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*THE INNOVATIVE ECONOMY IN TIMES OF GLOBAL CHALLENGES:
NEW APPROACHES TO GROWTH AND A SUSTAINABLE FUTURE*



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*"The Innovative Economy in Times of Global Challenges:
New Approaches to Growth and a Sustainable Future"*



Oikos Institute - Research Center Bijeljina
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3

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DECENTRALIZATION IN INTERNATIONAL PAYMENTS AND THE EVOLVING ROLE OF SWIFT

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ABSTRACT

The decentralization of international payments is emerging as a transformative trend in the global financial system, driven by blockchain technology, decentralized finance (DeFi), cryptocurrencies, and central bank digital currencies (CBDCs). This paper explores the shift from traditional, centralized payment infrastructures toward decentralized alternatives, assessing their impact on transaction efficiency, cost reduction, financial inclusion, and financial stability. A special focus is placed on the evolving role of the Society for Worldwide Interbank Financial Telecommunication (SWIFT), historically the backbone of international cross-border payments. Through a combination of theoretical review and empirical time series analysis based on SWIFT message data from 2014 to 2022, the study evaluates SWIFT's resilience and adaptation in the face of decentralization pressures. The findings reveal a permanent upward trend in SWIFT traffic, coupled with seasonal fluctuations, suggesting that while decentralization is expanding, SWIFT remains a central actor by innