30.5%;
- Georgia: 10%;
- Italy: 7%;
- Ukraine: 4%; and
- other countries: 14% (Azexport, 2025b).

Overall, export inquiries were received from 154 countries. Nevertheless, orders remained concentrated in neighbouring markets, particularly Russia, Türkiye, and Georgia, owing to the established demand for Azerbaijani products and comparatively favourable logistical conditions.

Data from the State Statistical Committee show that, in 2024, Russia accounted for 35% of Azerbaijan's non-oil exports, Türkiye for 16%, and Georgia for 8% (SSC, 2025). These

figures indicate a broad alignment between the geographical structure of actual non-oil exports and the distribution of orders received through the Azexport portal, as illustrated in Figure 1.

Figure 1. The dynamics of export orders received by Azexport and Azerbaijan's non-oil exports

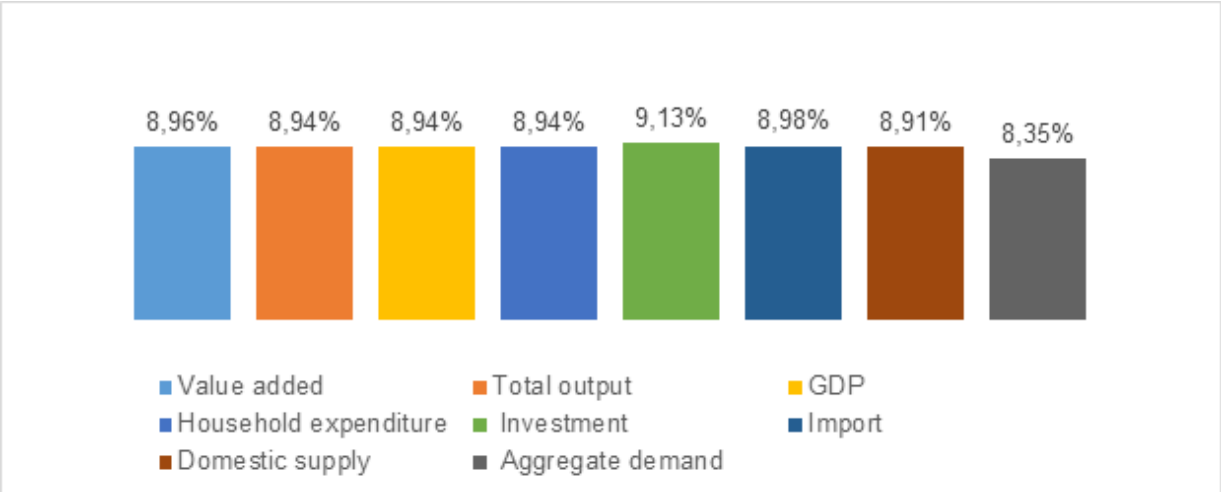


Source: SSC, 2025; Azexport, 2025b

For example, Azerbaijani cotton producers have reported securing more favourable export prices through the platform. Another notable case is AgroBioEkoTex, which used Azexport to enter foreign markets with its organic fertiliser products, despite not having previously operated as a conventional exporter.

The potential effects of export orders received through the portal on Azerbaijan's macroeconomic indicators were assessed using a modelling approach. Based on official statistical data for 2021, simulations conducted with a Social Accounting Matrix (SAM) multiplier model indicate that, if the export orders registered through Azexport are successfully fulfilled, they could affect Azerbaijan's key macroeconomic indicators as follows:

Figure 2. The results of simulations carried out using multiplier models based on the Social Accounting Matrix



Source: Authors calculation

Developing a globally recognised export platform exclusively for Azerbaijan, together with a sufficiently broad product base, would have required substantial financial, technical, and institutional resources. A more strategic approach was therefore adopted by

leveraging the infrastructure and international reach of established platforms such as Alibaba, Amazon, and eBay in ways that support the interests of Azerbaijani producers.

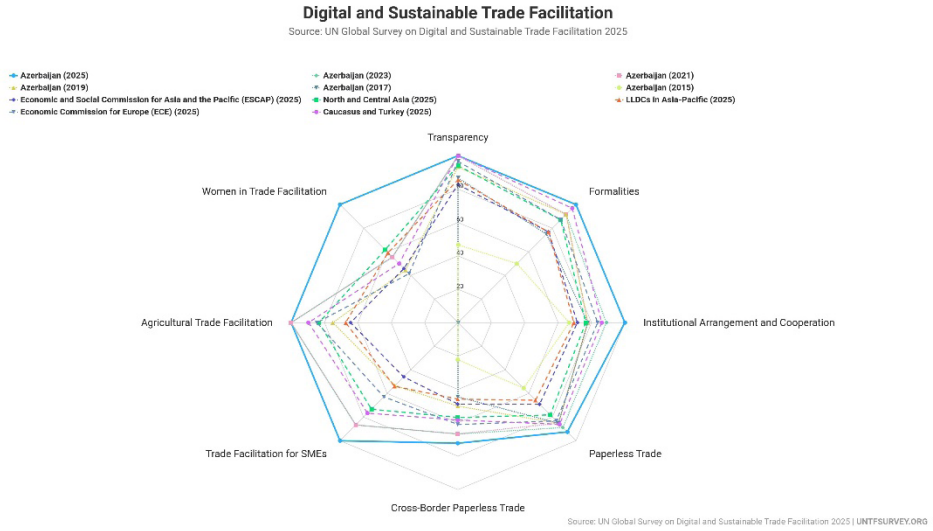
While large companies generally possess dedicated export departments and specialised personnel, Azexport has become an important instrument for small and medium-sized enterprises (SMEs), providing access to international markets with limited cost and administrative effort.

As an e-commerce platform, Azexport reduces transaction and coordination costs across agri-food value chains by connecting producers directly with foreign buyers. Farmers can list their products free of charge and obtain the required export documentation through the portal, thereby reducing both processing time and intermediary costs (Huseyn et al., 2020).

Surveys conducted among platform users indicate that more than 90% of potential exporters in Azerbaijan, particularly SMEs, are satisfied with Azexport's performance. The platform has also contributed to strengthening Azerbaijan's position in international assessments of digital trade facilitation.

According to the United Nations *Global Survey on Digital and Sustainable Trade Facilitation*, Azerbaijan achieved an overall score of 92.5% in 2025 across five major areas of trade facilitation, placing it among the ten highest-performing economies in Asia (UN, 2025). The country received full scores for transparency, formal procedures, institutional cooperation, and coordination, while achieving 92.59% in paperless trade and 72.2% in cross-border paperless trade.

Figure 3. Digital and Sustainable Trade Facilitation



Source: UN Global Survey, 2025

In the 2025 edition of the *Global Survey on Digital and Sustainable Trade Facilitation*, Azerbaijan recorded substantial progress across all major indicators. Compared with 2015, the transparency score increased by 53.3 percentage points, while formal procedures improved by 50 percentage points and by a further 8.3 percentage points relative to 2023. Institutional cooperation and coordination rose by 33.3 percentage points from 2015 and by 11.1 percentage points from 2023. Paperless trade improved by 37 percentage points compared with 2015 and by 3.7 percentage points compared with 2023, while cross-border paperless trade increased by 50 and 5.6 percentage points, respectively.

Overall, the survey confirms that Azerbaijan steadily strengthened its implementation of digital and sustainable trade-facilitation measures between 2015 and 2025. Azexport appears to have contributed to this progress by supporting digital export procedures, market transparency, and access to international e-commerce channels.

The analysis shows that most orders received through Azexport relate to agricultural and food products, including hazelnuts, tomatoes, cotton, tobacco, pomegranates, poultry, eggs, pomegranate juice, and wine. When incoming orders indicate a potential shortage of a particular product, Azexport informs relevant institutions, including CAREC, which may assess production capacity and communicate the findings to the appropriate government authorities.

Within a relatively short period, Azexport evolved into a digital marketing and trade-facilitation instrument that promotes Azerbaijani products internationally at limited cost. The platform also enables exporters to obtain the documentation and certificates required for cross-border trade through online procedures, thereby reducing administrative burdens.

Early Warning System and Real-Time Market Intelligence

Azexport functions not only as a digital marketplace but also as a source of real-time market intelligence. Sudden increases in orders for particular products may signal emerging supply shortages in neighbouring markets. For example, increased demand for eggs from Russia and onions from Türkiye provided early indications of local market disruptions.

Such information enables producers and policymakers to respond more rapidly to changes in regional demand. Where necessary, public authorities may introduce export-management measures to protect domestic supply and limit sharp price increases. The use of e-commerce data for early warning, market monitoring, and policy response represents one of the platform's most distinctive functions.

Azexport's integration with Alibaba enables Azerbaijani producers to publish product listings automatically across more than ten international marketplaces (Alibaba, 2025). Rather than requiring each producer to establish and manage separate accounts, the platform performs this function centrally and free of charge, thereby reducing financial and technical barriers for SMEs.

Azerbaijani products are managed through a centralised "Gold Supplier" account on Alibaba, which provides:

- lower marketing and promotional costs;
- greater product visibility and improved search rankings; and
- centralised management of inquiries and orders.

This model has expanded the international reach of Azerbaijani products, particularly in Europe, the Middle East, and Central Asia.

Facilitating Global Market Access and Digital Certification

To support entry into international markets, Azexport introduced the Certificate of Free Sale, which helps exporters address regulatory requirements, particularly for food, cosmetic, and pharmaceutical products. The certificate facilitates access to more than 30 markets, including Qatar, Indonesia, the Philippines, the United Arab Emirates, and Israel.

Azexport has also launched a Virtual Exhibition Hall that enables exporters to present their products in an interactive digital environment available continuously to international buyers.

Strategic International Recognition and Cooperation

The Organization of Turkic States has recognised Azexport as a national e-commerce model with potential for replication across member countries. Its experience in cross-border e-commerce, export analytics, and digital certification has contributed to initiatives such as the OTS AgroData platform and the emerging "OTS Made" brand.

Azexport has also signed a cooperation agreement with GS1 Azerbaijan to facilitate the in-

tegration of business-registration and product-identification data. This cooperation supports automated data exchange, improves the accuracy of exporter profiles, and promotes alignment with international identification and traceability standards.

According to the United Nations, Azexport represents an innovative approach to the digitalisation of export procedures, real-time trade transparency, and market analysis. Such recognition reflects the platform's evolution from a national export-promotion portal into a broader model of digital trade facilitation.

By 2024, more than 300 Azerbaijani products had been listed on Alibaba.com, generating over 150,000 views during that year. This level of exposure indicates growing international interest in Azerbaijani goods.

To strengthen the visibility, traceability, and legal protection of Azerbaijani products on platforms such as Amazon and eBay, Azexport should deepen its strategic cooperation with GS1 Azerbaijan. This partnership could focus on the verified use of Global Trade Item Numbers and Global Location Numbers, ensuring that products are accurately identified and traceable in accordance with international standards. Initial measures could include a formal data-sharing protocol and pilot legal-support services to help local producers protect their digital identities and product listings in international markets.

4.2. EVALUATION OF AZEXPORT'S ACTIVITIES USING OECD/ DAC METHODOLOGY

The results of the evaluation of the portal's activities using the OECD/DAC methodology (2019) are given in Table below.

Table 1. Evaluation of the Azexport's activities using OECD/DAC methodology

Evaluation criteria	Evaluation results
Relevance	How does the Azexport's activity support the enabling accessibility and Inclusion through digital trade and e-commerce? Are Azexport's activity objectives in line with non-oil exporters' needs? Azexport, the first platform in the South Caucasus a "virtual exhibition hall" and a "virtual conference space," has been instrumental in facilitating accessibility and inclusion through digital trade and e-commerce in Azerbaijan. Findings from the survey conducted by portal demonstrate that the portal's activities are well-aligned with the needs of non-oil exporters.
Coherence	How well does the Azexport's activity align with the country's Digital Trade and E-commerce measures and with other government support measures? Azexport's initiatives are fully aligned with the Azerbaijani government's strategic objective of fostering accessibility and inclusion via digital trade and e-commerce. Portal is essential to the internationalization of SMEs in Azerbaijan, particularly in promoting self-employment and giving vulnerable groups access to international markets.
Effectiveness	Are the Azexport's activity achieving their objectives? Without incurring extra expenses, the platform enables SMEs to advertise their goods on well-known international e-commerce sites like Alibaba, Amazon, and eBay. What distinguishes portal is its emphasis on actively marketing the products listed on the portal rather than the portal itself. Reduced Transaction Costs and Streamlined Export Documentation: Integration with logistics providers, payment systems, and a "single window" for export certifications (including Push2Export and Free Sales Certificates) lowers coordination costs for SMEs and accelerates export processes.

Evaluation criteria	Evaluation results
Efficiency	Could the outputs be produced with fewer resources or do they cost more than initially foreseen? Was the policy implemented in a timely manner? As a result of Azexport's efforts, Azerbaijan's products are now 2500 times more prevalent on various international digital trade platforms, and the country has risen from the bottom of the CIS rankings to the front rows. Positive Price Effects for Key Commodities: Evidence indicates a substantial increase in cotton fiber export prices for companies using portal, with reported gains of approximately USD 400–450 per ton compared to previous benchmarks, suggesting improved price discovery and market access. High Return on Investment Indicators (Require Verification): Internal data reports indicate strong leverage, with claims such as every USD 1 invested generating approximately USD 3,000 in quotation requests, and every USD 0.7 spent yielding USD 1,470 in quotation requests and sales.
Sustainability	Are the outcomes achieved sustainable? The information gathered through portal is extremely valuable for forecasting future output, tracking price movements, and in certain situations, acting as an early warning system. In the case of Azerbaijan, portal has played a unique role in implementing the Enabling Accessibility and Inclusion through Digital Trade and E-commerce initiative, and it is currently being discussed for implementation in other Organization of Turkic States members. International Recognition and Replicability: Azexport has gained recognition from initiatives such as EU4Digital and the Organization of Turkic States, positioning it as a replicable model for other countries aiming to enhance digital trade infrastructure and export promotion.
Impact	Has the Azexport platform contributed significantly to the growth and internationalization of Azerbaijans non-oil exports between 2017 and 2024? To what extent have the results contributed to immediate or ongoing change? As a result of Azexport's efforts, Azerbaijan's products are now 2500 times more prevalent on various international digital trade platforms, and the country has risen from the bottom of the CIS rankings to the front rows. Strong Non-Oil Export Growth Coinciding with Azexport Development: Azerbaijan's non-oil exports increased 2.2 times over the period, reaching USD 3,357 million in 2024. The growth in export orders and the expansion of Azexport's platform activities closely track this upward trend. Rapidly Growing Order Flow and Platform Expansion: Since its launch with 100 companies in 2016, Azexport grew to register 3,500 companies by 2024. The portal cumulatively processed over 50,000 unique orders and inquiries, reflecting significant market engagement. Broad International Reach with Regional Concentration: Export orders originated from 154 countries in 2024. However, a majority of orders were concentrated in Russia (34.5%), Türkiye (30.5%), and Georgia (10%), mirroring the country-level export shares reported by the State Statistical Committee (Russia 35%, Türkiye 16%, Georgia 8%). This pattern reflects both demand structures and logistical advantages. Inclusive SME Participation and Social Impact: Azexport lowers barriers to international trade by offering SMEs including persons with disabilities and artisans cost-free access for product listing, marketing, and membership. The platform actively supports the export of handmade and creative products on global marketplaces such as Amazon and eBay, promoting social inclusion. Market Intelligence and Early-Warning Capabilities: The platform functions beyond marketing by serving as a real-time observer of international demand fluctuations. Spikes in orders for specific products (e.g., eggs, onions) have enabled timely policy responses to stabilize domestic markets and prices. Macroeconomic Multiplier Effects: Simulations based on a Social Accounting Matrix (SAM) model suggest that fulfilling Azexport-generated orders has positive effects on GDP and employment.

The analysis of Export operations highlights several structural and institutional challenges that continue to affect the expansion of Azerbaijan's non-oil exports:

Insufficient Supply to Meet Regional Food Demand**.** Market analysis indicates strong demand for Azerbaijani food products, particularly in neighboring countries. However, domestic production volumes remain inadequate to fully capture these opportunities, re-

flecting constraints in agricultural capacity and productivity.

Limited Export Experience among SMEs**.** Small and medium-sized enterprises (SMEs) possess minimal experience in engaging with international markets. Even when potential buyers are identified, many enterprises face difficulties in completing transactions due to a lack of export specialists and limited capacity to prepare the required documentation.

Weak Compliance with International Standards. Entrepreneurs seeking to access foreign markets need to improve product quality and obtain internationally recognized certificates. Azerbaijani producers often lag behind competitors in this regard. In response, Azexport has initiated targeted training programs to enhance awareness and compliance with international certification requirements.

Small-Scale Agricultural Production. A significant proportion of Azerbaijani agricultural producers operate on fragmented, small land plots, resulting in limited production volumes. This prevents them from fulfilling bulk foreign orders. Encouraging producers to form cooperatives or producer groups has been identified as a pathway to achieving economies of scale and meeting international demand.

Unlocking Hidden Export Potential through Digital Trade. Digital trade platforms have demonstrated their ability to create market opportunities for products previously considered non-tradable. A notable example is sheep wool, which remained largely unused in Azerbaijan for years but was successfully marketed to international buyers through portal.

4.3. PROBLEMS REQUIRING RESOLUTION

Several challenges remain to be addressed in order to expand the activities of Azexport and enhance the development of the portal. It is important to note that when Azexport was launched in 2016, the global and domestic landscape of digital trade and e-commerce was considerably different from what it is today. Over the past nine years, this field has undergone rapid transformation, driven by technological innovation, regulatory shifts, and changing consumer behavior. In particular, the growing integration of artificial intelligence into trade facilitation, market intelligence, and e-commerce operations presents both new opportunities and policy challenges compared to the conditions that prevailed at the time of Azexport's inception.

To fully unlock the potential of e-commerce for Azerbaijani exporters, it is proposed that amendments be made to the following key legal acts: the "Rules for the Declaration of Goods and Vehicles Moved Across the Customs Border," approved by Decree No. 263 of the Cabinet of Ministers of the Republic of Azerbaijan dated July 22, 2014; and the "Rules for Regulating Import-Export Operations in the Republic of Azerbaijan," approved by Decree No. 609 of the President of the Republic of Azerbaijan dated June 24, 1997.

Customs and Contractual Requirements

Identified problem. Under paragraph 2 of the *Rules for the Declaration of Goods and Vehicles Moved Across the Customs Border*, goods must be declared to the customs authorities using a contract and an invoice confirming the underlying foreign trade transaction. This requirement creates a significant obstacle for business models used by major e-commerce platforms such as Amazon. These platforms generally do not require exporters to conclude a traditional sales contract or issue an invoice before goods are placed in overseas fulfilment centres. Instead, sellers must maintain an active platform account and comply with the platform's packaging, labelling, and product-listing requirements.

Proposed legislative amendments.

- Amendment to Cabinet of Ministers Decree No. 263. The applicable rules should include specific provisions for e-commerce transactions and permit the use of alterna-

tive supporting documents in place of a traditional contract and invoice. Acceptable documentation could include an agreement with the e-commerce platform, confirmation of an active seller account, or an electronic export order generated through the platform's internal system.

- Simplified customs procedures. A simplified customs declaration or dedicated clearance procedure should be introduced for low-value e-commerce consignments. Such measures would accelerate customs processing, particularly for goods exported through Azexport and the Digital Trade Hub.

Financial Transactions and Repatriation of Export Proceeds

Identified problem. Under the *Rules for Regulating Import-Export Operations*, approved by Presidential Decree No. 609, legal entities and individuals must ensure that export proceeds are transferred to an authorised bank account in Azerbaijan within 180 days. However, payments generated through e-commerce platforms are commonly processed through international payment service providers such as Payoneer, Wise, and WorldFirst. As accounts held with these providers are not recognised as authorised bank accounts in Azerbaijan, exporters may encounter difficulties in satisfying the repatriation requirement and may consequently face the risk of financial penalties.

Proposed legislative amendments.

- Amendment to Presidential Decree No. 609. The rules should include a dedicated chapter or exemption governing e-commerce transactions. This provision should recognise funds received through approved international payment systems as legitimate export proceeds. Official account statements, transaction reports, or payment confirmations issued by e-commerce platforms and payment providers should be accepted as supporting evidence.
- Cooperation with authorised banks. The Central Bank should authorise selected domestic banks to establish direct operational arrangements with international e-commerce payment providers. Special verification and processing procedures could then be introduced for e-commerce exporters, facilitating both the receipt and monitoring of export proceeds.

4.3.3 Full Digitalisation of Export Certification Procedures

Identified problem. The transition towards fully digital export certification has not yet been completed. Remaining paper-based or fragmented procedures continue to increase the administrative burden on exporters and limit the efficiency of cross-border e-commerce.

The following measures are therefore recommended:

- complete the online issuance of all export-related certificates, including phytosanitary, veterinary, and certificates of origin;
- develop and implement an AI-supported electronic customs declaration system specifically designed for e-commerce exports; and
- establish a legal framework for simplified digital customs declarations applicable to small-scale and low-value e-commerce transactions.

5. CONCLUSIONS

Azexport has developed into an important government instrument for promoting exports by domestic producers. By combining digital infrastructure with data-driven market intelligence, the platform directly connects Azerbaijani suppliers with international buyers. Rather than functioning solely as a product catalogue, it generates verified export inquiries and commercial opportunities, thereby reducing traditional market-entry barriers

and demonstrating how digital trade ecosystems can strengthen the international competitiveness of smaller economies.

Through integration with global platforms such as Alibaba, Amazon, and TradeKey, as well as the provision of export services and analytical tools at no cost, Azexport has broadened access to international trade, particularly for small and medium-sized enterprises. Its experience demonstrates that well-designed digital trade platforms can contribute to export diversification, business internationalisation, and sustainable economic development.

Between January 2017 and January 2025, the total value of export quotation requests and sales received from 136 countries reportedly reached USD 4.2 billion. Initial key performance indicator analysis suggests that every USD 0.70 spent on the platform generated approximately USD 1,470 in quotation requests and sales. The visibility of Azerbaijani products across international digital marketplaces also increased substantially, helping domestic manufacturers identify new buyers, obtain more competitive prices, expand production, and initiate new export-oriented projects.

The Digital Trade Hub of Azerbaijan further strengthens this ecosystem by providing integrated electronic business services through a single digital interface. Based on the "single-window" principle, the Hub automates business procedures, generates documents required for export and import clearance, and integrates trade-related public services. By replacing fragmented offline procedures with a unified online system, it reduces administrative costs, saves time, and simplifies business operations for both domestic entrepreneurs and foreign investors.

These developments indicate that Azerbaijan's digitalisation strategy in support of export-led growth and business development has generated significant institutional and commercial benefits. Azexport has facilitated international market access, supported national export objectives, and promoted accessibility and inclusion in digital trade. SMEs can use global marketplaces without incurring substantial listing and promotional costs, while services such as the Virtual Exhibition Hall and Virtual Conference Space provide additional channels for international visibility and business communication.

The platform also supports the economic participation of vulnerable groups by facilitating self-employment and the international promotion of their products and services. Its integration with major global marketplaces enables businesses and public institutions to monitor changing demand, respond to market disruptions, improve supply-chain coordination, and contribute to domestic price stability.

Overall, Azexport illustrates how government-supported digital trade infrastructure can combine export promotion, administrative simplification, market intelligence, and social inclusion. It therefore provides a potentially replicable model for countries seeking to strengthen their participation in the global economy through digital innovation and inclusive trade facilitation.

REFERENCES

Alibaba. (2025). Alibaba profil of Azexport. https://azexport.trustpass.alibaba.com/productlist.html?spm=a2700.shop_index.88.13.4f321c8ccEucXa

Aliyev, I. (2017). Ilham Aliyev chairs the republican conference of non-oil exporters in Yevlakh [online]. https://president.az/en/articles/view/23369

Azertag. (2018). 60 tons of sheep wool exported to Russia via the Azexport portal. https://azertag.az/xeber/azexport_portali_vasitesi_ile_rusiyaya_60_ton_qoyun_yunu_ixrac_olunub-1223168

Azexport. (2025a). Terms & Conditions. [online]. https://azexport.az/en/terms

Azexport. (2025b). Database of export orders received by Azexport. https://azexport.az

Decree of the President of Azerbaijan (DoP). (2017a). Decree of the President of the Republic of Azerbaijan on additional measures to strengthen the position of the Republic of Azerbaijan as the Digital Trade Hub and expand foreign trade operations. Baku. https://e-qanun.az/framework/34919

Decree of the President of Azerbaijan (DoP). (2017b). Decree of the President of the Republic of Azerbaijan on approval of the "Rules for issuing electronic signature certificates to non-residents through diplomatic missions and consulates of the Republic of Azerbaijan" and the Regulations on the "www.azexport.az" internet portal". Baku. https://e-qanun.az/framework/36462

DTH. (2025). Digital Trade Hub of Azerbaijan. https://dth.az/index

Export Review. (2025). Export Review, The Center for Analysis of Economic Reforms and Communication, January, 1 (94). [online]. https://ereforms.gov.az/files/review/pdf/az/71f2a-76ca8b765e7a3bc995111e7265d.pdf

Huseyn, R., Gardashov, Z. (2019). Digitization for export-led development strategy: lessons from Azerbaijan. International scientific and technical conference on "Innovative technologies in telecommunications". p.318-320. https://www.researchgate.net/publication/380315811_DIGITIZATION_FOR_EXPORT-LED_DEVELOPMENT_STRATEGY_LESSONS_FROM_AZERBAIJAN

Huseyn, R., Huseynov, R., Museyibov, A. (2020). Empowering agricultural development through digital transformation in Azerbaijan. "Sustainable Development of Agriculture: Global Challenges and Reforms in Azerbaijan" scientific-practical conference. p.141-149. https://atm.gov.az/pdf/magazine/4.pdf

NP. (2021), Azerbaijan 2030: National Priorities for Socio-Economic Development. Baku. https://eqanun.az/framework/46813

OoP. (2016). Order of President of the Republic of Azerbaijan on the creation of a unified database of goods produced in the Republic of Azerbaijan, Baku. https://e-qanun.az/framework/33720

Organisation for Economic Co-operation and Development. (2019). Better Criteria for Better Evaluation Revised Evaluation Criteria Definitions and Principles for Use OECD/DAC Network on Development Evaluation. https://www.oecd.org/en/publications/better-criteria-for-better-evaluation_15a9c26b-en.html

SRM. (2016). Strategic Roadmap for National Economy Perspective of the Republic of Azerbaijan. Baku. https://e-qanun.az/framework/57112

SSED. (2022), Strategy of Socio-economic Development of the Republic of Azerbaijan in 2022-2026. Baku. https://e-qanun.az/framework/50013

State Statistical Committee of Azerbaijan Republic (SSC). (2023), Economic Statistics-System of National Accounts and Balance of Payments. Available from: https://www.stat.gov.az/source/system_nat_accounts/?lang=en

State Statistical Committee of the Republic of Azerbaijan. (2024a). Statistical Yearbook of Azerbaijan 2024. Official Publication. Baku, 695 p. https://stat.gov.az/menu/6/statistical_yearbooks/

State Statistical Committee of the Republic of Azerbaijan. (2024b). Digital Development in Azerbaijan - Statistical Yearbook. Official Publication. Baku, "Azmega Croup" Publishing House, 144 p. https://stat.gov.az/menu/6/statistical_yearbooks/

State Statistical Committee of the Republic of Azerbaijan. (2024c). Trade in Azerbaijan - Statistical Yearbook. Official Publication. Baku, "Azmega Croup" Publishing House, 182 p. https://stat.gov.az/menu/6/statistical_yearbooks/

State Statistical Committee of the Republic of Azerbaijan. (2025, June 11). The foreign trade of Azerbaijan. [online]. https://stat.gov.az/source/trade/?lang=en

UN Global Survey. (2025). UN Global Survey on Digital and Sustainable Trade Facilitation. Trade Facilitation and Paperless Trade in Azerbaijan. https://www.untfsurvey.org/economy?id=AZE

UNESCO. (2022). Creative Azerbaijan: export opportunities for creative products through the azexport.az portal. https://www.unesco.org/creativity/en/policy-monitoring-platform/creative-azerbaijan-export-opportunities-creative-products-through-azexportaz-portal

XIV TRADITIONAL SCIENTIFIC CONFERENCE
NEW 2026 ECONOMY
New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

HUNTING TOURISM POLICIES AND THE ROLE OF DIGITALIZATION: A COMPARATIVE PERSPECTIVE ON ROMANIA AND HUNGARY

Tatar Beata[1*], Pal (Tordai) Noemi[1], Moga Alexis- Monica[1], Oltean Flavia Dana[2]

Received 27.02.2026. | Send to review 16.03.2026. | Accepted 06.08.2026.

Original Article

CC BY NC ND

[1] George Emil Palade University of Medicine, Pharmacy, Science and Technology of Târgu Mureş, Târgu Mureş,Romania

[2] George Emil Palade University of Medicine, Pharmacy, Science and Technology of Târgu Mureş, Târgu Mureş, Romania,

***Corresponding Author:**
Tatar Beata

Email:
tatar.beata.24@stud.umfst.ro

JEL Classification:
L83, Q57, Q28, F63, O33

Doi: 10.61432/CPNE0401313b

UDK: 339.5:[331.548:005.591.5

ABSTRACT

Hunting tourism represents a specialised form of active tourism in which hunting constitutes the primary travel motivation, generating both economic value and symbolic significance for destinations. In Romania, the hunter-tourist experience is shaped by a combination of complementary services, including organisation, guiding, accommodation, logistics, and trophy evaluation. The integration and quality of these components influence not only visitor satisfaction but also destination image and competitive positioning.This study examines the role of tourism policies in the development of hunting tourism and investigates how digitalisation contributes to destination promotion, stakeholder communication, and market visibility within this niche segment. Particular attention is given to pricing as a strategic instrument of market positioning, with emphasis on the concept of total price, which incorporates not only financial costs but also time, effort, and perceived risks associated with the experience.The research adopts a comparative approach between Romania and Hungary, combining an analysis of legislative frameworks, institutional documents, and tourism practices with empirical research conducted among hunting and sport fishing associations in Transylvania. The empirical analysis is based on an adapted SERVQUAL questionnaire administered to 135 respondents from the counties of Mureş, Alba, Bistriţa-Năsăud, and Sibiu.The results indicate an overall negative SERVQUAL gap (-0.66), revealing a discrepancy between stakeholder expectations and perceived service performance. The findings suggest that Romania's competitiveness in hunting tourism is constrained not by the availability of natural resources, but by limitations in service quality, perceived value creation, digital communication, and destination branding. Compared with Hungary, Romania continues to rely predominantly on resource-based advantages, while opportunities related to digital transformation and integrated service development remain insufficiently exploited.The study concludes that strengthening the competitiveness of hunting tourism destinations requires coherent tourism policies, improved service delivery, enhanced digital engagement, and strategic approaches to value creation.

Keywords: *hunting tourism, tourism policy, digitalisation, pricing strategies, comparative analysis, Romania and Hungary, perceived value, destination competitiveness*

1. INTRODUCTION

Hunting tourism occupies a distinctive position within the tourism industry because it cannot be easily assigned to a single category. It exists at the intersection of nature con-

servation, the economic utilisation of natural resources, and the ways in which individuals construct meaningful experiences in relation to the environment. Unlike conventional forms of tourism, where consumption is often passive and primarily service-oriented, hunting tourism involves a direct and active dimension centred around the hunting experience itself. Beyond the practical aspects related to organisation, comfort, and logistics, the experience carries a strong symbolic dimension, with the trophy representing not merely an outcome but an important element of the personal narrative created through the journey (Lovelock, 2020; Komppula& Gartner, 2013).In the academic literature, hunting tourism is generally defined as a form of tourism in which visitors, most commonly international hunters, pay to participate in organised hunting activities. However, the value of the experience extends beyond the outcome. The process itself plays a crucial role, including anticipation, uncertainty, patience, and the opportunity to encounter a rare or valuable specimen. These elements differentiate hunting tourism from other forms of nature-based tourism, where the primary focus is typically placed on observation, recreation, or relaxation (Naidoo et al., 2016).From an economic perspective, hunting tourism generates effects that extend beyond direct revenues from services, permits, or taxation. In many rural regions, it contributes to maintaining local economic structures and supporting employment opportunities, although this contribution is not always sufficiently recognised. This perspective is reflected in the frequently discussed principle that natural resources are more likely to be preserved when they generate economic value, often summarised through the logic that resources are protected when they provide benefits to local communities (Lovelock, 2020). Nevertheless, the relationship between economic value and conservation is not automatic. Without appropriate governance mechanisms, hunting tourism may generate challenges such as resource overexploitation or unequal distribution of economic benefits. Furthermore, changing social attitudes towards hunting and increasing international scrutiny continue to influence both regulatory frameworks and the public image of this form of tourism (UNWTO, 2023). In Romania, hunting tourism operates within a relatively established legislative framework, primarily regulated by Law no. 407/2006. At the operational level, the sector involves multiple stakeholders, including Romsilva, private hunting area managers, and AJVPS-type associations, each contributing to wildlife management, financial administration, and the organisation of hunting experiences.At the local level, AJVPS associations represent some of the most important actors in the functioning of the hunting tourism sector. Their role extends beyond wildlife management, as they maintain direct relationships with hunters, organise hunting experiences, and significantly influence perceptions of service quality. Consequently, their perspective provides valuable insight into the practical functioning of the sector. Despite the availability of significant natural resources, including assets with European-level potential, hunting tourism has not yet been fully developed in Romania as a coherent strategic tourism product. Current approaches remain focused primarily on regulation rather than integrated tourism development, while fragmented institutional responsibilities contribute to limited coordination and weaker strategic management(European Commission, 2022).

2. LITERATURE REVIEW

The literature on hunting tourism emphasises the central role of competitiveness, perceived value, pricing strategies, and digitalisation in shaping tourism experiences and influencing destination performance. These concepts provide the theoretical foundation for the present study. A comparison with Hungary reveals important differences in the organisation, positioning, and promotion of hunting tourism. In Hungary, hunting tourism is developed and communicated as a premium tourism product, with stronger integration

into destination marketing strategies and clearer market positioning. The competitive advantage does not necessarily arise from superior natural resources alone, but from the ability to organise, package, and communicate these resources as a coherent and valuable experience. As highlighted by Crouch (2011), destination competitiveness depends not only on resource availability but also on the capacity to transform those resources into differentiated tourism experiences. Similarly, Ritchie and Crouch (2003) conceptualise destination competitiveness as a multidimensional phenomenon involving service quality, infrastructure, destination management, policy support, and broader environmental conditions. Dwyer and Kim (2003) further emphasise that competitiveness emerges from the interaction between inherited resources, created resources, destination management capabilities, and supporting factors. Within this framework, price cannot be interpreted merely as a reflection of production costs. In hunting tourism, pricing incorporates multiple dimensions, including trophy characteristics, organisational quality, destination reputation, service reliability, and exclusivity. Consequently, price functions as an indicator of perceived value, influencing both consumer decision-making and the market positioning of the tourism offer.

At the same time, digitalisation has become an increasingly important component of tourism competitiveness (Rustemova et al., 2026; Seisenbekov et al., 2026). Online visibility, accessibility of information, communication speed, and the presentation of tourism products increasingly influence consumer perceptions and purchasing decisions (Aumeboonsuke & Caplanova, 2026). Therefore, digitalisation should not be viewed solely as a promotional instrument, but rather as an integral element of destination competitiveness (Hunady et al., 2026). Previous research demonstrates that information and communication technologies enhance destination visibility, customer engagement, and service accessibility, thereby strengthening market positioning (Law et al., 2014). More recent studies further show that digital platforms facilitate real-time interaction and value co-creation between tourism providers and visitors, contributing to more competitive and adaptive tourism systems (Buhalis&Sinarta, 2019).

Building on these theoretical considerations, this study examines the functioning and competitiveness of hunting tourism in Romania. The research combines an analysis of the legislative framework and relevant literature with empirical investigation among AJVPS associations, using a questionnaire adapted to the specific characteristics of hunting tourism services. The empirical approach aims to identify differences between stakeholder expectations and perceived service performance. A central analytical concept is the identification of a "perceived value gap", understood as the difference between the potential offered by available resources and the extent to which these resources are effectively developed, communicated, and recognised by the market. This perspective provides a deeper understanding of sector competitiveness and highlights possible directions for improving positioning and value creation. The analysis further adopts the perspective that price represents more than a monetary exchange value. In hunting tourism, particularly within premium segments, price reflects a broader combination of factors, including time investment, physical effort, comfort level, perceived uncertainty, and opportunity costs. Beyond its economic dimension, price also carries symbolic meaning, being associated with exclusivity, status, and uniqueness, approaching the logic of Veblen-type goods. This interpretation is particularly relevant in hunting tourism because perceived value is not determined solely by the outcome, such as obtaining a trophy, but by the entire experience surrounding it. This includes access to the resource, quality of organisation, professional guidance, accommodation, logistical support, and the symbolic significance attached to the trophy itself. Therefore, price may be conceptualised as a "total price", incorporating both monetary and non-monetary components of the tourism experience.

Within this perspective, the total price includes factors such as financial expenditure, time commitment, physical effort, comfort conditions, perceived risk, and opportunity cost. In hunting tourism, these elements become especially significant due to the uncertainty inherent in the activity. Variables such as animal behaviour, environmental conditions, seasonality, and the unpredictability of the hunting process directly influence the experience and, consequently, the value perceived by visitors. To better understand this multidimensional structure, the following table summarises the main components of the "total price" concept in hunting tourism, highlighting both its economic dimensions and the related managerial implications.

Table 1. Components of the "total price" in hunting tourism

Component	Example	Managerial involvement
Monetary	Shooting fee, trophy fee, accommodation, meal, guide	Pricing clarity, packages, upsell
Time	duration of travel, duration of stay, seasonal windows	scheduling, reducing "downtime"
Effort / comfort	terrain conditions, hunting pace, accommodation standard	segmentation; service levels
Perceived risk	probability of success, weather conditions, safety	information policies, rules, insurance
Opportunity cost	Holidays, Alternatives (Other Destinations)	Differentiation: trophies, reputation, experience

Source: Own elaboration based on Lovelock (2020); Komppula& Gartner (2013)

Table 1 presents the total price structure and highlights the fact that, in hunting tourism, the value perceived by the customer is determined not only by monetary costs, but also by non-monetary factors, such as effort, time and risk associated with the experience. These elements become essential in the context of the uncertainty specific to hunting activities.

In this sense, the price does not only function as a cost recovery mechanism, but also as a signal of quality, exclusivity and market positioning. In the premium segments it acquires a symbolic dimension, being associated with prestige and limited access to resources, approaching the logic of Veblen-type goods, where the high price level can positively influence demand.

Price formation in hunting tourism is the result of the interaction between macroeconomic and microeconomic factors. At the macro level, elements such as the legislative framework, taxation, exchange rate evolution or restrictions imposed by environmental policies, especially in protected areas, intervene. In Romania, changes in VAT rates have, for example, had a direct impact on the price structure, influencing the competitiveness of offers on the international market.At the microeconomic level, the price is influenced by the characteristics of the hunting fund – the density and quality of the game populations – but also by factors such as the reputation of the fund, the level of infrastructure, the qualification of the personnel or the structure of the services offered. These variables do not act independently, but in a relationship of interdependence, which makes the final price the result of a complex architecture, not of a simple cost calculation.

Within this architecture, the cost structure plays a key role. Fixed costs, associated with habitat, staff and infrastructure management, remain relatively constant, while variable costs depend on the intensity of tourism activity and include elements such as field transport, trophy processing or hospitality services. This differentiation directly influences pricing strategies and the need for rigorous bid planning. Another distinctive element is the standardization of trophy valuation through the methodology of the International Council for Hunting and Wildlife Conservation, which allows for international compara-

bility and provides an objective basis for price differentiation. In this context, rates reflect not only physical dimensions, but also a symbolic value associated with rarity and prestige, strengthening the link between price and value perception.

In practice, the hunting tourism market uses several pricing strategies, the most common of which are market-oriented (benchmark-based), value-oriented and package-based pricing models. Among these, the packageization of offers is emerging as a dominant trend, as it allows the integration of various services into a coherent offer, easier to communicate and manage from an economic point of view. Beyond the conceptual structure of the price, the way in which the offer is built in practice becomes essential for understanding the perceived value. In hunting tourism, servicesare not consumed separately, but integrated into a package, which makes the final experience depend on the coherence and transparency of this structure.

In practice, hunting tourism services are typically bundled into integrated packages combining accommodation, guiding, and hunting activities. The structure of these packages reflects the need to combine traditional tourism services, such as accommodation and food, with elements specific to hunting activities. The clear separation between the included and optional components helps to increase transparency and reduce uncertainty for the customer, especially in the case of international tourists, for whom access to information is a decisive factor.

At the same time, the offer is not uniform but adapted to different market segments. In this regard, the literature highlights the existence of some types of packages, which vary depending on the level of services and the profile of the customer.

Packages generally vary from standard to premium, depending on the level of service and exclusivity offered.This classification shows that the hunting tourism market is segmented, and premium packages play an essential role in building perceived value. They are associated with personalized services and access to scarce resources, contributing to positioning on the high-end segment. At the same time, the existence of entry-level and standard packages allows attracting a wider audience and maintaining a constant volume of demand.

In practice, these package structures are reflected in different market segments, from standard offers to high-end premium experiences, where value is determined by the overall service integration rather than by the trophy alone.

At the same time, they reflect the fact that value is not only determined by the trophy, but by the entire overall experience offered.To better understand Romania's positioning in a regional context, a comparative analysis of the main game categories and the associated price levels in relation to Hungary is useful.

Table 2. Comparative pricing structure in hunting tourism (Romania vs Hungary)

Species	Romania (€)	Hungary (€)	Observation
deer	2800–3800	4000–6000	HU premium positioning
Wild boar	250–600	400–800	More structured offers in HU
Small game	300–500/day	500–800/day	Standardized packages in HU

Source: Own elaboration based on Romsilva's practices and specialized literature based on the European Commission (2022); comparative data from the regional market

The comparative analysis reveals substantial differences between the two countries. Although Romania benefits from a favourable value-to-price relationship and significant natural resources, Hungary demonstrates a stronger positioning within the premium segment, supported by a more established destination image and a higher degree of service standardisation. These differences cannot be explained solely by variations in resource

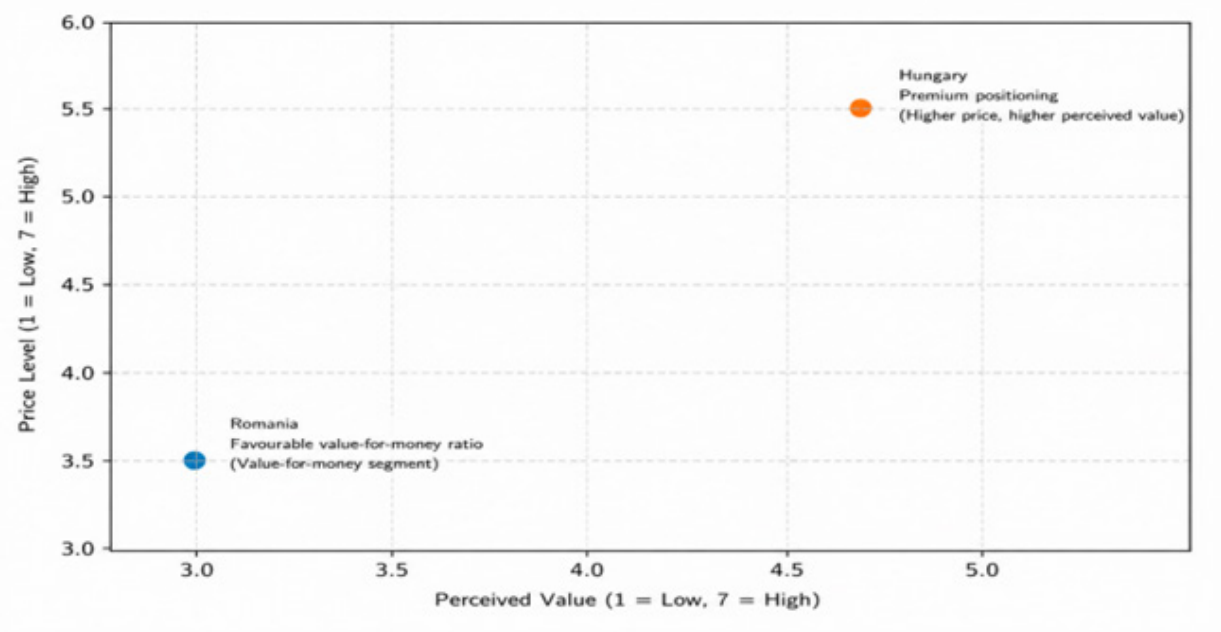
availability; rather, they reflect how effectively these resources are incorporated into public policies, tourism strategies, and market-oriented development approaches.

The professionalisation of tourism offers and the coherence of promotional systems represent key factors in shaping competitiveness. From a managerial perspective, effective product packaging reduces information asymmetry between providers and customers by making the value proposition clearer and facilitating consumer decision-making. At the same time, both pricing structure and price level contribute directly to destination image formation and influence perceptions of service quality.

This relationship can be conceptualised through a value-creation framework in which price influences perceived value, perceived value shapes customer satisfaction, and satisfaction contributes to destination image development and long-term loyalty. In this context, price extends beyond its traditional economic function and becomes a strategic positioning instrument within the hunting tourism market.

To further synthesise the relationship between pricing and perceived value, a conceptual model of comparative positioning can be developed, illustrating how different destinations are interpreted by consumers according to the interaction between resource quality, service organisation, pricing strategy, and perceived experience value.

Figure 1. Conceptual model of comparative positioning of destinations



Source: Authors' own elaboration based on Romsilva public tariff data and Hungarian Tourism Agency (2022)

Figure 1 illustrates the relative positioning of Romania and Hungary within the Central European hunting tourism market based on two synthetic dimensions: price level and perceived experience value.

Within this framework, Hungary occupies a clear premium-market position, characterised by higher prices and higher perceived value, supported by a more coherent development strategy, stronger market communication, and a more established destination image. Romania, by contrast, occupies an intermediate position, offering a favourable value-to-price ratio but not yet fully converting its resource advantages into a premium tourism proposition.

This distinction becomes even more apparent when considering the broader institutional context, including public policies, sector governance, and the organisation of tourism ser-

vices. The competitive difference between the two destinations is therefore not primarily a consequence of resource availability, but rather of how effectively these resources are managed, packaged, promoted, and transformed into a differentiated tourism experience.

Table 3: Public policies in hunting tourism – Hungary–Romania Comparative Table

Analyzed size	Hungary	Romania
Status in tourism policies	Strategic tourism product	Secondary activity, regulated
Institutional coordination	Centralized	Fragmented
International promotion	State-backed	Limited, decentralized
Taxation	Stable, favorable	High
Integration with rural development	High	Partial

Source:Own elaboration based on the legislative framework and institutional documents European Commission, 2022; Romania, 2006,Hungarian Hunting Chamber. (2025), Hungarian Tourism Agency (2022)

Table 3 demonstrates that the observed differences between Romania and Hungary cannot be attributed solely to variations in natural resource availability, but rather to the way these resources are incorporated into broader tourism development strategies. Hungary approaches hunting tourism as a strategic tourism product, supported by stronger institutional coordination, systematic promotion, and clearer market positioning. Romania, in contrast, continues to manage the sector primarily through a regulatory framework, resulting in a more fragmented organisational structure and limited strategic integration within tourism policy.

This difference in approach is also reflected in the economic value generated by the sector. The comparison suggests that Romania's competitive advantage remains largely based on resource availability and cost attractiveness, whereas Hungary has developed a more value-oriented model based on service standardisation, destination image, and the ability to deliver a more differentiated premium experience.

Table 3.1. Economic impact of hunting tourism – comparative implications

Indicator	Hungary	Romania
Revenue predictability	High	Medium–low
Integration into the tourism economy	High	Limited
Local multiplier effect	Clearly outlined	Uneven
Attractiveness for foreign tourists	High	Selective

Source: Own elaborationbased on statistical data on tourism and economic impact (Institutul-Național de Statistică, 2024; Eurostat, 2023)

Table 3.1 presents a comparative overview of the economic integration of hunting tourism in Romania and Hungary. Hungary demonstrates a higher degree of integration within the tourism economy, generating more predictable economic effects and a stronger contribution to local development. In Romania, although similar economic effects are present, they appear less consistent, suggesting that the existing potential of the sector remains only partially capitalised.

Overall, these differences help explain why Hungary has been more successful in attracting premium market segments and developing a stronger international destination image, while Romania continues to compete primarily through its favourable value-to-price ratio. Consequently, the main challenge for Romanian hunting tourism does not concern the availability of natural resources, but rather the capacity to transform these resources into a coherent, reliable, and internationally competitive tourism experience.

Within this context, the present study examines the factors influencing the competitiveness of hunting tourism in Romania and compares them with the Hungarian experience. Particular attention is given to the role of service quality, perceived value, pricing strategies, and digitalisation as determinants of destination performance. The research combines documentary analysis with empirical investigation among hunting and sport fishing associations in Transylvania to identify the main challenges and opportunities for sector development.

The following sections examine the principal theoretical perspectives related to hunting tourism competitiveness, pricing mechanisms, perceived value creation, and digitalisation, providing the conceptual foundation for the proposed analytical framework.

3. CONCEPTUAL FRAMEWORK AND RESEARCH PROPOSITIONS

Based on the literature reviewed, the competitiveness of hunting tourism can be understood as the outcome of the interaction between several interconnected dimensions, including service quality, perceived value, pricing structures, and digitalisation. Given the exploratory character of this study, a conceptual framework is developed to illustrate the expected relationships among these factors and to provide guidance for the empirical analysis.

The proposed framework does not aim to statistically test causal relationships. Instead, it serves as an analytical foundation for developing research propositions that are examined through the empirical findings. The framework assumes that the competitiveness of hunting tourism destinations emerges through the cumulative effect of service performance, value perception, strategic positioning, and the capacity to transform available resources into a coherent tourism experience.

The following research propositions are formulated:

P_1: The perceived quality of hunting tourism services positively influences the perceived value of the overall hunting experience.

P_2: Negative discrepancies between visitor expectations and perceived service performance (SERVQUAL gaps) negatively influence the perceived competitiveness of hunting tourism services.

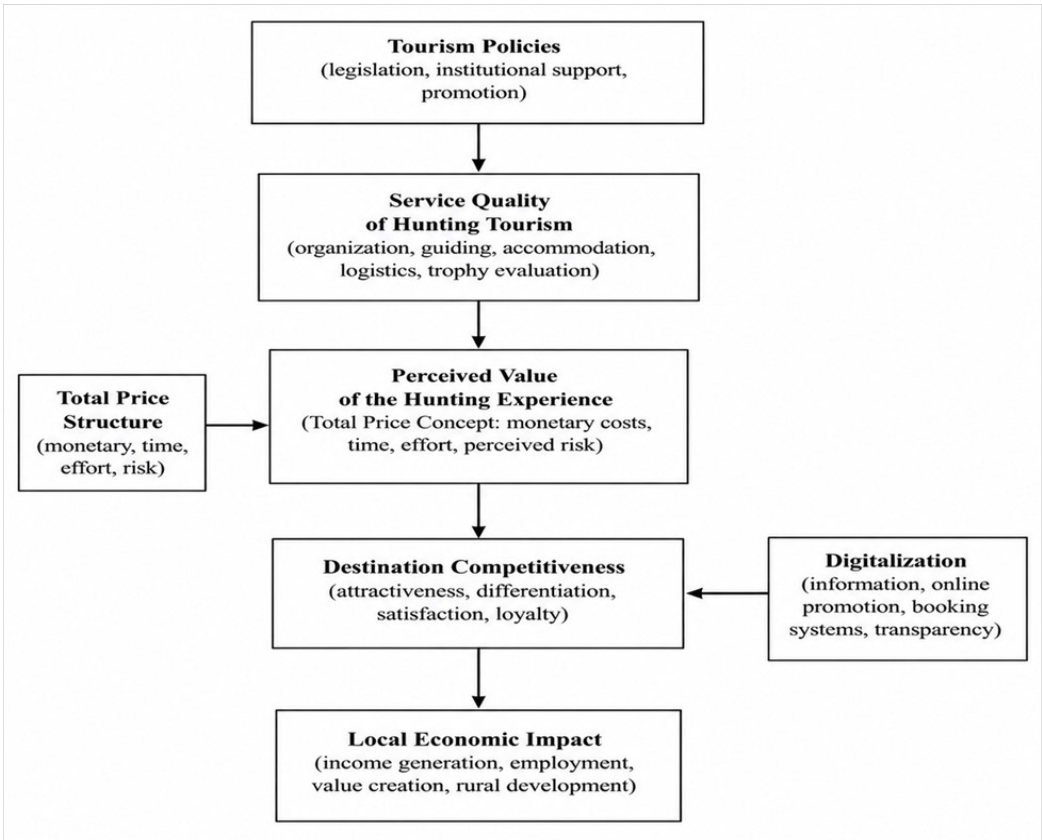
P_3: The perceived structure of total price influences the perceived value of hunting tourism experiences.

P_4: The level of digitalisation positively influences the perceived competitiveness of hunting tourism destinations.

P_5: Perceived value positively influences the competitiveness of hunting tourism destinations.

P_6: The perceived competitiveness of hunting tourism contributes positively to local economic impact.

Figure 2. Conceptual framework of hunting tourism competitiveness and economic impact



Source: Own elaboration

The conceptual framework illustrates the relationships identified in the literature between service quality, perceived value, pricing structures, digitalization, and competitiveness in tourism. In the context of hunting tourism, these dimensions are closely interconnected and shape both the tourism experience and the broader economic contribution of the sector. The framework serves as an analytical guide for interpreting the empirical findings and understanding the factors that may influence competitiveness within hunting tourism destinations.

4. METHODS

This research assumes that hunting tourism cannot be fully explained through regulatory frameworks or economic mechanisms alone. Beyond its formal and operational dimensions, hunting tourism includes experiential and perceptual components that significantly influence how this form of tourism functions in practice. Therefore, a mixed methodological approach was adopted, combining theoretical analysis with empirical investigation based on the perspectives of stakeholders directly involved in the sector.

The literature conceptualises trophy hunting as a niche tourism market in which the product is not standardised but rather represents a complex and highly personalised experience. Elements such as rarity, exclusivity, restricted access, and symbolic value make hunting tourism difficult to explain through traditional economic approaches alone. Consequently, a flexible methodological design was considered appropriate, integrating conceptual analysis with empirical research adapted to the specific characteristics of hunting tourism.

The first stage of the research involved a documentary analysis of relevant academic literature, institutional documents, and regulatory frameworks. International studies were examined to understand the economic dimensions of hunting tourism, particularly the

relationship between perceived value, pricing mechanisms, and demand formation. In parallel, Romania's legislative and institutional framework was analysed to clarify how hunting activities are regulated, organised, and managed. Within this perspective, hunting tourism was approached as a specific economic system in which price reflects not only direct costs but also intangible dimensions such as prestige, reputation, exclusivity, and symbolic value. At the same time, the analysis considered that supply is influenced not only by economic factors but also by biological constraints and legislative requirements.

To complement the documentary analysis, empirical research was conducted among hunting and sport fishing associations located in Transylvania, covering the counties of Mureş, Alba, Bistriţa-Năsăud, and Sibiu. The selection of these counties aimed to capture diverse local contexts rather than focusing on a single geographical area. The empirical sample consisted of 135 respondents, approximately 25% of whom were active hunters, while the remaining participants were involved in administrative, operational, or managerial activities. This composition enabled the study to incorporate both the practical dimension of hunting tourism and the organisational perspective of those responsible for managing and delivering these services.

A purposive sampling strategy was employed to ensure the inclusion of respondents directly involved in hunting tourism management and organisation. Given the exploratory nature of the research, the objective was not to achieve statistical representativeness at the national level, but rather to identify perceived service quality gaps, sectoral challenges, and development opportunities.

The empirical instrument was based on the SERVQUAL model and adapted to the specific characteristics of hunting tourism. Rather than applying the original model unchanged, the measurement dimensions were adjusted to reflect the particularities of the sector. The central SERVQUAL principle, comparing expectations and perceptions, was maintained, while indicators were reformulated to capture aspects such as service organisation, direct interaction, personalisation, and overall experience management.

In addition to service quality dimensions, the questionnaire included items addressing price perception, tariff transparency, and the competitiveness of Romanian hunting tourism services. A digitalisation component was also incorporated due to the growing importance of online visibility, communication channels, and access to information in attracting potential customers, particularly international visitors.

The questionnaire contained a total of 45 items covering five analytical dimensions: service quality, pricing, digitalisation, competitiveness, and economic impact. The reliability of the SERVQUAL-based measurement scale was assessed using Cronbach's alpha. The obtained value ($\alpha = 0.82$) indicates satisfactory internal consistency, confirming the suitability of the instrument for analysing service quality perceptions in the context of hunting tourism. In social science research, values above 0.70 are generally considered acceptable indicators of measurement reliability.

The empirical analysis was conducted by calculating average scores for each dimension and comparing expectations with perceptions through gap analysis. This approach allowed the identification of areas where delivered services fail to meet stakeholder expectations and provided insights into the main factors affecting sector competitiveness. The interpretation of results was conducted in relation to the conceptual framework, focusing on the relationship between service performance, perceived value, and destination positioning.

The methodology is exploratory and interpretative in nature. The objective is not statistical generalisation but rather the identification of relevant patterns and a deeper understanding of the mechanisms influencing hunting tourism competitiveness. This approach is particularly suitable given the importance of intangible factors such as experience qual-

ity, exclusivity, symbolic meaning, and perceived value within this tourism segment.

The main limitation of the research concerns the sample size and sampling approach. However, the inclusion of respondents from several counties contributes to a broader understanding of the sector and reduces the likelihood that findings reflect only one local context. The results therefore provide relevant insights into the current dynamics of Romanian hunting tourism and establish a foundation for future national-level or comparative research.

The research design was developed to examine the relationships proposed in the conceptual framework, particularly the links between service quality, perceived value, digitalisation, competitiveness, and economic impact. The analysis focuses on identifying expectation–perception gaps and understanding their implications for market positioning and value creation.

It should also be emphasised that the study reflects primarily a supply-side perspective, as respondents were directly involved in the management and operation of hunting activities. Consequently, the findings should not be interpreted as direct measurements of tourist satisfaction. Future research should complement this perspective by incorporating the experiences and evaluations of domestic and international hunting tourists.

5. RESULTS

The results of the research reveal a clear gap between the objective potential of hunting tourism in Romania and the way this potential is translated into perceived service quality. Respondents generally evaluate the country's hunting resources positively, highlighting the value of hunting areas, resource diversity, and the overall attractiveness of the destination. However, perceptions become considerably more critical when the assessment shifts from resource availability to the organisation of the tourism experience and the quality of supporting services.

This distinction suggests that Romania's competitive advantage is primarily rooted in its natural resource base, while the transformation of these resources into a complete and internationally competitive tourism product remains insufficiently developed. Although the country possesses significant potential, the available resources are not yet consistently converted into a coherent experience capable of supporting stronger market positioning.

The empirical data were collected through a questionnaire distributed both online via digital platforms and directly during local sector-related activities. The sample consisted of 135 respondents from four county hunting and sport fishing associations (AJVPS) located in Transylvania: Mureș, Alba, Bistrița-Năsăud, and Sibiu. The composition of the sample includes both active hunters and individuals involved in the administrative, organisational, and operational management of hunting activities, providing a broader perspective on how the sector is experienced and managed.

At the organisational level, these associations are responsible for managing hunting areas organised into multiple hunting units with significant territorial coverage. For example, Mureș County manages 11 hunting areas, while Alba County includes more than 20 such areas, illustrating the operational scale and organisational complexity of the sector. Although comprehensive public information is not available for all counties included in the research, the institutional structure of the associations follows a comparable administrative model.

Within this context, hunting tourism should not be understood merely as a recreational activity, but as a specialised economic sector in which the tourism product extends beyond the trophy itself. The overall experience includes multiple interconnected elements, such as organisation, infrastructure, professional guidance, accommodation, auxiliary services, and the symbolic value associated with the activity. To evaluate this multidimensional service experience, the SERVQUAL model was applied, allowing direct comparison between stakeholder expectations and their perceptions of actual service performance.

Table 4. SERVQUAL Assessment of Hunting Tourism in Romania

Size	Expectations (E)	Perceptions (P)	**Gap (P–E)**
Tangibility	4.2	3.4	-0.8
Reliability	4.3	3.6	-0.7
Responsiveness	4.1	3.6	-0.5
Professionalism	4.2	3.7	-0.5
Empathy	4.3	3.5	-0.8
Average score	4.22	3.56	-0.66

Source: Own elaboration based on empirical research

Table 4 presents the SERVQUAL results and reveals an overall negative average gap of -0.66, indicating that the perceived performance of hunting tourism services remains below stakeholder expectations. The largest discrepancies are observed in the dimensions of tangibility and empathy, suggesting that the main weaknesses are associated with physical infrastructure, accommodation conditions, and the capacity to provide personalised experiences. In other words, the central challenge does not concern the availability of hunting resources, but rather the way these resources are transformed and delivered as a complete tourism experience.

The negative SERVQUAL gap confirms the existence of a perceived value gap between expected and experienced service performance. Despite Romania's significant hunting potential, the inability to consistently meet stakeholder expectations may contribute to a weaker perception of competitiveness at the destination level. This finding supports the argument that natural resources alone are insufficient to ensure market competitiveness unless they are supported by adequate service systems and experience-oriented management.

Beyond the SERVQUAL dimensions, respondents provide a more practical assessment of the main challenges affecting the sector. Infrastructure is identified as the most important weakness, mentioned by approximately 35% of respondents, followed by organisational issues (25%), promotion deficiencies, and the overall level of services provided. Accommodation facilities and complementary services receive generally moderate evaluations, indicating the existence of a functional foundation, but one that remains insufficiently developed to support a premium tourism segment.

Within this context, digitalisation emerges as an increasingly important determinant of competitiveness. Respondents perceive the current level of digital development as fragmented, limiting both market visibility and access to information, particularly for international clients. The absence of well-structured digital platforms, transparent online offers, and coherent communication strategies reduces the ability of Romanian hunting tourism providers to effectively promote existing resources. Therefore, the challenge is not only related to service delivery but also to the way the tourism product is communicated and positioned in the market.

The development of modern digital platforms at the level of AJVPS associations represents an important strategic opportunity. Updated multilingual websites with clearly structured information could improve transparency, accessibility, and consumer confidence. At the same time, social media platforms could contribute to destination promotion through visual storytelling, which plays an increasingly important role in shaping tourism decisions.

Furthermore, the integration of online booking systems and direct communication channels could reduce dependence on intermediaries, improve operational efficiency, and simplify access to hunting tourism offers. The collection and analysis of user behaviour data would also enable providers to adapt services more effectively and develop more targeted marketing strategies.

Consequently, digitalisation should not be understood merely as a promotional instrument, but as an integral component of perceived value creation. The way information is presented, accessed, and communicated directly influences how potential customers evaluate the attractiveness and credibility of the destination.

Regarding pricing, respondents generally perceive Romanian hunting tourism offers as competitive. However, the results indicate that price levels are not always aligned with the quality and range of services provided. This imbalance negatively affects perceived value, as customers may perceive a mismatch between the financial cost and the overall experience delivered. In addition, access to hunting areas is considered moderate or difficult by respondents, suggesting the presence of operational barriers that may reduce destination attractiveness.

The findings also reveal strong support for integrated tourism packages. A large proportion of respondents express a preference for complete offers combining hunting activities with accommodation, meals, and complementary services. Such packages are perceived as increasing convenience, reducing uncertainty, and improving overall value, particularly for international visitors. Therefore, the development of structured, transparent, and professionally managed packages represents an important opportunity for strengthening the competitiveness of Romanian hunting tourism.

Overall, the results indicate that Romania's main challenge is not the lack of valuable hunting resources, but the insufficient transformation of these resources into a coherent, accessible, and high-value tourism experience. Improvements in service quality, digital integration, pricing transparency, and package development are essential steps towards stronger international positioning.

Table 5. Perception of competitiveness of Romanian hunting tourism

Reply	Estimated weight
Competitive	15%
Partially competitive	25%
Weaker	60%

Source: Own elaboration based on the questionnaire

The results presented in Table 5 reveal a generally critical assessment of the competitiveness of hunting tourism in Romania. A substantial proportion of respondents perceive the current tourism offer as less competitive compared with international alternatives, particularly due to weaknesses related to infrastructure, limited-servicestandardization and insufficient promotional activity.

Further insights emerge from respondents' previous international hunting tourism experiences. A significant share of participants reported having engaged in hunting tourism abroad, with Hungary being one of the most frequently mentioned destinations. Most of these respondents evaluated foreign experiences more favourably, emphasising superior organisation, greater transparency of offers, and a higher degree of service integration. These comparative perceptions reinforce the argument that Romania's competitiveness gap is not primarily determined by the availability or quality of natural resources, but by differences in how tourism services are organised, packaged, communicated, and delivered.

The findings therefore suggest that improving the competitiveness of Romanian hunting tourism requires a transition from a resource-based model towards a more experience-oriented approach, where service quality, destination management, and value creation become central elements of market positioning.

Table 5.1. International hunting tourism experience and satisfaction

Indicator	Percentage (%)
Respondents with experience broad	58%
Satisfied with services abroad	72%
Perceive services abroad as better	65%
Would prefer full packages abroad	70%

Source: Own elaboration based on questionnaire data

The findings presented in Table 5.1 indicate, most respondents with international experience perceive services abroad as better organized and more integrated. The preference for full-service packages is also higher in this context, suggesting that structured offers play a key role in shaping perceived value and competitiveness.

At the same time, an interesting aspect emerges although services are valued more reservedly, prices are perceived as relatively attractive. This combination suggests a positioning based mainly on value for money, and less on premium quality or differentiated experience. Overall, the findings suggest that Romania's current competitive position is influenced more strongly by its favourable value-for-money ratio than by a premium service image or a highly differentiated tourism experience.

The data suggest that hunting tourism contributes to increasing employment in accommodation units, stimulating consumption in restaurants and developing related services, such as transport or ancillary activities. In addition, there is also an important social component, linked to the creation of jobs, especially seasonal ones, and the generation of indirect income for local communities.

Interpretation of Research Propositions

P_1: Service Quality → Perceived Value

The SERVQUAL analysis reveals a consistent negative gap between stakeholder expectations and perceived service performance, with an average gap of **-0.66**. This indicates that the quality of services currently provided does not fully correspond to expected standards, particularly in areas related to infrastructure, organisation, and the personalisation of the hunting experience. Since perceived value is strongly influenced by the quality of the overall experience, these service deficiencies directly affect how stakeholders evaluate the attractiveness and value of hunting tourism offers.

Interpretation: The findings support **Proposition 1**, indicating that service quality represents an important determinant of perceived value in the hunting tourism experience.

P_2: SERVQUAL Gap → Competitiveness

The identified service quality gaps appear to negatively influence perceptions of destination competitiveness. This relationship is reflected in respondents' evaluations, with approximately **60%** considering Romanian hunting tourism less competitive compared with alternative destinations. The results suggest that weaknesses in infrastructure, service organisation, and experience management reduce the ability of Romanian destinations to compete effectively, despite the availability of valuable hunting resources.

Interpretation: The findings support **Proposition 2**, suggesting that negative SERVQUAL gaps contribute to lower perceived competitiveness within the hunting tourism sector.

P_3: Total Price → Perceived Value

The analysis confirms that price in hunting tourism is perceived as a multidimensional

concept rather than merely a financial cost. Respondents associate value with a combination of monetary expenditure, time investment, effort, comfort, uncertainty, and perceived risk. Although Romanian hunting tourism is generally considered competitively priced, the results indicate that a mismatch between price levels and service quality may reduce the overall value perceived by customers.

Interpretation: The findings support **Proposition 3**, demonstrating that the perceived structure of total price influences the value attributed to the hunting tourism experience.

P_4: Digitalisation → Competitiveness

The results indicate that digitalisation within Romanian hunting tourism remains relatively limited and fragmented. Respondents identify difficulties related to information accessibility, transparency of offers, and online communication, which may restrict the ability of destinations to attract international customers. In a market where purchasing decisions increasingly depend on digital visibility and access to reliable information, limited digital development represents a competitiveness constraint.

Interpretation: The findings support **Proposition 4**, suggesting that digitalisation is perceived as an important factor influencing the competitiveness of hunting tourism destinations.

P_5: Perceived Value → Competitiveness

The findings highlight the central role of perceived value in determining competitiveness. Although Romania benefits from significant natural resources and relatively attractive pricing, these advantages are not fully converted into competitive strength because service quality, organisation, and experience design remain insufficiently developed. Consequently, the destination struggles to position itself within the premium segment of the international hunting tourism market.

Interpretation: The findings support **Proposition 5**, indicating that perceived value represents a key mechanism through which tourism resources are transformed into destination competitiveness.

P_6: Competitiveness → Economic Impact

The results indicate that hunting tourism contributes to local economic development through employment generation, local consumption, and associated service activities. However, the scale and consistency of these economic effects appear to depend on the level of organisation, market positioning, and overall competitiveness of the destination. More competitive and better-integrated tourism systems are likely to generate stronger and more predictable economic benefits.

Interpretation: The findings support **Proposition 6**, suggesting a positive relationship between hunting tourism competitiveness and local economic impact.

Overall Interpretation

Overall, the findings indicate that the main challenge facing Romanian hunting tourism is not the availability of natural resources, but the limited capacity to transform these resources into a coherent, high-value, and internationally competitive tourism product. The relationships identified between service quality, perceived value, pricing structures, digitalisation, and competitiveness demonstrate the need for a more integrated approach to destination development. Strengthening service delivery, improving digital visibility, increasing transparency, and developing experience-oriented packages represent essential steps towards enhancing Romania's position within the international hunting tourism market.

6. CONCLUSIONS

This study examined the competitiveness of hunting tourism in Romania by analysing the relationships between service quality, perceived value, pricing structures, digitalisation, and destination positioning. The findings demonstrate that Romania's main competitive challenge is not the availability of hunting resources, but rather the limited capacity to transform these resources into a coherent, high-value tourism experience. Although the country benefits from significant natural potential, weaknesses related to service integration, infrastructure, standardisation, digital communication, and experience management reduce the perceived value of the offer.The comparative analysis with Hungary highlights that competitiveness in hunting tourism depends less on resource endowment and more on the ability to organise, package, and communicate those resources effectively. Hungary's stronger market position is associated with a more integrated approach, where tourism policies, service delivery, promotion, and destination image are aligned. Romania, by contrast, continues to rely primarily on resource advantages and favourable pricing, without fully developing a premium positioning strategy.The empirical results confirm the importance of service quality as a determinant of perceived value. The negative SERVQUAL gap (–0.66) indicates that current service performance does not fully meet stakeholder expectations, particularly in areas related to infrastructure, accommodation, and personalisation of the experience. At the same time, the findings show that pricing should be understood beyond its monetary dimension. In hunting tourism, perceived value is influenced by the relationship between price, service quality, comfort, effort, uncertainty, and the overall experience delivered.Digitalisation represents another important factor affecting competitiveness. Limited online visibility, insufficient transparency of offers, and weak digital communication reduce the ability of Romanian hunting tourism providers to reach international markets. Strengthening digital platforms, improving access to information, and developing integrated booking and communication systems represent important steps towards increasing market accessibility and customer confidence. The study also highlights the broader economic relevance of hunting tourism, particularly in rural areas. Beyond direct revenues, the sector generates indirect effects through accommodation, gastronomy, transport, and other complementary services. However, these benefits depend on the level of organisation and integration of hunting tourism within the wider local economy.The main contribution of this research lies in identifying the gap between the objective potential of Romanian hunting tourism resources and the value perceived through the delivered experience. By combining the analysis of service quality with economic and strategic dimensions, the study demonstrates that competitiveness is created not only through resource availability, but through the effective management and communication of value.Several limitations should be acknowledged. The empirical analysis is based on a sample of 135 respondents from selected regions of Transylvania and reflects primarily the supply-side perspective of hunting associations and sector stakeholders. Therefore, the findings should not be interpreted as a direct measure of tourist satisfaction. Future research should extend the analysis through larger samples, international tourist perspectives, cross-country comparisons, and advanced quantitative approaches such as regression analysis or structural equation modelling.

Overall, the findings suggest that the future competitiveness of Romanian hunting tourism depends on a transition from a resource-based model towards an experience-oriented and value-driven approach. Improved service integration, stronger digitalisation, clearer market positioning, and closer cooperation between hunting organisations and tourism stakeholders represent essential conditions for transforming Romania's hunting tourism potential into a sustainable and internationally competitive tourism product.

7. APPENDIX A. QUESTIONNAIRE USED IN THE EMPIRICAL RESEARCH ON HUNTING TOURISM SERVICES

Introduction:

This questionnaire aims to assess perceptions regarding the quality, pricing, and competitiveness of hunting tourism services in Romania. The responses are anonymous and will be used exclusively for academic research purposes.

Section 1. General Information

1. What is your role?
   ☐ Active hunter ☐ Staff ☐ Manager ☐ Other: ____
2. Years of experience
   ☐<5 ☐ 5–10 ☐>10
3. Age group
   ☐<30 ☐ 30–50 ☐>50
4. Have you participated in hunting tourism abroad?
   ☐ Yes ☐ No
5. If yes, where?
   ☐ Hungary ☐ Austria ☐ Germany ☐ Other: ____
6. Were you satisfied with the services abroad?
   ☐ Very satisfied ☐ Satisfied ☐ Neutral ☐ Unsatisfied

Section 2. Service Quality

Please rate the following statements on a scale from 1 (very low) to 5 (very high).

EXPECTATIONS

7. The infrastructure should be modern and well maintained.
   1☐ 2☐ 3☐ 4☐ 5☐
8. Services should be reliable and well organized.
   1☐ 2☐ 3☐ 4☐ 5☐
9. Staff should respond promptly to requests.
   1☐ 2☐ 3☐ 4☐ 5☐
10. Personnel should demonstrate professionalism.
    1☐ 2☐ 3☐ 4☐ 5☐
11. Services should be personalized according to client needs.
    1☐ 2☐ 3☐ 4☐ 5☐
12. Accommodation quality should be high
    1☐ 2☐ 3☐ 4☐ 5☐
13. Food services should meet expectations
    1☐ 2☐ 3☐ 4☐ 5☐
14. Organization should be efficient
    1☐ 2☐ 3☐ 4☐ 5☐

PERCEPTIONS

15. The infrastructure is modern and well maintained.
    1☐ 2☐ 3☐ 4☐ 5☐
16. Services are reliable and well organized.
    1☐ 2☐ 3☐ 4☐ 5☐
17. Staff responds promptly to requests.
    1☐ 2☐ 3☐ 4☐ 5☐

18. Personnel demonstrates professionalism.
1☐ 2☐ 3☐ 4☐ 5☐
19. Services are personalized according to client needs.
1☐ 2☐ 3☐ 4☐ 5☐
20. Accommodation quality is satisfactory
1☐ 2☐ 3☐ 4☐ 5☐
21. Food services are satisfactory
1☐ 2☐ 3☐ 4☐ 5☐
22. Organization is efficient
1☐ 2☐ 3☐ 4☐ 5☐

Section 3.Pricing and Perceived Value

23. Price reflect the quality of services offered.
1☐ 2☐ 3☐ 4☐ 5☐
24. Prices include time/effort/risk
1☐ 2☐ 3☐ 4☐ 5☐
25. Hunting tourism offers good value for money
1☐ 2☐ 3☐ 4☐ 5☐
26. Pricing is transparent
1☐ 2☐ 3☐ 4☐ 5☐
27. Trophy value influences price perception
1☐ 2☐ 3☐ 4☐ 5☐

Section 4. Digitalization

28. Information is easy to access online
1☐ 2☐ 3☐ 4☐ 5☐
29. Websites are well structured
1☐ 2☐ 3☐ 4☐ 5☐
30. Online communication is effective
1☐ 2☐ 3☐ 4☐ 5☐
31. Social media improves visibility
1☐ 2☐ 3☐ 4☐ 5☐
32. Digital booking would be useful
1☐ 2☐ 3☐ 4☐ 5☐

Section 5. Competitiveness

33. Romania is competitive internationally
1☐ 2☐ 3☐ 4☐ 5☐
34. Romania is competitive vs Hungary
1☐ 2☐ 3☐ 4☐ 5☐
35. Services meet international standards
1☐ 2☐ 3☐ 4☐ 5☐
36. Romania can attract premium tourists
1☐ 2☐ 3☐ 4☐ 5☐

Section 6. Economic Impact

37. Hunting tourism creates jobs

☐ Yes ☐ No

38. It supports local businesses

☐ Yes ☐ No

39. It contributes to local development

☐ Yes ☐ No

Section 7. Hunting Experience & Packages

40. Would you choose a full package (accommodation + meals + hunting)?

☐ Yes ☐ No

41. Do full packages increase perceived value?

☐ Yes ☐ No

42. Do packages simplify decision-making?

☐ Yes ☐ No

43. What type of package do you prefer?

☐ Standard ☐ Premium ☐ Customized

Section 8. General Evaluation

44. Main weaknesses of hunting tourism in Romania

☐ Infrastructure ☐ Organization ☐ Promotion ☐ Services

45. Overall evaluation

☐ Competitive ☐ Partially competitive ☐ Weak

Thank you for your participation!

8. REFERENCES

Alba County Association of Sport Hunters and Fishermen. (2023). *Institutional data and information on hunting activity*. https://ajvpsab.ro/

AsociaţiaGenerală a VânătorilorşiPescarilorSportivi din România (AGVPS). (2025). Official website. https://www.agvps.ro/

Aumeboonsuke, V., & Caplanova, A. (2026). Determinants of the Digital Gap: A Comparative Analysis of Central Europe and Southeast Asia, 2002–2024. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 309-332. https://doi.org/10.2478/eoik-2026-0038

Bistriţa-Năsăud County Association of Sport Hunters and Fishermen. (2023). *Institutional data and information on hunting activity*. https://ajvpsbn.ro

Buhalis, D., &Sinarta, Y. (2019). *Real-time co-creation and nowness service: Lessons from tourism and hospitality. Journal of Travel & Tourism Marketing, 36(5), 563–582.* https://www.tandfonline.com/doi/full/10.1080/10548408.2019.1592059

Crouch, G. I. (2010). *Destination competitiveness: An analysis of determinant attributes. Tourism Management, 32(1), 27–45.* https://doi.org/10.1177/0047287510362776

Csányi, S., Lehoczki, R., &Sonkoly, K. (2010). *National Game Management Database of Hungary. International Journal of Information Systems and Social Change, 1(4), 34–43.* https://www.ova.info.hu/index-en.html

Dwyer, L., & Kim, C. (2003). *Destination competitiveness: Determinants and indicators. Current Issues in Tourism, 6(5), 369–414.* https://doi.org/10.1080/13683500308667962

European Commission. (2022). *EU biodiversity strategy for 2030*. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

European Commission, *Directorate-General for Taxation and Customs Union. (2020). Customs value of hunting trophies.* https://taxation-customs.ec.europa.eu/system/files/2020-09/17-09-2020-customs_value_of_hunting_trophies_en.pdf

Hunady, J., Demeova, E., & Chylakova, V. (2025). The role of digital skills and digitalisation in enhancing labour productivity in the EU. *Collection of Papers New Economy, 3*(1), 33-45. https://doi.org/10.61432/CPNE0301033h

Hungarian Hunting Chamber. (2025). Official website. https://omvk.hu

Hungarian Tourism Agency. (2022). Official tourism information and market data. https://www.untourism.int/affiliate-member-organization/10633

Hungary. (1996). *Act LV of 1996 on the protection, management and hunting of game. Ministry of Agriculture*. https://njt.jog.gov.hu/

Hungarian Game Management Database (OVA). (2025). *National Game Management Database. Hungarian University of Agriculture and Life Sciences*. https://www.ova.info.hu/index-en.html

International Council for Game and Wildlife Conservation (CIC). (2025). *Trophy evaluation system handbook*. https://cic-wildlife.org

Komppula, R., & Gartner, W. C. (2013). Hunting as a travel experience: An auto-ethnographic study of hunting tourism in Finland and the USA. Tourism Management, 35, 168–180. https://www.sciencedirect.com/science/article/abs/pii/S0261517712001276?via%3Dihub

Law no. 407/2006 on hunting and protection of the hunting fund. Romania. (2006). Official Gazette. https://legislatie.just.ro

Law, R., Buhalis, D., &Cobanoglu, C. (2014). *Progress on information and communication technologies in hospitality and tourism. International Journal of Contemporary Hospitality Management*. https://www.researchgate.net/publication/265857956_Progress_on_Information_and_Communication_Technologies_in_Hospitality_and_Tourism

Lovelock, B. (2020). Tourism and the consumption of wildlife: Hunting, shooting and sport fishing. Routledge. https://www.routledge.com/Tourism-and-the-Consumption-of-Wildlife-Hunting-Shooting-and-Sport-Fishing/Lovelock/p/book/9780415759519

Ministry of Agriculture (Hungary). (2022). *Hunting tourism is a major revenue-generating sector*. https://2015-2019.kormany.hu/en/government-spokesperson/news/hunting-tourism-is-a-major-revenue-generating-sector

Mureş County Association of Sport Hunters and Fishermen. (2023). *Institutional data and information on hunting activity*. https://ajvpsmures.ro

Naidoo, R., Fisher, B., Manica, A., &Balmford, A. (2016). *Estimating economic losses to tourism in Africa from the illegal killing of elephants.Nature Communications, 7, 13379*. https://doi.org/10.1038/ncomms13379

National Forest Administration – Romsilva. (2021). *Hunting activities and tariffs*. https://www.rosilva.ro/

National Institute of Statistics. (2024). *Tourism activity – quarterly series*. https://insse.ro

Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1988). SERVQUAL: *A multiple-item scale for measuring consumer perceptions of service quality. Journal of Retailing, 64(1), 12–40*. https://www.researchgate.net/publication/200827786_SERVQUAL_A_Multiple-item_Scale_for_Measuring_Consumer_Perceptions_of_Service_Quality

Rustemova, S., Nassanbekova, S., Tleubayeva, A., Rakhimzhanova, T., & Tukibayeva, K. (2026). Unlocking Tourist Loyalty in Heritage Destinations: Assessing the Mediating Role of Memorable Tourism Experiences in Semey, Kazakhstan. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 375-391. https://doi.org/10.2478/eoik-2026-0041

Sibiu County Association of Sport Hunters and Fishermen. (2023). *Institutional data and information on hunting activity*. https://www.apssibiu.ro/

Seisenbekov, A., Beisenova, M., Koshetayev, D., Akhmetova, Z., & Suyunbayev, S. (2026). The Impact of Digitalization and Innovation on Postal and Courier Services In the Context of Sustainable Economic Development: Evidence from Kazakhstan. *ECONOMICS - Innovative and Economic Research Journal, 14*(2), 249-268. https://doi.org/10.2478/eoik-2026-0035

Szabó, M. (2022). The beginnings of intensive wildlife management and hunting tourism along the Drava. TurisztikaiésVidékfejlesztésiTanulmányok, 7(3), 61–75. https://www.turisztikaitanulmanyok.hu/wp-content/uploads/2022/10/TVT-7evf-3szam_05.pdf

World Tourism Organization (UNWTO). (2023). *UNWTO World Tourism Barometer*. https://www.unwto.org

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

LAND CONSOLIDATION IN POLAND: CONTEMPORARY BARRIERS TO SUSTAINABLE RURAL DEVELOPMENT

Bartosz Mickiewicz[1*], Katsiaryna Volkava[1]

Received 05.03.2026. | Send to review 30.03.2026. | Accepted 07.08.2026.

Original Article

[1] The University College of Professional Education in Wroclaw, Poland

***Corresponding Author:**
Bartosz Mickiewicz

Email:
bartosz.mickiewicz@wskz.pl

JEL Classification:
Q15, Q18, R52

Doi: 10.61432/CPNE0401333m

UDK: 332.2/.6:005.591.5(475)

ABSTRACT

Land consolidation represents a critical instrument for rural development, designed to rectify fragmented land ownership and enhance agricultural productivity. This study examines the evolution and implementation of land consolidation policies in Poland across consecutive European Union programming periods: 2004–2006, 2007–2013, 2014–2020, and the current 2021–2027 framework under the Common Agricultural Policy (CAP) Strategic Plan. The analysis reveals a progressive increase in both financial allocation and project scale, with the 2021–2027 perspective allocating EUR 376.5 million—a significant rise compared to previous periods. By the first quarter of 2026, 154 projects covering 112.4 thousand hectares had been approved under the current framework, demonstrating improved implementation dynamics attributable to digitalization and streamlined administrative procedures. A key development is the strengthened environmental component, which integrates consolidation with climate adaptation, water retention, soil protection, and biodiversity conservation, thereby aligning with European Green Deal objectives. Spatial analysis confirms persistent concentration of consolidation activities in south-eastern and central Poland, where land fragmentation remains most severe. Despite progress, challenges persist, including lengthy administrative procedures (averaging 3–4 years) and the complexity of obtaining landowner consents. The findings underscore that while land consolidation in Poland has evolved into a more efficient and environmentally integrated tool, the scale of intervention remains insufficient relative to historical fragmentation levels, necessitating continued support and procedural refinement in future programming periods.

Keywords: *land consolidation, rural development, agrarian structure, Common Agricultural Policy, sustainable development, Poland*

1. INTRODUCTION

Rural development through land consolidation has been implemented in many European countries, including Germany, the Netherlands, France, Belgium, Luxembourg, Austria, Switzerland, as well as Finland, Norway, and Sweden. The underlying demand for land consolidation was similar across all these states, stemming from the need to correct unfavorable land divisions and promote appropriate land use without altering ownership status. Depending on the country, differences existed in the objectives and procedures of consolidation,

shaped by historical conditions, culture, tradition, and legal systems. The common initiative of land consolidation in various countries aimed to adapt proven solutions and functions developed in Europe regarding land amalgamation processes (Sabates-Wheeler, 2002).

Land consolidation is not regulated by a single European act but is based on the legislation of individual member states. The primary goal of consolidation is to improve production factors through land exchange to achieve a shape that meets users' needs. Beyond the function of land exchange, efforts are made to improve road networks, enable agricultural land drainage, enhance landscape architecture, protect the environment, and manage rural areas more efficiently. The consolidation procedure involves administrative decisions, which in most countries are issued by administrative bodies. Landowners within the consolidation area typically form associations that, depending on the country, hold a stronger or weaker position in the project implementation process. In countries such as France, Germany, or the Netherlands, these associations possess significant legislative powers and can participate in valuation, planning, and project execution (Pašakarnis, Malienė, 2010).

Land consolidation in all these countries constitutes one of the most important economic and agricultural instruments, comprehensively improving the organization of agricultural production areas. Its aim is to transform a layout of fragmented, excessively elongated, or checkerboard-like plots into as large and regular areas as possible. The necessity for consolidation is indicated by detailed analyses of parameters determining the need for land amalgamation, which are conducted during the development of management plans. Comprehensive land consolidation is perceived as an activity closely linked to post-consolidation development processes (Seisenbekov et al., 2026). According to the principle of equivalence, participants in consolidation or exchange receive new land of equal estimated value in return for their previously held land (Vitikainen, 2004).

Despite the extensive implementation of land consolidation across Europe, the effectiveness of these policies varies considerably across member states, and the transferability of successful models to countries with different historical trajectories remains a subject of scholarly debate. Poland presents a particularly relevant case study due to its unique historical path—characterized by post-1944 land reform that parceled out large estates and persistent resistance to agricultural collectivization—which created a distinct fragmentation pattern unlike that found in Western European countries. This study addresses a gap in the existing literature by providing a systematic longitudinal assessment of land consolidation implementation across four successive EU programming periods, examining not only quantitative progress but also procedural challenges and the integration of environmental objectives

2. SUBJECT, AIM, AND SCOPE OF THE STUDY

Consolidation works in Poland were regulated by the 1982 Act on Land Consolidation and Exchange. The aim of land consolidation was to create more favorable farming conditions in agriculture by improving the area structure of agricultural holdings, rationally shaping land layout, adjusting property boundaries to the water drainage system, constructing roads, and adapting land relief.

The primary aim of the study was to identify and compare activities across four indicated programming periods (2004–2006, 2007–2013, 2014–2020, and 2021–2027). Specifically, the study addresses three research questions: (1) What are the implementation dynamics and spatial patterns of land consolidation across successive EU programming periods? (2) How has the integration of environmental and climate objectives evolved within consolidation interventions? and (3) What are the key procedural barriers limiting the effectiveness of consolidation efforts, and how might these be addressed through policy reforms?

The authors assumed that Poland belongs to the countries characterized by the highest level

of land fragmentation due to the historical context of implemented land reforms, traditions resulting from inheritance and succession, socio-economic policies, and other factors. For this reason, agriculture bears specific economic costs that hinder competitiveness in the common European agricultural market. The nationwide research was based on Rural Development Programmes, reporting data from the Agency for Restructuring and Modernisation of Agriculture (ARMA), results from the Central Statistical Office (CSO), and other documents.

The methodological approach employed in this study is primarily descriptive-analytical, utilizing secondary analysis of official institutional data. Data sources include: (1) Rural Development Programme documents for each programming period, (2) ARMA implementation reports and ex-post evaluations, (3) CSO agricultural statistics, (4) Ministry of Agriculture and Rural Development strategic documents, and (5) implementing regulations and legal acts governing land consolidation procedures. The analysis employs quantitative indicators (number of projects, area covered, financial allocations, completion rates) supplemented by qualitative assessment of procedural frameworks and policy innovations. While this approach allows for systematic comparison across programming periods, it is subject to certain limitations, including variations in data reporting methodologies across periods and the absence of systematic micro-level data on farm-level outcomes. These limitations are addressed in the discussion section

3. LAND CONSOLIDATION IN THE SECTORAL OPERATIONAL PROGRAMME 2004–2006

The Sectoral Operational Programme "Restructuring and modernisation of the food sector and rural development" outlined the strategy and directions for agricultural and rural development. The "Land consolidation" measure was implemented in areas characterized by significant land fragmentation. Support for the consolidation procedure aimed to improve land layout in individual agricultural holdings. By reducing the number of plots per holding, improvements in management efficiency were expected through reduced transport costs and the facilitated mechanization of field cultivation. Furthermore, within the consolidation project, works related to post-consolidation development were carried out, taking into account natural environment protection requirements. Financial support under this measure aimed to improve the area structure of farms, reduce the number of plots per farm, allocate equivalent land to farmers at a short distance from the farmstead, and delineate and construct functional access roads to land, adapted to the agricultural equipment used (ARMA Regulations, 2004).

Activities related to land consolidation fell within the responsibilities of staff delegated to marshal offices. However, beneficiaries were county heads (starostowie), responsible for preparing the complex procedure of obtaining farmers' consent to commence consolidation works. Consolidation works could be initiated upon application by owners of agricultural holdings located within the planned consolidation area, whose total area exceeded half of the planned consolidation area. Consolidation procedures could also be initiated ex officio, after obtaining the opinion of the village council and socio-professional farmers' organizations active in the area.

According to the ex-post evaluation data of the Sectoral Operational Programme 2004–2006, consolidation procedures were not undertaken in four voivodeships (Kuyavian-Pomeranian, Warmian-Masurian, Malopolska, and West Pomeranian) due to a lack of interest from potential beneficiaries. A total of 45 applications were submitted by county heads, of which 32 (71.1%) were approved for implementation in twelve voivodeships. On average, 154 agricultural holdings participated in one project. Nationwide, few projects were implemented, but they were extensive in terms of the number of participating farmers. The total area covered by the consolidation process in all implemented projects was 20.4 thousand ha of agricultural land. The Programme specified that as a result of

launching land consolidation projects, the agrarian structure would improve over an area exceeding 42.0 thousand ha, and this target was achieved at 49%. Areas subject to consolidation were located in one or several villages or their parts. When relocation of land constituting parts of agricultural holdings was necessary for rational land layout, it occurred through mutual exchange (Ex-post Evaluation, 2009).

In the Sectoral Operational Programme 2004–2006, EUR 21.2 million was allocated for agricultural land consolidation, including EUR 17.0 million from EU funds and EUR 4.3 million from national support. A total of 31 projects were implemented under this measure, for which EU aid amounted to PLN 62.8 million (EUR 16.5 million), representing 77.8% of the EU funds earmarked for implementing this measure.

4. LAND CONSOLIDATION ISSUES IN THE RDP 2007–2013

Council Regulation (EC) of 2005 stated that to ensure sustainable rural development, efforts should focus on a limited number of basic objectives, mainly related to the competitiveness of the agricultural sector and diversification of activities in rural areas. Special support should be directed towards land management methods leading to appropriate land use practices consistent with the need to preserve the natural environment and landscape and to protect and improve the state of natural resources. Agricultural land consolidation was identified under the measure "Infrastructure related to the development and adaptation of agriculture and forestry" (Council Regulation (EC), 2005).

Under the RDP for 2007–2013, projects concerning consolidation works and post-consolidation development were implemented. Support was granted under the measure "Improving and developing infrastructure related to the development and adaptation of agriculture and forestry through land consolidation," aiming to improve the area structure of individual agricultural holdings. It was expected that reducing the number of plots would improve management efficiency by lowering transport costs and facilitating field cultivation mechanization (Mayorga-Abril et al., 2026). Post-consolidation works, in turn, ensured each plot had access to technical infrastructure. These included the construction of necessary access roads to agricultural land owned by municipalities and the improvement of technical parameters of drainage facilities.

Land consolidation processes play a significant role in rural land management, rendering economic, social, and environmental functioning more efficient (Alsharaideh et al., 2026). Rural areas are still characterized by an unregulated and complex legal situation. In many cases, agricultural plots lack direct road access. Besides roads, the drainage system was also neglected, lacking maintenance and not adapted to farming realities. The defective spatial structure of farms also posed a certain obstacle to obtaining financial support in the form of direct payments for agricultural areas. The number of owners and ownership rights should not change during the land consolidation process. However, the consolidation process alters the layout of land boundaries. Each participant in the consolidation received land of equal estimated value in exchange for the land they held before consolidation. The decision approving the land consolidation project served as a legal title for disclosing the new property status in the land and mortgage register.

The measure was implemented under two schemes: Scheme I – Land consolidation and Scheme II – Agricultural water resources management. The measure under Scheme I aimed to improve the area structure of farms through consolidation works, delineation and construction of a functional network of access roads to agricultural and forest land and farm buildings, as well as the allocation of necessary land for technical and social infrastructure as part of consolidation works. It was expected that 346 projects would be launched, and the total area of land subject to consolidation would amount to 207 thou-

sand ha. In reality, the number of implemented consolidation projects was significantly lower than assumed. Most consolidation works, among the 109 decisions issued, were carried out in the Lublin Voivodeship – 39 (35.8%), Podlaskie – 13 (11.9%), Lower Silesian – 11 (10.1%), and Silesian – 9 (8.2%). These four voivodeships absorbed 70.4% (PLN 268.3 million) of the funds allocated for this purpose.

Table 1 presents a comparative summary of implementation metrics across the first three programming periods, illustrating the gradual expansion of consolidation activities.

Table 1. Land Consolidation Implementation Across EU Programming Periods in Poland (2004–2026)

Indicator	2004–2006	2007–2013	2014–2020	2021–2027 (as of Q1 2026)
EU Programme	Sectoral Operational Programme	RDP 2007–2013	RDP 2014–2020	CAP Strategic Plan 2023–2027
Intervention Measure	Land consolidation	Infrastructure related to agriculture and forestry	Land consolidation	I.13. Land consolidation
EU Financial Allocation (EUR million)	17.0	n/a	139.0	376.5 (total public)
Total Financial Allocation (EUR million)	21.2	n/a	n/a	376.5 (including EUR 239.2 from EAFRD)
Projects Approved for Implementation	32	109	207	154 (as of Q1 2026)
Projects Completed (Finalized)	31	109	n/a	68 (as of Q1 2026)
Area Covered (thousand ha)	20.4	Not fully comparable	~145.0	112.4 (approved)
Area Completed (thousand ha)	20.4	Not fully comparable	~145.0	48.7 (completed)
Targeted Area (thousand ha)	42.0	207.0	n/a	n/a
Target Achievement (%)	49%	~53% (109 of 346 projects)	Exceeded projections	In progres
Average Participation (holdings per project)	154	n/a	n/a	n/a
Average Plot Reduction (%)	n/a	n/a	n/a	62% (preliminary)
Environmental Infrastructure Allocated (thousand ha)	n/a	n/a	n/a	1.2
Access Roads Built/ Modernized (km)	n/a	n/a	n/a	487
Water Relations Regulated (thousand ha)	n/a	n/a		

Source: Authors' compilation based on ARMA reports and ex-post evaluations (2009, 2016)

5. FINANCIAL PERSPECTIVE 2021–2027 AND IMPLEMENTATION STATUS

In the current European Union financial framework for 2021–2027, support for land consolidation has been incorporated into the Common Agricultural Policy Strategic Plan for

2023–2027, approved by the European Commission on August 31, 2022. The implementing instrument is intervention I.13. "Land consolidation," which represents a continuation and development of actions undertaken in previous programming periods, alongside a significant strengthening of the environmental and climate components.

Legal Basis and Objectives of the Intervention

The legal basis for implementing land consolidation in the new perspective includes:

- Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the CAP (Strategic Plans Regulation),

- The Act of February 8, 2023, on the Strategic Plan for the Common Agricultural Policy for 2023–2027,
- The Regulation of the Minister of Agriculture and Rural Development of April 14, 2023, on detailed conditions and procedures for granting financial aid under intervention I.13. "Land consolidation."

The main objective of the intervention remains the improvement of the area structure of agricultural holdings through:

1. Reduction of the number of plots per holding and improvement of their shape,
2. Reduction of distances between plots and the farmstead,
3. Equipping farms with necessary technical infrastructure (access roads, drainage facilities),
4. Rational shaping of property boundaries in relation to natural environment components.

A novelty compared to previous programming periods is the clear linkage of support with the objectives of the European Green Deal and the "Farm to Fork" strategy. Under the intervention, projects that contribute to the following are prioritized:

- Mitigation of and adaptation to climate change,
- Improvement of water management and increased retention,
- Protection of soil against erosion and degradation,
- Preservation of biodiversity and agricultural landscape features,
- Consideration of environmental protection requirements, including in Natura 2000 areas.

Land consolidation may be initiated:

- Upon application by the majority of owners of holdings located within the planned area, whose total area exceeds half of the consolidation area,
- Ex officio, after obtaining the opinion of the village council and socio-professional farmers' organizations.

The beneficiary of support, similar to previous periods, is the county head (starosta) competent for the location of the land, who is responsible for carrying out the entire consolidation procedure and post-consolidation development works.

The co-financing level has been maintained at 100% of eligible costs. However, more differentiated maximum aid rates per hectare of land subject to consolidation have been introduced, taking into account:

- Regional diversity (lowland and mountain voivodeships),
- Project complexity level (including the scope of necessary infrastructure works),
- Specific environmental conditions (e.g., protected areas).

The maximum support amount per project is specified in the implementing regulation

and is subject to annual indexation.

6. RESOURCE ALLOCATION AND IMPLEMENTATION PROGRESS

In the Strategic Plan for 2023–2027, a total of EUR 376.5 million was allocated for intervention I.13. "Land consolidation" from public national and EU funds (including EUR 239.2 million from the EAFRD). This constitutes a significant increase in allocation compared to the previous perspective (EUR 139.0 million in RDP 2014–2020), reflecting the growing importance of this instrument in rural development policy.

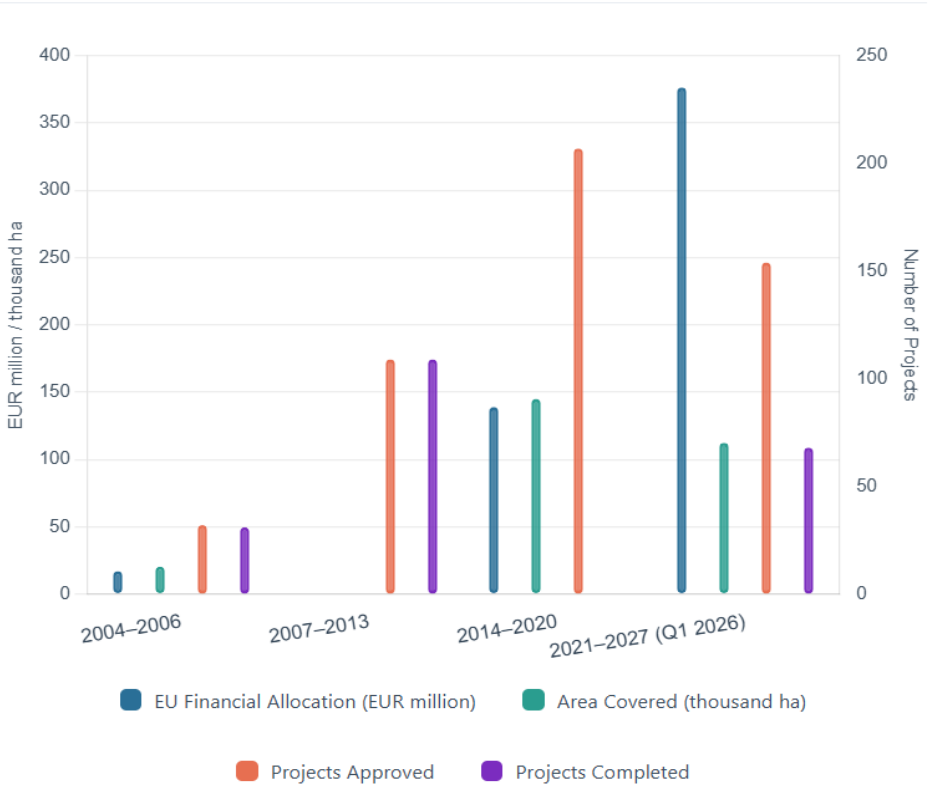
According to data from the Agency for Restructuring and Modernisation of Agriculture (ARMA) and the Ministry of Agriculture and Rural Development, as of the end of the first quarter of 2026 (status as of March 2026):

- A total of 187 aid applications were submitted, of which 154 were approved for implementation,
- The total area of land covered by approved projects is approximately 112.4 thousand ha,
- 68 consolidation projects have been completed (finalized), covering a total area of 48.7 thousand ha,
- 86 projects covering a total area of 63.7 thousand ha are currently under implementation.

Compared to the 2014–2020 programming period, in which approximately 145 thousand ha were consolidated (aggregate data for the entire period), the new perspective demonstrates higher dynamics in the initial years of implementation. This is attributed to streamlined administrative procedures and increased awareness among local governments and farmers regarding the benefits of consolidation.

Figure 1 illustrates the progressive increase in financial allocations and implementation scale across programming periods.

Figure 1. The progressive increase in financial allocations and implementation scale across programming periods



Source: own studies

7. SPATIAL DIFFERENTIATION OF IMPLEMENTATION

Spatial analysis of approved projects under the 2021–2027 perspective confirms trends observed in previous periods. The highest number of projects and the largest area covered by consolidation are recorded in the following voivodeships:

- Lublin – 27 projects, 19.6 thousand ha,
- Malopolska – 21 projects, 12.8 thousand ha,
- Subcarpathian – 19 projects, 14.3 thousand ha,
- Masovian – 18 projects, 13.5 thousand ha,
- Swietokrzyskie – 14 projects, 9.2 thousand ha.

Simultaneously, relatively low activity continues to be observed in the western and northern voivodeships (West Pomeranian, Lubuskie, Warmian-Masurian), where the agrarian structure is historically more favorable, and the demand for consolidation is lower. This indicates a persistent spatial polarization of consolidation processes, concentrated in areas with the highest degree of land fragmentation, located mainly in south-eastern and central Poland.

Several factors contribute to this spatial pattern. First, historical land reform implementation varied across regions, with former Prussian territories in the west and north experiencing different ownership structures than former Russian and Austrian partition areas in the east and south. Second, socio-economic conditions, including higher population density and smaller average farm sizes in south-eastern Poland, create stronger demand for consolidation. Third, institutional capacity differences across county offices affect the readiness and ability to initiate and manage consolidation projects. Fourth, farmer attitudes and awareness of consolidation benefits vary regionally, influenced by local traditions and past experiences with land management interventions. These interlocking factors require spatially differentiated policy approaches rather than uniform national strategies.

8. NEW CHALLENGES AND INNOVATIONS IN THE CONSOLIDATION PROCESS

In the current perspective, several solutions have been introduced to streamline the implementation of land consolidation:

1. Digitization of the process – implementation of an electronic system for consolidation documentation circulation (e-consolidation), which shortens administrative procedures and improves communication between county offices, geodetic offices, and ARMA.
2. Integration with other CAP instruments – land consolidation is increasingly implemented in conjunction with investments in water management infrastructure (intervention I.14. “Water management in agriculture”) and actions for soil protection and biodiversity.
3. Strengthening social participation – mandatory broader public consultations at the preparatory stage, involving not only direct participants of the consolidation but also residents of the area, non-governmental organizations, and economic entities.
4. Flexibility in shaping land layout – the possibility of allocating land for public purposes (e.g., local investments, mid-field greenery, retention) with a greater share of financial compensation than before has been permitted, increasing social acceptance for projects.

However, these innovations also introduce new challenges. The digitization process requires significant investment in staff training and technical infrastructure, particularly in rural county offices with limited resources. Enhanced social participation, while norma-

tively desirable, may extend consultation timelines and create additional procedural complexity. The integration with other CAP instruments demands greater inter-departmental coordination that may exceed current institutional capacities. These tensions between innovation and implementation feasibility should be acknowledged in policy design.

9. PRELIMINARY ASSESSMENT OF EFFECTS

Preliminary monitoring results for intervention I.13. indicate positive effects concerning:

- Reduction in the number of plots in consolidated holdings – by an average of 62%,
- Improved road access – within completed projects, a total of 487 km of access roads to agricultural land were built or modernized,
- Regulation of water relations – on an area of 22.4 thousand ha, works related to the reconstruction and modernization of drainage networks were carried out,
- Allocation of land for environmental infrastructure – a total of 1.2 thousand ha were designated for mid-field afforestation, ponds, and other elements enhancing retention and biodiversity.

While these quantitative metrics suggest positive outcomes, several important caveats should be noted. First, the 62% reduction in plot numbers may vary significantly across projects and regions, and the underlying baseline data may not be fully standardized. Second, the allocation of 1.2 thousand hectares for environmental infrastructure, while a positive development, represents only approximately 1.1% of the total consolidated area, raising questions about whether this share is sufficient to meaningfully advance European Green Deal objectives. Third, the monitoring framework does not systematically capture farm-level economic outcomes, such as changes in productivity, profitability, or competitiveness, which are ultimately the key criteria for assessing consolidation effectiveness. Fourth, social impacts, including effects on small-scale farmers, land tenure patterns, and community cohesion, are not comprehensively evaluated in current monitoring systems. These gaps in the assessment framework limit the ability to draw definitive conclusions about the overall effectiveness of consolidation interventions.

Simultaneously, challenges are being identified, including:

- Lengthy administrative procedures (averaging 3–4 years from application submission to project completion),
- Difficulties in obtaining the required majority of owner consents in areas with complex ownership structures,
- Rising costs of geodetic and infrastructure works under inflationary conditions.

10. COMPARATIVE PERSPECTIVE: LESSONS FROM OTHER EUROPEAN COUNTRIES

A comparative analysis of land consolidation practices in other European countries offers valuable insights for addressing Poland's implementation challenges. Germany, with its long history of consolidation dating back to the 19th century, has developed sophisticated procedures that typically complete within 2–3 years—significantly faster than Poland's 3–4 year average. Key success factors in the German system include: (1) stronger legislative authority for consolidation associations, which can initiate proceedings with lower consent thresholds; (2) dedicated professional staff at the regional level with specialized training; and (3) well-established procedures for resolving disputes through specialized land consolidation courts (Thomas, 2006).

The Netherlands provides another relevant model, where consolidation has been integrated with comprehensive spatial planning since the 1920s. Dutch consolidation projects typically incorporate broader rural development objectives, including nature con-

servation, recreation, and landscape management, from the outset rather than as add-on components (van Dijk, 2003). This integrated approach has contributed to higher stakeholder acceptance and more efficient project implementation. The Dutch experience also demonstrates the importance of sustained, long-term funding commitments rather than project-based, periodic funding cycles.

France offers lessons in managing consolidation in areas with strong resistance from small-scale farmers. The French system employs extensive consultation mechanisms and allows for flexible project boundaries that can exclude particularly resistant landowners, reducing overall project delays while still achieving meaningful consolidation outcomes (Pauchard et al. 2016). This pragmatic approach may be relevant for Poland's south-eastern regions where landowner resistance has historically been a barrier.

From these comparative cases, several transferable lessons emerge for Poland: (1) reducing consent thresholds through stronger associational powers could significantly accelerate project initiation; (2) integrating consolidation more comprehensively with spatial planning and rural development objectives would enhance stakeholder buy-in and project efficiency; (3) developing specialized professional cadres at the regional level would reduce reliance on overstretched county office staff; and (4) creating dedicated dispute resolution mechanisms would reduce the time spent on individual landowner objections. These reforms, however, would require legislative changes and substantial investment in institutional capacity development.

11. POTENTIAL NEGATIVE CONSEQUENCES AND MITIGATION STRATEGIES

While land consolidation is predominantly framed as a beneficial intervention, scholarly literature and empirical evidence from various European contexts suggest several potential negative consequences that warrant careful consideration. First, consolidation may contribute to social displacement, as smaller farmers and part-time agriculturalists may be pressured to sell or exchange land in ways that disadvantage their economic position (Dijk & Koomen, 2003). In the Polish context, where a significant portion of agricultural land is held by small-scale, semi-subsistence farmers, this risk is particularly acute. Mitigation strategies could include guaranteed minimum land parcels for participants, enhanced compensation mechanisms for land quality differentials, and the provision of advisory services to help smaller farmers navigate the consolidation process.

Second, landscape homogenization represents another potential concern. Consolidation often prioritizes regular, large plots that facilitate mechanized farming but may eliminate valuable landscape elements such as hedgerows, field margins, wetlands, and small woodlands that support biodiversity and provide ecosystem services (Pinto-Correia & Vos, 2004). While the 2021–2027 framework includes provisions for environmental infrastructure allocation, the modest scale of such allocation (1.2 thousand hectares out of 48.7 thousand completed) suggests that this risk may not be adequately addressed. Strengthening environmental safeguards through mandatory ecological assessments and higher minimum allocations for green infrastructure would help mitigate this concern.

Third, consolidation may disrupt established social networks and community structures, as farmers are relocated to new plots and the traditional spatial organization of villages is altered (Scott, 2004). This is particularly relevant in areas with strong place-based identities and traditional land use patterns. Enhanced social participation and community engagement in project planning, already introduced in the current programming period, could be further strengthened through community facilitators, local advisory committees, and transparent communication about project implications.

Fourth, the concentration of land through consolidation may contribute to increased economic inequality, as larger farms with greater consolidation benefits may become more competitive while smaller farms face heightened pressure to exit agriculture (Haldrup, 2015). This outcome is at odds with the EU's stated commitment to supporting family farms and maintaining vibrant rural communities. Countermeasures could include progressive support structures that provide proportionally greater benefits to smaller holdings, integration with early retirement and generational renewal programs, and the development of non-agricultural livelihood options in consolidated areas.

Fifth, consolidation creates path dependencies that may limit future land use flexibility. Once plots are consolidated and infrastructure is developed, returning to more diversified land use patterns becomes economically and administratively difficult. This is particularly relevant in the context of climate change, where future agricultural systems may require more diverse and resilient spatial arrangements. Flexible consolidation designs that incorporate options for future adjustments, coupled with periodic review mechanisms, would help address this concern.

12. FINAL CONCLUSIONS

Rural development through land consolidation has occurred in many European countries. The pursuit of land consolidation originated from a similar source across all countries, i.e., the need to adjust unfavorable land divisions and promote an appropriate shape of agricultural property perceived as a uniform and compact unit. The fundamental principle was to maintain the ownership status, and when changes occurred, they were introduced based on the principle of equivalence. Within the EU, depending on the country, differences existed in the objectives and procedures of land consolidation. The costs and methods of financing consolidation also varied. Procedures were typically shaped under the influence of historical trends, culture, tradition, and the law of each country.

In Poland, the consolidation process was influenced by the 1982 Act, as subsequently amended. Land consolidation involved the delineation of new plots with a shape different from the original. Land consolidation aimed to reduce the number of small, fragmented plots constituting an agricultural holding and increase their average size. Consolidation projects also included post-consolidation land development works, which consisted, in particular, of constructing functional access roads to agricultural land and carrying out works affecting the regulation of water relations within the consolidation area.

The conducted research demonstrated that the land consolidation process was implemented only in a few villages due to high costs and the necessity to obtain consent from the majority of farmers. In the process of land consolidation and exchange, we are still at the beginning of a project leading to the resolution of this issue. The scale of consolidation works should be considered in light of the number of villages (42.8 thousand) or sołectwos (40.3 thousand) that are appropriate areas for conducting land consolidation.

In the past, agrarian changes in Poland involved implementing land reform (1944), which resulted in the parceling out of large estates. Furthermore, Poland belonged to the group of South-Eastern European countries that opposed the process of creating agricultural production cooperatives. Therefore, in Poland, the land consolidation process had a different character and socio-economic conditions compared to other countries, resulting in fragmented agriculture and the creation of a large number of agricultural plots. In this process, an appropriate land layout can be achieved through land consolidation and exchange.

Analysis of land consolidation implementation across successive European Union programming periods indicates gradual, albeit still insufficient relative to the needs, progress in improving Poland's agrarian structure. In the 2004–2006 financial perspective,

31 projects covering 20.4 thousand ha were implemented; in the 2007–2013 period, 109 projects (area data not fully comparable due to methodological changes); in the 2014–2020 perspective, 207 projects covering approximately 145 thousand ha; whereas under the CAP Strategic Plan for 2023–2027 (2021–2027 perspective), by the end of the first quarter of 2026, 154 projects covering 112.4 thousand ha were approved, of which 68 projects (48.7 thousand ha) have already been completed. The implementation dynamics in the new perspective are higher than in previous periods, which can be attributed to streamlined procedures, process digitization, and increased awareness among local governments and farmers regarding the benefits of consolidation.

At the same time, it should be emphasized that despite the increased scale of intervention, a significant disparity persists between the needs and the actual scope of implementation. Considering that there are approximately 1.3 million agricultural holdings larger than 1 ha in Poland, a significant portion of which exhibit unfavorable spatial structures, the cumulative area covered by consolidation across all programming periods (approximately 320 thousand ha) constitutes only a fraction of the areas requiring intervention. Sustaining concentrated support for the south-eastern voivodeships (Lublin, Malopolska, Subcarpathian) and central voivodeships (Masovian, Swietokrzyskie), where the problem of land fragmentation is most acute and which, as data from the 2021–2027 perspective shows, concentrate the greatest application activity, is particularly important.

The new financial perspective has also brought a significant strengthening of the environmental component of land consolidation. An increasing number of projects incorporate actions for climate change adaptation, soil protection, increasing water retention, and shaping biodiversity. In completed projects under intervention I.13., a total of 1.2 thousand ha were allocated for environmental infrastructure, a positive sign of integrating productive and protective objectives. However, further efforts should be made to increase this share, particularly in the context of implementing the European Green Deal objectives.

Shortening the duration of administrative procedures and simplifying the process of obtaining the required majority of landowner consents remain key challenges. The average implementation time for a consolidation project is currently 3–4 years, which, within a seven-year EU budget perspective, limits the potential for full utilization of the allocated funds. The continued implementation of the e-consolidation system and the development of staff competencies in county offices and geodetic bureaus should be pursued as key streamlining actions.

The findings of this study have several implications for policy and practice. First, while increased financial allocation is welcome, the effectiveness of consolidation depends equally on institutional capacity and procedural efficiency. Investment in county office staffing and training should accompany financial increases. Second, the integration of environmental objectives must move beyond modest land allocations to become a systematic component of consolidation design, with higher minimum requirements for green infrastructure. Third, the comparative evidence from Germany, Netherlands, and France suggests that stronger associational powers and lower consent thresholds could significantly accelerate project implementation without compromising landowner rights. Fourth, a more comprehensive monitoring framework is needed to assess economic, social, and environmental outcomes beyond the current focus on implementation metrics. Fifth, future programming periods should consider experimental or pilot approaches in particularly challenging regions, testing innovative procedures that could be scaled up if successful.

The study's limitations should also be acknowledged. The analysis relies primarily on aggregated institutional data that may mask significant regional and local variations in consolidation effectiveness. The absence of systematic micro-level data on farm-level out-

comes limits the ability to assess whether consolidation achieves its stated objectives of improving competitiveness and sustainability. The temporal scope of the analysis, while capturing long-term trends, does not allow for detailed assessment of project-level dynamics that would require qualitative case study research. Future research should address these gaps through comparative regional studies, farm-level economic analyses, and longitudinal tracking of consolidated holdings to assess whether the improvements in land structure translate into tangible economic and environmental benefits.

In conclusion, land consolidation in Poland, although implemented for two decades with the participation of EU funds, is still in the phase of building a systemic and permanent instrument for agrarian structure restructuring. The increased allocation in the 2021–2027 perspective (EUR 376.5 million) and the higher project implementation dynamics indicate the growing importance of this tool in rural development policy. Nevertheless, considering the scale of historical backlog and the number of villages and sołectwos requiring intervention, it is necessary to maintain and strengthen support in subsequent programming periods after 2027, while further simplifying procedures and strengthening the environmental component. Only in this way will it be possible to gradually mitigate the adverse historical legacy of land fragmentation and create lasting foundations for competitive and sustainable agriculture in Poland.

REFERENCES

Agency for Restructuring and Modernisation of Agriculture. (2004). Organisational Regulations of ARMA. [Internal document]. (In Polish)

Agency for Restructuring and Modernisation of Agriculture. (2026). Periodic reports on the implementation of intervention I.13. Land consolidation – status as of March 31, 2026. Warsaw: ARiMR. (In Polish, internal report)

Alsharaideh, A. M. A., Alzubi, M. M. S., Alqudah, A. M. A., Alqudah, O. M. A., & Darabah, K. (2026). AI-Enabled Frugal Innovation: Extending the Dynamic Capabilities Framework for Sustainable Development. *ECONOMICS - Innovative and Economic Research Journal*, 14(2), 435-455. https://doi.org/10.2478/eoik-2026-0044

Council of the European Union. (2005). Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD). *Official Journal of the European Union*, L 277, 1–40. https://eur-lex.europa.eu/eli/reg/2005/1698/oj/eng

Dijk, T. van. (2003). Dealing with Central European land fragmentation: A critical assessment on the use of Western European instruments [Doctoral dissertation, Delft University of Technology].

Haldrup, N. O. (2015). Agreement based land consolidation – In perspective of new modes of governance. *Land Use Policy,* 46, 163-171. https://doi.org/10.1016/j.landusepol.2015.01.027

Mayorga-Abril, C., Vanegas-López, J. G., Ruiz-Guajala, M., Tamayo-Vásquez, M., & Santana-Mayorga, R. (2026). Gender Discrimination and Women's Decision-Making in Sustainable Agriculture: Evidence from Ecuador. *ECONOMICS - Innovative and Economic Research Journal*, 14(2), 53-66. https://doi.org/10.2478/eoik-2026-0025

Ministry of Agriculture and Rural Development. (2025). Report on the implementation of the CAP Strategic Plan for 2023–2027 for the year 2024. Warsaw: MRiRW. (In Polish)

Pašakarnis, G., & Malienė, V. (2010). Towards sustainable rural development in Central and Eastern Europe: Applying land consolidation. *Land Use Policy*, 27(2), 545–549. https://doi.org/10.1016/j.landusepol.2009.07.008

Pauchard, L., Madeline, P., & Marie, M. (2016). L'échange parcellaire : une nouvelle étape dans l'aménagement foncier de l'Ouest français [Plot exchanges: A new step in rural land planning in Western France]. *Norois,* (240), 7-24. https://hal.science/hal-01610452v1

Pinto-Correia, T., & Vos, W. (2004). Multifunctionality in Mediterranean landscapes – past and future. In R. H. G. Jongman (Ed.), The New Dimensions of the European Landscapes (pp. 135-164). *Springer*.

Sabates-Wheeler, R. (2002). From the state to the market? Pension reform paths in Central-Eastern Europe and the Former Soviet Union. *Social Policy & Administration*, 36(2), 142–155. https://doi.org/10.1111/1467-9515.00277

Scott, J. C. (2004). Seeing like a state: How certain schemes to improve the human condition have failed. Yale University Press. https://yalebooks.yale.edu/book/9780300078152/seeing-like-a-state/

Seisenbekov, A., Beisenova, M., Koshetayev, D., Akhmetova, Z., & Suyunbayev, S. (2026). The Impact of Digitalization and Innovation on Postal and Courier Services in the Context of Sustainable Economic Development: Evidence from Kazakhstan. *ECONOMICS - Innovative and Economic Research Journal,* 14(2), 249-268. https://doi.org/10.2478/eoik-2026-0035

Thomas, J. (2006). Property Rights, Land Fragmentation and Emerging Structure of Agriculture in Central and East European Countries. eJADE: *Electronic Journal of Agricultural and Development Economics,* 3(2), 225-275. https://ideas.repec.org/a/ags/ejade1/112607.html

Vitikainen, A. (2004). An overview of land consolidation in Europe. *Nordic Journal of Surveying and Real Estate Research*, 1(1), 25–43. https://journal.fi/njs/article/view/41504

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

AI-ENABLED STRATEGIC TRANSFORMATION: ORGANIZATIONAL CAPABILITIES AND COMPETITIVE ADVANTAGE IN A CHANGING BUSINESS ENVIRONMENT

Sara Drakul[1*]

Received 04.03.2026. | Send to review 06.04.2026. | Accepted 28.08.2026.

Original Article

[1] Faculty of Technical Sciences, University of Novi Sad

***Corresponding Author:**
Sara Drakul

Email:
sara.drakul1@gmail.com

JEL Classification:
O33, M15, L25

Doi: 10.61432/CPNE0401347d

UDK: 331.5.024.52:007.52

ABSTRACT
Artificial intelligence is increasingly reshaping business strategies, organizational capabilities, and sources of competitive advantage across industries. This paper provides a structured thematic literature review of recent studies on the role of AI in strategic transformation within a changing business environment. The review synthesizes findings related to digital capabilities, data-driven differentiation, organizational learning, responsible AI governance, and business model transformation. The Resource-Based View, Technology Acceptance Model, and Dynamic Capabilities Framework are used to interpret the main mechanisms through which AI affects organizational performance and strategic adaptation. The reviewed literature indicates that AI alone does not create sustainable competitive advantage; rather, its value depends on complementary organizational resources, process redesign, employee acceptance, governance, and the ability to adapt continuously. The paper concludes with theoretical and practical implications for organizations seeking to integrate AI into their strategic transformation processes.

Keywords: *Artificial Intelligence, Strategic Transformation, Competitive Advantage, Dynamic Capabilities, Technology Acceptance, Organizational Change*

1. INTRODUCTION

The growing use of artificial intelligence in organizational decision-making is changing the way firms formulate and implement strategy. Rather than functioning only as an operational technology, AI increasingly supports strategic planning, business model development, and organizational adaptation. Previous research emphasizes that the strategic value of AI depends on an organization's ability to connect technological capabilities with managerial expertise and clearly defined business objectives (Kitsios & Kamariotou, 2021). From a strategic management perspective, AI can also enhance the quality and speed of managerial decision-making, although its contribution to business performance depends on how effectively it is incorporated into broader planning processes (Stipic, 2021). Digitalization has also encouraged organizations to reconsider traditional approaches to corporate strategy and business model design. Akmaeva et al. (2020) argue that contemporary political, economic, and technological developments require firms to adopt more flexible forms of management and to integrate advanced digital technologies into a broader range of business activities. In this context, AI may support faster infor-

mation processing, more adaptive organizational structures, and the development of new approaches to value creation. Its strategic relevance therefore extends beyond automation, as it can influence how organizations respond to environmental change, allocate resources, and pursue long-term growth.

2. LITERATURE REVIEW AND RESEARCH QUESTION SPECIFICATION

Digital transformation refers to organizational changes based on digital technologies. Digital transformation can be understood as a constant process in which digital technologies have a disruptive effect on the organization, imposing the need to develop an appropriate response, as well as changing the way the company will create value (Vial, 2019). AI contributes to the aforementioned phenomenon by accelerating the processes of prediction and learning, but also by improving the autonomous capabilities of digital systems. While digital transformation traditionally includes concepts such as business information systems, cloud technologies, mobile platforms or e-commerce, AI-driven digital transformation includes real-time analytics, intelligent automation, computer vision, generative AI, decision-making supported by machine learning and natural language processing. In contrast, Bharadwaj et al. (2013) argue that digital business strategy is a combination of business strategy and information technology. With the development of AI, business strategies and IT integration become easier, as AI is integrated into important products, customer engagement processes, management decision-making procedures and logistics. For example, it is possible to replace manual credit application assessment procedures with risk assessment with the help of AI algorithms; to replace traditional machine maintenance with proactive predictive maintenance; to replace generic marketing campaigns with personalized marketing recommendations; improving the treatment process by applying AI-based diagnostics and optimizing patient flow. The above examples clearly show that AI is changing both the process architecture and the logic of value creation in the company. Based on the resource-based theory of competitive advantage, advantage is gained by possessing rare, valuable, non-substitutable and difficult-to-imitate resources (Barney, 1991). In terms of AI deployment, competitive advantage cannot come from just having AI software, as nowadays, a large number of tools are readily available. Instead, the source of competitive advantage can be found in the combination of AI with the company's data, expertise in a certain area, the ability and agility of the organization to learn, the scalability of the infrastructure. AI capability is defined as an organization's ability to use AI-specific resources to improve business performance and foster creativity (Mikalef & Gupta, 2021). Table 1 presents the evolution of research priorities in the field of AI.

Table 1. Evolution of AI Research Focus

Research Focus	2018-2020	2021-2023	2024-2025	Growth Rate
AI Implementation Challenges	15%	4%	2%	-87%
Predictive Analytics	18%	6%	2%	-89%
Digital Transformation	22%	19%	8%	-64%
AI Ethics & Governance	8%	15%	18%	+125%
ML Applications	32%	38%	28%	-12%
Generative AI	5%	18%	42%	+740%

Source: Author's adaptation based on Shakil et al. (2025, Table 1)

Recent research suggests that the organizational benefits of AI emerge gradually rather than automatically following technological adoption. Holmström et al. (2025) conceptualize AI transformation as an organizational journey in which firms progressively build capabilities, establish a strategic direction, and communicate the purpose of transforma-

tion across the organization. Evidence also suggests that weak business outcomes from AI projects are frequently associated with insufficient organizational adjustment rather than with limitations of the technology itself (Gao, 2024). Accordingly, the implementation of AI should be viewed as part of a broader organizational transformation process. The introduction of new technology alone is unlikely to generate substantial strategic benefits unless it is accompanied by changes in organizational routines, structures, leadership practices, and culture. Research on digital transformation therefore stresses the importance of aligning technological initiatives with the organization's overall strategic orientation (Kemp, 2024). From the Resource-Based View perspective, the strategic importance of AI does not primarily arise from access to the technology itself. Because many AI applications are commercially available, firms are more likely to differentiate themselves through the complementary assets surrounding their use of AI. These may include proprietary datasets, specialized knowledge, skilled employees, technological infrastructure, and organizational routines that competitors cannot easily reproduce. AI can therefore contribute to sustained differentiation when it becomes embedded in a distinctive combination of organizational resources and capabilities (Azagury & Moore, 2024; Barney & Reeves, 2024). The Dynamic Capabilities Framework adds a temporal dimension to this argument by emphasizing the capacity of organizations to renew their resource base as conditions change. In an AI-intensive environment, firms need to recognize emerging technological opportunities, mobilize appropriate resources, and revise existing processes when technologies or markets evolve. Such capabilities allow organizations to move beyond static possession of AI-related assets and continuously adapt the way those assets are used (Doshi et al., 2025; Shakil et al., 2025). Based on previous studies, the following research questions are formulated:

1. What new sources of competitive advantage emerge from AI adoption?
2. Through which mechanisms does AI influence strategic decision-making and business performance?
3. Which organizational capabilities and transformation requirements enable successful AI integration?

3. METHODOLOGY

This study adopts a structured thematic literature review based exclusively on secondary sources. The methodological approach follows the general principles of literature review research proposed by Snyder (2019), with the aim of synthesizing existing knowledge rather than conducting a systematic meta-analysis or primary empirical investigation. The review draws on peer-reviewed journal articles, review papers, and selected industry reports addressing artificial intelligence, strategic transformation, competitive advantage, organizational capabilities, technology acceptance, responsible AI governance, and business performance. Priority was given to recent studies published between 2019 and 2026 in order to reflect the rapid development of AI technologies, while several earlier seminal studies were retained where necessary to establish the theoretical foundations of the Resource-Based View, Technology Acceptance Model, and Dynamic Capabilities Framework. To enhance the transparency of the literature selection process, the literature search was conducted using Scopus, Web of Science, and Google Scholar. The search strategy employed different combinations of keywords, including "artificial intelligence," "AI strategy," "strategic transformation," "competitive advantage," "organizational capabilities," "dynamic capabilities," "technology acceptance," "digital transformation," "AI governance," "strategic decision-making," and "business performance." These terms were combined in different ways to identify publications addressing the strategic and organizational implications of artificial intelligence. The literature selection process was con-

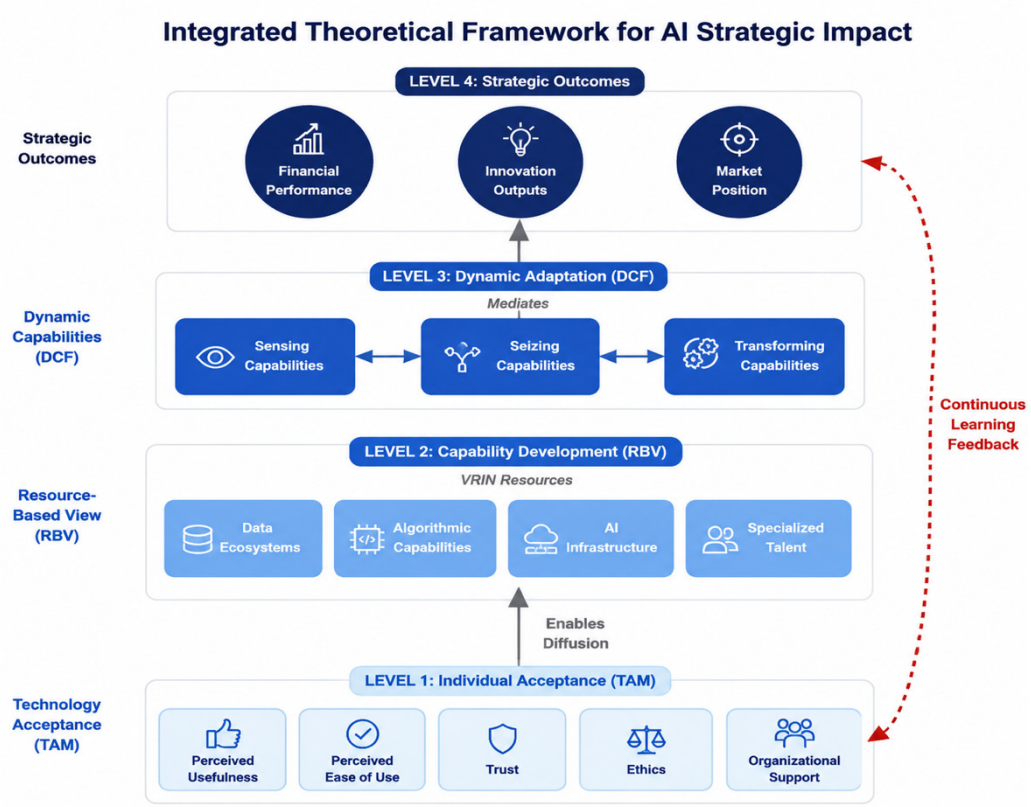
ducted in several stages. First, potentially relevant publications were identified on the basis of their titles, abstracts, and keywords. Second, studies considered relevant to the research questions were examined in greater detail. Sources were included when they met at least one of the following criteria: (1) direct relevance to the strategic application of AI in organizations; (2) contribution to the explanation of AI-enabled competitive advantage or organizational transformation; (3) empirical or conceptual evidence concerning digital capabilities, organizational adaptation, employee acceptance, governance, strategic decision-making, or business performance; or (4) relevance to the theoretical perspectives applied in this study. Studies focusing primarily on technical AI development without a clear organizational or strategic dimension were excluded. Priority was given to peer-reviewed academic publications indexed in Scopus and Web of Science, while selected industry reports were included when they provided recent empirical evidence, organizational statistics, or practical insights that complemented the academic literature. The selected literature was analyzed thematically. The analysis involved identifying recurring concepts and findings across studies and grouping them into several analytical themes: AI-related resources and capabilities, organizational transformation, process redesign, organizational learning, strategic decision-making, responsible AI governance, and business performance. Similar findings were compared across sources, while differences and emerging research directions were considered in order to develop a broader interpretation of the strategic role of AI. The interpretation of the reviewed literature was guided by three complementary theoretical perspectives: the Resource-Based View (RBV) (Barney, 1991), the Technology Acceptance Model (TAM) **(**Davis, 1989), and the Dynamic Capabilities Framework (DCF) (Teece et al., 1997**).** These perspectives were used to explain different but interconnected dimensions of AI-enabled strategic transformation, including individual acceptance, organizational capability development, continuous adaptation, and strategic outcomes.

Based on these theoretical perspectives, the study adopts and adapts the integrated conceptual framework proposed by Shakil et al. (2025). The adapted framework organizes the strategic impact of AI into four interconnected levels:

- Level 1 - Individual Acceptance: The first level concerns employees' willingness to interact with and use AI-supported systems. Adoption is shaped by perceptions of usefulness and usability, organizational support, confidence in AI-generated outcomes, and ethical considerations.
- Level 2 - Capability Development: At the organizational level, firms develop the resources required for effective AI deployment, including data assets, technological infrastructure, AI-related expertise, and specialized human competencies.
- Level 3 - Dynamic Adaptation: Organizations continuously adjust and recombine their resources as technological opportunities and competitive conditions evolve. Such adaptation enables AI capabilities to remain strategically relevant over time.
- Level 4 - Strategic Outcomes: The interaction between acceptance, capability development, and organizational adaptation may contribute to innovation, stronger market positioning, improved financial performance, and more sustainable forms of competitive advantage.

Since the study is based entirely on previously published evidence and secondary data sources, it does not claim to provide new primary empirical evidence or independent econometric testing. Its contribution lies in the thematic synthesis of recent literature and the integration of complementary theoretical perspectives into an adapted conceptual interpretation of AI-enabled strategic transformation.

Figure 1. Integrated AI Strategic Impact Model



Source: Adapted from Shakil et al. (2025, Figure 3)

4. LITERATURE FINDINGS AND DISCUSSION

4.1. STRATEGIC PATTERNS IDENTIFIED IN PREVIOUS STUDIES

Evidence reported by Azagury and Moore (2024) indicates that organizations follow substantially different approaches to AI adoption. A relatively small group classified as "Makers" develops highly customized AI solutions and records the strongest sales performance. "Shapers" combine AI with proprietary organizational data and modify their business models, while "Takers" rely predominantly on standardized solutions with limited customization. The reported sales growth rates are 12.4% for Makers, 8.7% for Shapers, and 4.2% for Takers. These differences suggest that greater organizational commitment to developing distinctive AI capabilities is associated with stronger performance outcomes. Shakil et al. (2025) report statistically significant differences among the three strategic archetypes. The reviewed literature supports the Resource-Based View, according to which competitive advantage arises from the combination of AI capabilities and heterogeneous complementary resources rather than from AI technology alone (Table 2).

Table 2. Performance Comparison

Archetype	Sample %	Sales Growth	EBIT Impact	TRS Premium	Example Companies
Takers	51%	4.2%	1.8%	2.1 pts	Traditional retailers
Shapers	42%	8.7%	5.3%	10.7 pts	Walmart, JP Morgan
Makers	7%	12.4%	8.9%	15.2 pts	Microsoft, Bloomberg

Source: Author's adaptation based on Shakil et al. (2025, Table 4)

The reviewed evidence also indicates that the performance effects associated with AI are influenced by an organization's capacity to adapt. Dynamic capabilities can strengthen the link between technological adoption and organizational outcomes by enabling firms

to modify resources, routines, and processes as new opportunities emerge. At the same time, the relationship does not appear to operate exclusively through these adaptive mechanisms, since certain AI applications may generate direct operational benefits through automation. An important theme emerging from the reviewed studies is the redesign of work processes. Evidence reported by Holmström et al. (2025) suggests that organizations achieve considerably greater business impact when AI implementation is accompanied by substantial changes in the way work is organized. The reported average EBIT contribution reaches 7.3% in organizations undertaking comprehensive redesign, compared with 0.4% when implementation is largely limited to technological upgrading. Despite this difference, only around 21% of organizations have substantially redesigned their work processes (Shakil et al., 2025). Among the organizational practices considered in previous research, process redesign appears particularly important because it links technological adoption with changes in talent, data management, organizational support, and change management. This reinforces the broader argument that AI implementation should be approached as a sociotechnical transformation rather than as an isolated technology project.

4.2. SOURCES OF AI ADVANTAGE

The following discussion builds on and further interprets the six sources of AI-driven competitive advantage identified by Shakil et al. (2025). Proprietary organizational data can become an important source of differentiation when combined with AI capabilities. Firms that possess extensive, specialized datasets may be able to develop applications that are difficult for competitors to reproduce. BloombergGPT illustrates this principle by drawing on decades of financial information. However, effective exploitation of such resources remains limited: approximately 30% of organizations have developed comprehensive data-management arrangements for AI (McKinsey & Company, 2024b), while a substantial proportion of corporate information remains unstructured. Technological infrastructure represents another important foundation for AI-based advantage. Organizations with well-developed digital platforms can introduce and scale AI applications more rapidly than firms whose systems remain fragmented. Relevant infrastructure may include cloud-based environments, integrated data platforms, APIs, and modular digital architectures. Deloitte (2024) reports substantial differences in implementation speed between organizations with strong and weak digital foundations, while managerial confidence in existing digital cores remains relatively low. Organizational learning also affects the extent to which AI investments generate value. Firms that identify changes early, test possible applications, learn from pilot projects, and scale successful solutions are better positioned to convert technological experimentation into strategic outcomes. Previous evidence indicates that organizations characterized by faster learning processes obtain substantially greater benefits from their AI investments. This reflects the broader role of sensing, experimentation, and organizational renewal in dynamic capability development. Limited automation of individual activities may create short-term efficiency improvements, but deeper transformation occurs when AI is integrated across interconnected organizational functions. Such integration is more difficult for competitors to reproduce because it combines technology with organizational routines, knowledge, and complementary resources. The AI-supported drug-development platform used by Insilico Medicine provides an example of this approach, with reported reductions of 95% in development time and 99% in costs (McKinsey & Company, 2024a). External relationships can further support the development of AI capabilities. Collaboration with technology providers, research organizations, and specialized service partners may provide access to expertise and infrastructure that would otherwise require substantial internal investment. At the same time, the strategic use of AI increasingly depends on organizational

trust and responsible governance. Although only a relatively small proportion of organizations have fully institutionalized responsible AI practices, transparency, explainability, ethical data use, and accountability are becoming increasingly important elements of stakeholder confidence (Camilleri, 2024).

Figure 2. Sources of AI Advantages



Source: Author's adaptation based on Shakil et al. (2025, Figure 4)

4.3. STRATEGIC DECISION-MAKING TRANSFORMATION

AI is changing strategic decision-making by expanding the amount of information that organizations can process and by shortening the time required to evaluate alternative courses of action. Scenario analysis. AI-supported systems can assist managers in exploring numerous possible future conditions and evaluating how alternative decisions may perform under different assumptions. This is particularly relevant to decisions involving markets, supply chains, resource allocation, and pricing. Forecasting and predictive analysis. Machine-learning techniques allow organizations to identify patterns in historical and real-time information and use them to anticipate changes in demand, market conditions, and risk. Such applications are increasingly used in financial services for fraud and risk assessment and in retail for demand planning, where inventory-related savings of approximately 20–30% have been reported (Forrester Research, 2024). Reduction of repetitive managerial workload. AI can take over selected routine decisions and analytical tasks, enabling managers to devote more attention to problems that require judgement and strategic interpretation. Previous evidence indicates that the time devoted to repetitive decision processes can be reduced by approximately 30–50% (Shakil et al., 2025). Support for more evidence-based judgement. AI may also help managers identify patterns that would otherwise be overlooked and can provide an additional analytical perspective when human judgement is affected by cognitive biases. Nevertheless, AI does not automatically eliminate bias. When historical data contain systematic distortions, algorithmic outputs can reproduce or even reinforce them, which highlights the importance of responsible AI governance (Camilleri, 2024).

4.4. THEORETICAL AND PRACTICAL IMPLICATIONS

The reviewed literature supports the relevance of an integrated framework combining the Resource-Based View, the Technology Acceptance Model, and the Dynamic Capabilities

Framework. The RBV explains how valuable and difficult-to-imitate AI-related resources contribute to competitive advantage, while TAM highlights the importance of employee acceptance and organizational readiness. Recent empirical evidence further confirms that digital capabilities strengthen organizational innovation and competitive advantage by extending the Resource-Based View in the context of digital transformation (Ha, 2026). The Dynamic Capabilities Framework explains how organizations reconfigure their resources and capabilities in response to technological and market change. Recent research has further extended this framework by demonstrating that AI-enabled organizational capabilities support innovation and long-term sustainable development (Alsharaideh et al., 2026). Taken together, the reviewed evidence suggests that organizations derive greater value from AI when technological investment is accompanied by deliberate changes in business processes and organizational capabilities. From a practical perspective, managers should prioritize organizational transformation over the simple acquisition of AI tools and integrate AI with proprietary data, specialized capabilities, responsible governance, and continuous learning (Azagury& Moore, 2024).

Although the reviewed studies broadly agree that AI can strengthen organizational performance and strategic decision-making, they differ in how they explain the mechanisms through which such benefits emerge. Some studies emphasize more direct operational effects of AI, particularly through automation, predictive analytics, and improved information processing (Gao, 2024; Doshi et al., 2025). In contrast, research grounded in the Resource-Based View and Dynamic Capabilities perspective suggests that technological adoption alone is insufficient and that sustainable benefits depend on complementary organizational resources, process redesign, learning capabilities, and continuous adaptation (Mikalef & Gupta, 2021; Azagury & Moore, 2024; Holmström et al., 2025). This distinction is important because short-term efficiency improvements resulting from AI adoption should not automatically be interpreted as evidence of sustainable competitive advantage. Rather, sustained strategic value appears to depend on the extent to which AI becomes embedded in organizational routines, proprietary resources, and adaptive capabilities (Kemp, 2024; Shakil et al., 2025).

The reviewed literature also reveals different levels of emphasis regarding the human and organizational dimensions of AI adoption. While capability-oriented research focuses primarily on organizational resources such as data, technological infrastructure, specialized knowledge, and AI-related competencies (Mikalef & Gupta, 2021; Azagury & Moore, 2024), the Technology Acceptance Model emphasizes individual perceptions of usefulness and ease of use as important determinants of technology acceptance (Davis, 1989). In addition, recent research on responsible AI highlights the importance of trust, transparency, explainability, and accountability in organizational adoption processes (Camilleri, 2024). These perspectives are not necessarily contradictory; rather, they address different levels of AI-enabled transformation. Their integration suggests that successful strategic transformation requires alignment between individual acceptance, organizational capabilities, responsible governance, and the firm's ability to continuously reconfigure resources in response to technological and market change (Teece et al., 1997; Holmström et al., 2025).

The theoretical contribution of this study lies in integrating three complementary perspectives—the Resource-Based View, the Technology Acceptance Model, and the Dynamic Capabilities Framework—into a unified interpretation of AI-enabled strategic transformation. While these theoretical perspectives are frequently applied separately to explain organizational resources, technology acceptance, or adaptive capabilities, their combined application provides a more comprehensive explanation of how AI generates strategic

value. The proposed interpretation connects individual acceptance of AI-supported systems with the development of organizational capabilities, the continuous reconfiguration of resources, and the achievement of strategic outcomes. In this way, the study extends the existing discussion beyond technology adoption alone and conceptualizes AI-enabled transformation as a multilevel process in which human acceptance, organizational resources, responsible governance, and dynamic adaptation jointly shape the potential for sustainable competitive advantage.

5. CONCLUSION

This review shows that the strategic significance of artificial intelligence cannot be explained by technological adoption alone. Across the examined literature, organizational outcomes depend on how firms combine AI with data, human expertise, digital infrastructure, governance arrangements, and the capacity to modify existing business processes. The evidence therefore positions AI as part of a broader system of organizational capabilities rather than as an independent source of lasting competitive advantage. The review highlights the importance of combining the Resource-Based View, the Technology Acceptance Model, and the Dynamic Capabilities Framework to better understand how organizations create value through AI adoption. While the Resource-Based View explains the strategic importance of valuable and difficult-to-imitate resources, the Technology Acceptance Model emphasizes the role of user acceptance and organizational readiness, and the Dynamic Capabilities Framework explains how organizations continuously adapt their resources and capabilities in response to technological change. Together, these theoretical perspectives provide a comprehensive explanation of AI-enabled strategic transformation. The reviewed literature further indicates that successful AI implementation requires more than technological investment. Organizations that redesign business processes, develop digital competencies, establish responsible AI governance, and continuously strengthen organizational learning achieve more sustainable strategic outcomes than organizations that focus solely on technology adoption. Furthermore, trust, ethical AI practices, high-quality data, and collaboration with external partners emerge as important determinants of long-term organizational performance. Despite the growing body of research, several important research gaps remain. Future studies should further investigate the long-term organizational effects of AI adoption, compare implementation strategies across industries, and examine the interaction between technological capabilities, organizational culture, and human decision-making across different business contexts. Additional empirical studies are also needed to validate the proposed conceptual relationships and identify industry-specific factors influencing AI-enabled strategic transformation. This study is subject to several limitations inherent in the literature review approach. First, the analysis relies exclusively on previously published research and secondary evidence and therefore does not provide independent empirical validation of the relationships identified in the conceptual framework. Second, although the review follows a structured thematic approach, the selection and interpretation of relevant studies may involve a degree of researcher judgment. In addition, the inclusion of selected industry reports, while useful for capturing recent developments and practical evidence in a rapidly evolving field, may limit direct comparability with peer-reviewed academic studies. Finally, given the rapid development of artificial intelligence technologies, some of the strategic and organizational implications identified in the current literature may evolve as new applications, governance practices, and empirical evidence emerge. Overall, this literature review contributes to a better understanding of the strategic role of artificial intelligence by synthesizing recent scientific evidence and integrating key theoretical perspectives into a unified conceptual framework. The findings provide useful guidance for

researchers, managers, and policymakers seeking to implement AI successfully as a strategic resource for organizational transformation and sustainable competitive advantage.

REFERENCES

Akmaeva, R., Arykbaev, R., Epifanova, N., & Glinchevskiy, E. (2020). Influence of digitalization upon formation of corporate strategy and new business models of modern organizations. *SHS Web of Conferences*, 89, 03003. https://doi.org/10.1051/shsconf/20208903003

Alsharaideh, A. M. A., Alzubi, M. M. S., Alqudah, A. M. A., Alqudah, O. M. A., &Darabah, K. (2026). AI-enabled frugal innovation: Extending the dynamic capabilities framework for sustainable development. *ECONOMICS – Innovative and Economics Research Journal,* 14(2), 435–455. https://doi.org/10.2478/eoik-2026-0044

Azagury, J., & Moore, M. (2024). Competitive advantage in the age of AI. *California Management Review,* 67(1), 5–32. https://cmr.berkeley.edu/2024/10/competitive-advantage-in-the-age-of-ai/

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99-120. https://doi.org/10.1177/014920639101700108

Barney, B., & Reeves, M. (2024). AI won't give you a new sustainable advantage. *Harvard Business Review,* 102, 42–49. https://hbr.org/2024/09/ai-wont-give-you-a-new-sustainable-advantage

Bharadwaj, A., El Sawy, O., Pavlou, P., & Venkatraman, N. (2013). Digital business strategy: Toward a next generation of insight. *MIS Quarterly*, 37(2), 471-482. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2742300

Camilleri, A. (2024). Artificial intelligence governance: Ethical considerations and implications for social responsibility. *Expert Systems,* 41(5), e13406. https://doi.org/10.1111/exsy.13406

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340. https://doi.org/10.2307/249008

Deloitte. (2024). Build an AI-ready culture. https://www.deloitte.com/us/en/what-wedo/capabilities/applied-artificial-intelligence/articles/build-ai-ready-culture.html

Doshi, R., Bell, J., Mirzayev, E., & Vanneste, S. (2025). Generative artificial intelligence and evaluating strategic decisions. *Strategic Management Journal,* 46(1), 27–54. https://doi.org/10.1002/smj.3677

Forrester Research. (2024). The Total Economic Impact of Microsoft 365 Copilot. https://tei.forrester.com/go/microsoft/M365Copilot/

Gao, H.(2024). Machine learning applications in business and finance: A comprehensive review. *Financial Innovation,* 10(1), 86. https://doi.org/10.1186/s40854-024-00629-z

Ha, T. M. (2026). How digital capabilities drive innovation in banking: Extending the resource-based view in the era of digital transformation. *ECONOMICS – Innovative and Economics Research Journal,* 14(2), 353–373. https://doi.org/10.2478/eoik-2026-0040

Holmström, J., Lyytinen, K., Niemimaa, M., Pietiläinen, E., & Tuunanen, T. (2025). Navigating the organizational AI journey: The AI transformation framework. *Business Horizons,* 68(1), 15–28. https://doi.org/10.1016/j.bushor.2025.01.002

Kemp, A. (2024). Competitive advantage through artificial intelligence: Toward a theory of situated AI. *Academy of Management Review*, 49(3), 618–635. https://doi.org/10.5465/amr.2020.0205

Kitsios, F., & Kamariotou, M. (2021). Artificial intelligence and business strategy towards digital transformation: A research agenda. *Sustainability*, 13(4), 2025. https://doi.org/10.3390/su13042025

McKinsey & Company. (2024a). The next innovation revolution powered by AI. https://www.mckinsey.com/capabilities/quantumblack/our-insights/the-next-innovation-revolution-powered-by-ai

McKinsey & Company. (2024b). The state of AI: How organizations are rewiring to capture value. https://www.mckinsey.com/capabilities/quantumblack/our-insights/the-state-of-ai

Mikalef, P., & Gupta, M. (2021). Artificial intelligence capability: Conceptualization, measurement calibration, and empirical study on its impact on organizational creativity and firm performance. *Information & Management*, 58(3), 103434. https://doi.org/10.1016/j.im.2021.103434

Shakil, M., Hulimuzzaman, M., Khan, A., &Fardous, J. (2025). The impact of artificial intelligence on business strategy: Redefining competitive advantage in the digital era. *Journal of Information Technology, Cybersecurity, and Artificial Intelligence,* 2(3), 1–16. https://doi.org/10.70715/jitcai.2025.v2.i3.024

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Stipic, V. (2021). Interaction of strategic management processes and achieved corporate profitability: Evidence from Croatia. *Ekonomski forum*, 13, 133-149. https://www.ceeol.com/search/article-detail?id=993309

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal,* 18(7), 509–533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7%3C509::AID-SMJ882%3E3.0.CO;2-Z

Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems*, 28(2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003

XIV TRADITIONAL SCIENTIFIC CONFERENCE NEW 2026 ECONOMY New Horizons: Digital Economy and Responses to a Changing World

COLLECTION OF PAPERS
NEW ECONOMY
Volume 4, No. 1, 2026

MANAGING INDUSTRY 4.0 COMPETENCIES FOR THE DIGITAL ECONOMY: INDUSTRIAL ROBOTICS AND UNIVERSITY-INDUSTRY COLLABORATION IN ENGINEERING EDUCATION

Dawid Piotr Gądkowski[1*]

Received 07.03.2026. | Send to review 30.03.2026. | Accepted 03.09.2026.

Original Article

CC BY NC ND

[1] Wyższa Szkoła Biznesu - National Louis University, Nowy Sącz, Poland

***Corresponding Author:**
Dawid Piotr Gądkowski

Email:
dgadkowski@wsb-nlu.edu.pl

JEL Classification:
I23, J24, O33, M53, O14

Doi: 10.61432/CPNE0401359g

UDK: 007.52:681.51.012/.013

ABSTRACT

The digital economy and Industry 4.0 have reshaped the competencies required of engineering graduates. Employers increasingly seek professionals who combine technical knowledge with systems thinking process awareness, analytical adaptability, and the capacity to work in technologically advanced environments. This shift presents a strategic challenge for higher education institutions, which must ensure that competency development remains aligned with labour market needs. This paper examines how industrial robotics and university-industry collaboration can support the development and management of Industry 4.0 competencies in engineering education. Using a qualitative case study approach, the research focuses on an educational intervention conducted at a private university in southern Poland. The intervention integrated robotics-based laboratory activities with a structured study visit to a manufacturing company. The findings suggest that hands-on experience with an industrial robot, combined with direct exposure to real production processes, enhances students' understanding of industrial workflows, increases engagement, strengthens career awareness, and supports the acquisition of skills relevant to the digital economy. The paper concludes that such initiatives should be viewed not only as teaching improvements, but also as strategic managerial responses to the need for curriculum relevance, stakeholder cooperation, knowledge transfer, and quality-oriented adaptation in higher education.

Keywords: *digital economy, Industry 4.0, competency management, engineering education, industrial robotics, university-industry collaboration, experiential learning, higher education quality*

1. INTRODUCTION

The new economy is shaped by digitalisation, automation, advanced data processing, cyber-physical systems, artificial intelligence and the growing interdependence between technology, organisation, and human capital. These developments affect not only how value is created in industry, but also how universities are expected to prepare graduates for professional roles. In engineering fields, this challenge is particularly visible, as the competencies required in contemporary production systems increasingly extend beyond traditional technical knowledge. Graduates are now expected to understand how automation functions within broader process structures, how production logic is connected to organisational goals, and how digital tools influence decision-making, quality, and

coordination. In this context, higher education institutions can no longer rely solely on lecture-based teaching or fragmented technical content. As labour markets increasingly demand adaptive, competent, and practice-oriented engineers, universities must design educational processes that deliberately support the development of these competencies. This issue is especially relevant to management and quality sciences, as competency development is not merely a pedagogical concern, but also an organisational challenge. It involves identifying stakeholder expectations, managing educational resources, structuring learning environments, and ensuring that teaching remains responsive to social and economic change. The concept of Industry 4.0 has intensified debate on the future of engineering education. It highlights the need for stronger integration between technical knowledge, digital infrastructure, process understanding, and industrial practice. Universities are increasingly expected to modernise curricula, update laboratory infrastructure, cooperate with external partners, and create practice-based learning environments. However, access to modern equipment alone is insufficient. Educational activities must be designed so that students can connect theoretical knowledge with authentic technological and organisational contexts. University-industry collaboration is one of the most promising mechanisms for supporting this transition. Industrial partners can provide access to current technologies, real process standards, and practical expectations regarding graduate competencies. Universities, in turn, can translate this knowledge into structured educational experiences. Among the available forms of collaboration, two are particularly valuable in engineering education: direct work with industrial equipment and structured exposure to functioning production environments. Together, they reduce the gap between academic learning and industrial practice. Industrial robotics is especially useful as a learning platform because it reflects many characteristics of contemporary production systems. It requires logic, precision, sequence control, awareness of safety constraints, and understanding of inputs, outputs, and process dependencies. It is therefore not only a technical tool, but also a medium through which students can engage with the operational logic of the digital economy. When robotics-based learning is combined with observation in a factory environment, students can move beyond isolated technical tasks toward a more comprehensive understanding of how technological systems contribute to organisational value creation. This paper analyses an educational intervention implemented at WSB-NLU in Nowy Sacz, Poland. The intervention combined laboratory classes using an industrial robot with a structured study visit to a manufacturing company. The article interprets this initiative not as an isolated teaching activity, but as a mechanism for managing competency development in engineering education. This perspective situates the case within management and quality sciences, where the strategic design of educational processes, stakeholder alignment, and quality of outcomes are central concerns. The research problem addressed in this paper concerns how higher education institutions can manage the development of competencies required by the digital economy and Industry 4.0. Although technological transformation has changed the expectations placed on engineering graduates, many study programmes still rely on fragmented technical instruction and provide limited exposure to authentic industrial environments. This creates a gap between educational processes and the competency needs of the new economy. The main research question is therefore formulated as follows: How can industrial robotics and university-industry collaboration support the management of Industry 4.0-related competencies in engineering education for the digital economy? To support the analysis, three sub-questions are posed. First, what competencies relevant to Industry 4.0 can be developed through robotics-based experiential learning? Second, how does exposure to real industrial environments influence students' perceptions of professional readiness? Third, what role does university-industry collaboration play in aligning educational out-

comes with labour market needs? The contribution of this paper is fourfold. First, it offers a management-oriented interpretation of robotics-based education. Second, it shows how a focused educational intervention can create value for students, institutions, and external partners. Third, it introduces a quality perspective by examining how such interventions enhance the relevance, coherence, and applicability of engineering education in the digital economy. Fourth, it provides a conceptual basis for further doctoral research connecting competency management, higher education quality, and university-industry relations within a single analytical framework.

2. LITERATURE REVIEW

The transition to Industry 4.0 has accelerated the need to transform engineering education alongside technological change. Contemporary production systems are increasingly characterised by automation, digital connectivity, data integration, cyber-physical systems, and intelligent manufacturing. As a result, engineering graduates are expected to possess not only strong technical expertise but also systems thinking, analytical capabilities, adaptability, communication skills, and a comprehensive understanding of production processes. These changing requirements challenge higher education institutions to redesign curricula and learning environments to better prepare graduates for the digital economy.

Previous studies emphasise that engineering education must evolve to meet these emerging demands. For example, Coskun et al. (2019) argue that Industry 4.0 requires substantial changes in curriculum design, laboratory infrastructure, and learning environments. Likewise, Das et al. (2020) highlight the importance of active learning, interdisciplinary education, and stronger links between universities and industry. More recently, Pekarcikova et al. (2025) demonstrate that educational robotics provides an effective platform for developing technical, digital, and process-oriented competencies required in Industry 4.0 and Industry 5.0 environments. Recent review evidence also highlights implementation patterns, pedagogical strategies, and the importance of industry alignment in integrating Industry 4.0 into engineering education (Khan & Mourad, 2025).

Experiential learning has emerged as a key pedagogical approach for developing these competencies. Tembrevilla, et al. (2024) show that practical learning experiences strengthen student engagement, facilitate the application of theoretical knowledge, and foster professional identity. Similarly, Baena et al. (2017) describe learning factories as educational environments that replicate industrial processes and enable students to acquire practical skills in realistic settings. Vila et al. (2017) further demonstrate that project-based collaborative learning enhances Industry 4.0 competencies by integrating technical tasks within authentic manufacturing contexts. Likewise, Vilalta-Perdomo et al. (2022) report that challenge-based learning improves students' understanding of industrial systems by exposing them to real-world problem-solving scenarios.

Competency development has consequently become a central concern in both educational and management research. Kipper et al. (2021) identifies digital literacy, systems thinking, analytical capability, interdisciplinarity, and adaptability as essential competencies for Industry 4.0. From a management perspective, competency development should be viewed as a strategic organisational objective rather than an incidental outcome of teaching. This requires the alignment of curricula, instructional methods, assessment practices, educational infrastructure, and stakeholder expectations to ensure that graduates acquire competencies relevant to rapidly evolving labour market demands.

University-industry collaboration plays a critical role in achieving this alignment. According to Evans et al. (2023), effective collaboration between universities and industry facilitates knowledge exchange, supports digital transformation, and creates mutual

value for all stakeholders. Such collaboration may take the form of industrial site visits, practical workshops, guest lectures, internships, equipment sharing, or joint curriculum development. When embedded within educational programmes rather than implemented as isolated initiatives, these activities substantially enhance the authenticity and practical relevance of engineering education.

From the perspective of management and quality sciences, competency-based education and quality management provide complementary theoretical foundations for understanding these developments. Competency-based education emphasises learning outcomes centred on clearly defined professional capabilities rather than content coverage alone (Biggs & Tang 2011). Similarly, quality management in higher education highlights curriculum relevance, stakeholder engagement, continuous improvement, and responsiveness to societal and labour market needs as key determinants of institutional effectiveness (Harvey & Green 1993). Together, these perspectives suggest that integrating industrial robotics with direct industrial experience represents a strategic approach to improving both educational quality and graduate employability.

Despite the growing body of literature, an important research gap remains. Existing studies primarily focus on comprehensive educational reforms, smart factories, or extensive university-industry partnerships. Comparatively little attention has been devoted to targeted educational interventions that can be implemented with relatively limited resources while still generating meaningful educational and managerial outcomes. This study addresses this gap by examining an educational intervention that combines robotics-based laboratory instruction with a structured factory visit as an integrated approach to competency development for Industry 4.0.

2.1. THEORETICAL FRAMEWORK

This study is grounded in four complementary perspectives: competency-based education, the Triple Helix model, stakeholder theory, and quality management in higher education. Together, these perspectives provide a framework for understanding how educational interventions can support competency development while strengthening the relevance and quality of engineering education.

Competency-based education shifts the emphasis from knowledge acquisition to the development of capabilities that graduates are expected to demonstrate in professional practice (Biggs et al. 2011). Within engineering education, this approach encourages the design of learning environments that enable students to apply theoretical knowledge, solve practical problems, understand complex systems, and evaluate the consequences of engineering decisions.

The Triple Helix model views innovation as the outcome of interactions among universities, industry, and government (Etzkowitz & Leydesdorff, 2000). Although this study focuses primarily on university-industry collaboration, the model highlights the broader role of universities as contributors to innovation ecosystems and regional development. By collaborating with industry in curriculum design and practical learning activities, universities enhance graduate preparedness while supporting knowledge transfer and workforce development.

Stakeholder theory further explains the importance of aligning educational provision with labour market expectations. Universities are accountable not only to students and regulatory bodies but also to employers, industry partners, and society more broadly (Freeman, 1984). From a management perspective, educational programmes can be viewed as organisational processes whose quality depends on their ability to meet stakeholder needs while maintaining academic standards and institutional autonomy.

The quality management perspective complements these frameworks by emphasising continuous improvement, stakeholder orientation, process coherence, and outcome relevance as key dimensions of educational quality (Harvey & Green, 1993). Consequently, the effectiveness of higher education should be assessed not only by compliance with institutional standards but also by its capacity to develop competencies that are valued in contemporary professional environments.

Viewed through these theoretical perspectives, the educational intervention analysed in this study represents more than a teaching innovation. Robotics-based laboratory activities support competency development, the industrial study visit strengthens university-industry collaboration, engagement with industrial practice enhances stakeholder alignment, and the integration of both components into a coherent learning experience contributes to educational quality. Together, these elements position the intervention as a strategic approach to competency management within the context of Industry 4.0 and the digital economy.

Table 1. Competency areas supported by the educational intervention

Competency area	Educational trigger	Observed manifestation	Management relevance
Technical interpretation	Robot programming and motion logic	Students connected commands with machine behaviour and process consequences	Supports competence mapping to Industry 4.0 roles
Process awareness	Factory visit and sequence observation	Students recognised relationships between machines, flow, quality and coordination	Improves alignment between curriculum and production reality
Systems thinking	Combined laboratory and industrial exposure	Students linked isolated technical tasks with broader socio-technical systems	Strengthens curriculum integration
Communication and questioning	Interactive observation and guided discussion	Students asked more focused procedural and professional questions	Enhances engagement and reflective learning
Professional orientation	Exposure to departments, roles and industrial expectations	Students better understood how study content relates to work contexts	Supports employability and stakeholder value

Source: Author's elaboration

3. RESEARCH METHODOLOGY

This study adopts a qualitative case study approach to examine how an educational intervention can support competency development and enhance the relevance of engineering education in the context of Industry 4.0. Rather than seeking statistical generalisation, the study aims to generate an in-depth understanding of a context-specific educational process and its implications for competency management and educational quality. A qualitative case study is appropriate because it enables the investigation of complex phenomena within their real-life setting and facilitates process-oriented interpretation (Yin, 2018).

The case was conducted during the 2025/2026 academic year at a private university in southern Poland. This institutional context is particularly relevant because practice-oriented private universities operate in highly competitive environments and are under increasing pressure to align educational provision with labour market expectations and technological change.

The educational intervention comprised two integrated components. The first involved laboratory classes using an industrial robot as part of automation and robotics instruction. The second consisted of a structured study visit to a manufacturing company. These

activities were designed as complementary elements of a single learning process, enabling students to connect theoretical knowledge acquired in the laboratory with real industrial practice.

Data were collected through methodological triangulation to enhance the credibility and depth of the analysis (Yin, 2018). Four sources of qualitative evidence were examined: laboratory teaching materials and instructional scenarios, structured classroom observations, documentation and reflective records from the industrial visit, and instructor observations regarding student engagement, participation, and observable learning outcomes. Combining multiple sources of evidence enabled a more comprehensive interpretation of the educational intervention than reliance on a single data source.

The analysis was organised around themes derived from the research questions, including competency development, practical relevance of teaching, student engagement, professional orientation, university-industry collaboration, labour market alignment, and educational quality. These themes were interpreted through the theoretical perspectives of competency management, stakeholder orientation, and quality management in higher education.

As an exploratory study, the research does not seek to quantify competency gains or establish causal relationships. Instead, it identifies mechanisms through which the intervention appears to support competency development and improve the relevance of engineering education. This approach is consistent with qualitative case study methodology, which prioritises analytical insight and theoretical contribution over statistical inference.

The study is guided by four working assumptions. First, integrating industrial robotics into laboratory teaching enhances the practical relevance of engineering education. Second, direct exposure to industrial environments improves students' understanding of engineering practice and professional expectations. Third, combining robotics-based instruction with university-industry collaboration strengthens the alignment between educational outcomes and labour market needs. Fourth, embedding learning activities within authentic technological and organisational contexts enhances the quality and relevance of engineering education.

Several limitations should be acknowledged. The study examines a single institutional case and is based on qualitative observations and interpretive analysis. It does not assess long-term competency development or graduate employability, nor does it compare outcomes across multiple institutions or student cohorts. Nevertheless, the findings provide valuable insights into how relatively small-scale educational interventions can contribute to competency management and curriculum improvement. Future research could extend this work through comparative case studies, student surveys, longitudinal designs, or mixed method approaches to validate and expand the present findings.

4. CASE DESCRIPTION

The educational intervention was implemented at WSB-NLU in Nowy Sącz, Poland, a university that has increasingly emphasised practice-oriented education in fields related to information technology, automation, and modern manufacturing technologies. Within this strategic context, the introduction of industrial robotics was viewed not merely as a teaching innovation but as part of a broader institutional effort to enhance educational quality, curriculum relevance, and responsiveness to labour market needs.

A persistent challenge in engineering education is that students often encounter automation and robotics through simulations, simplified exercises, or theoretical lectures, with limited exposure to real industrial systems. Although these approaches provide an essential conceptual foundation, they frequently fail to capture the complexity of contemporary production environments. The intervention addressed this limitation by integrating ro-

botics-based laboratory instruction with direct exposure to industrial practice.

The first component consisted of laboratory classes using an industrial robot. Students were introduced to robot programming, coordinate systems, motion control, input-output operations, sequence programming, trajectory planning, and basic parameter configuration. Rather than focusing solely on programming techniques, the laboratories were designed to develop an understanding of how control logic translates into physical movement, process execution, and production performance.

From an educational perspective, the laboratory created an environment in which theoretical concepts could be immediately applied and verified. Students observed how modifications to programming commands influenced robot behaviour, reinforcing their understanding of precision, sequencing, safety requirements, and process control. Consequently, the laboratory functioned as a competency-development environment rather than simply a technical demonstration.

The second component involved a structured study visit to a manufacturing company in southern Poland. While the laboratory provided controlled interaction with industrial technology, the factory visit enabled students to observe automation within its organisational context. Participants examined production processes, automation systems, quality control procedures, and coordination between technical and operational functions. This experience demonstrated how engineering decisions contribute to production efficiency, quality assurance, and organisational performance.

Beyond technical observation, the industrial visit broadened students' understanding of engineering practice by illustrating the interaction between technological systems, organisational structures, and managerial processes. It highlighted that automation operates within broader production systems characterised by communication, coordination, quality standards and continuous improvement.

The educational value of the intervention resulted primarily from the integration of both components. Laboratory activities provided opportunities to acquire technical competencies in a controlled environment, whereas the industrial visit contextualised these competencies within authentic production settings. Together, they created a coherent learning sequence that strengthened the connection between theory and practice while enhancing the overall quality and relevance of the educational process.

The case also reflects broader institutional objectives. Universities seeking to strengthen their practical orientation must often balance resource limitations, curriculum requirements, and diverse stakeholder expectations. Consequently, educational innovation depends not only on access to advanced technologies but also on their purposeful integration into programme design. In this respect, the intervention represents a strategic approach to improving engineering education rather than an isolated teaching activity.

5. RESULTS AND DISCUSSION

The intervention produced several educational outcomes relevant to competency management and higher education quality. The most immediate effect was an improvement in students' understanding of technical concepts. Topics that are often perceived as abstract became more accessible once students observed how programming decisions influenced robot movement, sequencing, and process execution. Practical interaction with industrial equipment enabled students to connect theoretical concepts with observable system behaviour, reinforcing the value of experiential learning.

The factory visits further strengthened this understanding by demonstrating that automation is embedded within wider organisational processes. Students observed how production quality, efficiency, safety, and coordination depend on the effective integration

of technical systems with organisational practices. This broader perspective encouraged students to interpret engineering decisions not as isolated technical tasks but as contributors to organisational performance.

A second important outcome was increased student engagement. Practical learning environments encouraged students to ask more focused questions, explore alternative solutions, and actively investigate the operation of industrial systems. Exposure to a real manufacturing environment further enhanced motivation by demonstrating the practical relevance of the knowledge acquired during laboratory classes and illustrating potential career pathways.

The intervention also supported students' professional development by strengthening the connection between academic learning and industrial practice. Rather than perceiving engineering subjects as isolated modules, students gained a clearer understanding of how technical competencies are applied within production systems, quality management, and engineering departments. This contributed to a stronger awareness of professional expectations and graduate employability.

The findings further indicate that the intervention supported the development of competencies associated with Industry 4.0. Students demonstrated improved understanding of automated systems, process logic, sequencing, and system interdependencies while also recognising the importance of communication, observation, and analytical reasoning. These outcomes correspond with previous studies emphasising that modern engineering requires a combination of technical, analytical, and transferable competencies.

From a labour market perspective, the intervention improved the alignment between educational outcomes and employer expectations. Rather than replicating workplace conditions, the educational process enabled students to understand the organisational context in which engineering competencies are applied and the professional capabilities increasingly valued by industry.

The intervention also generated institutional benefits. It reinforced the university's practice-oriented profile, strengthened relationships with industrial partners, and enhanced the visibility of engineering programmes. Such initiatives contribute not only to educational improvement but also to institutional competitiveness, stakeholder confidence, and long-term strategic positioning. However, the findings suggest that these benefits depend on meaningful curriculum integration rather than the simple adoption of advanced technologies.

From the perspective of quality management, the intervention illustrates how educational quality can be enhanced through coherent curriculum design, stakeholder engagement and authentic learning experiences. Educational quality extends beyond compliance with formal standards; it also depends on the extent to which learning activities remain relevant, integrated and responsive to labour market needs.

Finally, the case highlights the importance of reinforcement and guided reflection in competency development. Students encountered similar principles in both laboratory and industrial settings, allowing theoretical knowledge to be consolidated across multiple contexts. Structured reflection supported this process by helping students interpret their observations and connect practical experience with conceptual understanding. These findings suggest that practical learning achieves the greatest educational value when accompanied by deliberate pedagogical guidance and opportunities for critical reflection.

Table 2. Management and quality dimensions of the intervention

Dimension	Before intervention	After intervention	Quality implication
Teaching relevance	Predominantly theoretical framing	Higher connection between theory and observable process logic	Improved curricular fitness for purpose
Stakeholder alignment	Limited direct contact with industrial context	Stronger exposure to employer reality and production expectations	Better alignment with external needs
Student engagement	Topic interest varied and remained partly abstract	More focused questions and stronger professional curiosity	Higher educational effectiveness
Institutional positioning	Practice-oriented profile developing	More visible evidence of authentic technology use and cooperation	Strengthened strategic differentiation
Competency coherence	Technical content partly fragmented	Integrated understanding of technical and organisational logic	Greater internal coherence of learning outcomes

Source: Author's elaboration

6. MANAGERIAL IMPLICATIONS

This study contributes to management and quality sciences by conceptualising competency development as a strategic organisational process rather than solely a pedagogical activity. From this perspective, the central challenge for higher education institutions is to design, implement, and evaluate educational processes that respond to evolving stakeholder expectations while maintaining academic standards. The findings demonstrate that industrial robotics and university-industry collaboration can serve as effective managerial mechanisms for achieving this objective (Freeman, 1984; Evans et al., 2023).

First, the intervention highlights the importance of stakeholder-oriented curriculum design. Educational programmes become more relevant when universities actively consider the expectations of students, employers, and society. Such alignment does not compromise academic autonomy; instead, it enhances the practical value of engineering education while preserving its scholarly foundations.

Second, the findings reinforce the role of quality management in higher education. Educational quality extends beyond formal accreditation and administrative procedures to include curriculum coherence, authentic learning experiences, and meaningful connections between theoretical knowledge and professional practice (Harvey & Green, 1993). By integrating laboratory instruction with industrial experience, the intervention strengthened the consistency and relevance of the learning process.

Third, the study demonstrates that meaningful educational innovation does not necessarily require large-scale investments. Even relatively modest initiatives can generate significant educational and organisational benefits when they are strategically designed and embedded within the curriculum. This finding is particularly relevant for institutions operating under financial or infrastructural constraints, where effective educational management depends more on purposeful design than on technological scale.

Fourth, the case illustrates that university-industry collaboration should be viewed as an integral component of educational quality rather than as a promotional or symbolic activity. When industry partnerships directly influence curriculum design and learning experiences, they enhance educational relevance, strengthen stakeholder relationships, and support institutional development.

Fifth, the findings suggest a practical approach to competency governance. Competencies are first identified through labour market requirements and curriculum objectives,

then developed through authentic learning activities, reinforced through industrial experience, and consolidated through structured reflection. This sequence demonstrates that competency development can be systematically planned, implemented, and evaluated as part of an institution's quality management strategy.

Finally, the study has implications for internal quality assurance. In addition to conventional indicators such as student satisfaction and course evaluations, quality systems should assess the authenticity of learning activities, the extent of industry engagement, and the alignment between intended learning outcomes and professional practice. Such an approach would provide a more comprehensive assessment of educational effectiveness and graduate preparedness.

Beyond its practical implications, the study offers a conceptual foundation for future research by positioning competency management as a bridge between management, quality assurance, and engineering education. This perspective provides opportunities for further investigation into programme governance, stakeholder management, educational innovation, and institutional adaptation in response to technological change.

6.1. A QUALITY-ORIENTED MODEL OF EDUCATIONAL INTERVENTION

Based on the findings, a quality-oriented model of educational intervention can be proposed. The model comprises five interconnected stages: (1) identification of competency requirements, (2) translation of these requirements into curriculum design, (3) implementation through authentic technological learning, (4) contextualisation through university-industry collaboration, and (5) reflection and competency consolidation. Each stage contributes to both educational quality and competency management.

The first stage involves identifying competencies demanded by the labour market, particularly those associated with Industry 4.0, including automation, robotics, digital technologies, and process-oriented thinking. The second stage translates these requirements into learning objectives, teaching methods, curriculum content, and resource allocation. At this stage, managerial decisions concerning infrastructure, partnerships, and educational planning play a crucial role.

The third stage focuses on authentic technological learning through direct interaction with industrial equipment. In the present study, this was achieved through robotics-based laboratory instruction, allowing students to develop practical competencies in a controlled educational environment. The fourth stage extends this learning through direct exposure to industrial practice. The factory visits enabled students to observe how technological systems operate within organisational processes, thereby strengthening the connection between technical knowledge and professional practice.

The final stage emphasises reflection and competency consolidation. Guided discussion enables students to interpret their experiences, integrate theoretical and practical knowledge, and understand the broader organisational significance of the competencies they have developed.

From a quality management perspective, this model demonstrates that educational effectiveness depends not on isolated innovations but on the coherence of the entire learning process. It also provides a framework for future empirical research, as each stage can be operationalised through competency indicators, curriculum evaluation measures, stakeholder feedback, or quality assessment criteria. Consequently, the model offers a practical foundation for designing, managing, and evaluating educational interventions that support competency development in the context of the digital economy and Industry 4.0.

7. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

This study has several limitations that should be acknowledged. First, it is based on a single institutional case and, therefore, the findings cannot be generalised to all higher education contexts. Second, the analysis relies on qualitative observations and interpretive evidence rather than standardised measures of competency development or student perceptions. Third, the study captures only one stage of the educational process and does not examine long-term outcomes such as graduate employability, competency retention, or differences across student cohorts. These limitations are consistent with the exploratory nature of qualitative case study research (Yin, 2018).

Despite these limitations, the study provides a foundation for future research. Subsequent studies could incorporate student surveys to assess perceived competency development, professional readiness, and the educational value of robotics-based learning. Developing competency frameworks based on Industry 4.0 requirements would also facilitate systematic comparisons between intended and achieved learning outcomes while strengthening methodological rigour.

Comparative research across universities would further enrich understanding of how similar interventions perform in different institutional settings, engineering disciplines, and forms of university-industry collaboration. Longitudinal studies could examine whether practical industrial exposure influences graduates' employability, adaptability and career development after entering the labour market.

Future research may also develop an integrated framework linking stakeholder expectations, competency management, educational quality and university-industry collaboration. Such a framework would contribute to management and quality sciences by explaining how higher education institutions can strategically design educational processes that respond to technological and labour market change.

8. CONCLUSION

This study examined how industrial robotics and university-industry collaboration can support competency management in engineering education within the context of the digital economy and Industry 4.0. Drawing on a qualitative case study conducted at a private university in southern Poland, the findings demonstrate that integrating robotics-based laboratory instruction with a structured industrial study visit enhances the relevance and quality of the educational process. The intervention strengthened the connection between theoretical knowledge and industrial practice, increased student engagement, improved professional awareness, and supported the development of competencies associated with Industry 4.0. At the institutional level, it reinforced the university's practice-oriented profile and strengthened cooperation with industry partners. More importantly, the findings suggest that competency development should be understood as a strategically managed educational outcome rather than a by-product of traditional teaching. From the perspective of management and quality sciences, the study highlights that educational quality depends on the alignment between curriculum design, stakeholder expectations, authentic learning environments and competency development. In this context, industrial robotics represents more than a technological teaching tool; it serves as a mechanism for enhancing curriculum relevance, supporting university-industry collaboration, and improving the overall quality of engineering education. Overall, the study demonstrates that robotics-based experiential learning, supported by meaningful collaboration with industry, provides a practical and scalable approach to preparing engineering graduates for the digital economy. By integrating competency management, stakeholder orientation, and quality enhancement within a single analytical framework, the paper contributes to

the growing literature on higher education management and offers a foundation for future research on educational innovation in the era of Industry 4.0.

REFERENCES

Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: The path to Industry 4.0. *Procedia Manufacturing*, 9, 73-80. https://doi.org/10.1016/j.promfg.2017.04.022

Biggs, J., & Tang, C. (2011). Teaching for quality learning at university: What the student does (4th ed.). *Open University Press*. https://books.google.pl/books/about/Teaching_For_Quality_Learning_At_Univers.html?id=XhjRBrDAESkC&redir_esc=y

Coşkun, S., Kayıkcı, Y., & Gençay, E. (2019). Adapting engineering education to Industry 4.0 vision. *Technologies*, 7(1), 10. https://doi.org/10.3390/technologies7010010

Das, S., Kleinke, D., & Pistrui, D. (2020). Reimagining engineering education: Does Industry 4.0 need Education 4.0? In Proceedings of the ASEE Virtual Annual Conference. https://www.researchgate.net/publication/339983822_Reimagining_Engineering_Education_Does_Industry_40_Need_Education_40

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and Mode 2 to a Triple Helix of university-industry-government relations. *Research Policy*, 29(2), 109-123. https://doi.org/10.1016/S0048-7333(99)00055-4

Evans, N., Miklosik, A., & Du, J. T. (2023). University-industry collaboration as a driver of digital transformation: Types, benefits and enablers. *Heliyon*, 9(10), e21017. https://doi.org/10.1016/j.heliyon.2023.e21017

Freeman, R. E. (1984). Strategic management: A stakeholder approach. *Pitman*. https://books.google.pl/books?id=NpmA_qEiOpkC&printsec=frontcover&hl=pl&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Harvey, L., & Green, D. (1993). Defining quality. Assessment & Evaluation in Higher Education, 18(1), 9-34. https://doi.org/10.1080/0260293930180102

Khan, S. H., & Mourad, A. H. I. (2025). Integrating Industry 4.0 in engineering education: Implementation patterns, pedagogical strategies, and industry alignment. *Cogent Education*, 12(1), 2588010. https://doi.org/10.1080/2331186X.2025.2588010

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by Industry 4.0. *Technology in Society*, 64, 101454. https://doi.org/10.1016/j.techsoc.2020.101454

Pekarcikova, M., Trebuna, P., Kliment, M., Kronova, J., & Matiscsak, M. (2025). Educational robotics for Industry 4.0 and 5.0 with Wlkata Mirobot in laboratory process modelling. *Machines*, 13(9), 753. https://doi.org/10.3390/machines13090753

Tembrevilla, G., Phillion, A., & Zeadin, M. (2024). Experiential learning in engineering education: A systematic literature review. *Journal of Engineering Education*, 113(1), 195-218. https://doi.org/10.1002/jee.20575

Vila, C., Ugarte, D., Ríos, J., & Abellán, J. V. (2017). Project-based collaborative engineering learning to develop Industry 4.0 skills within a PLM framework. *Procedia Manufacturing*, 13, 1269-1276. https://doi.org/10.1016/j.promfg.2017.09.050

Vilalta-Perdomo, E., Michel-Villarreal, R., & Thierry-Aguilera, R. (2022). Integrating Industry 4.0 in Higher Education Using Challenge-Based Learning: An Intervention in Operations Management. *Education Sciences*, 12(10), 663. https://doi.org/10.3390/educsci12100663

Yin, R. K. (2018). Case study research and applications: Design and methods (6th ed.). SAGE Publications. https://ebooks.umu.ac.ug/librarian/books-file/Case%20Study%20Research%20and%20Applications.pdf

UDK 33(082) (0.034.2)

ISSN 2831-1736

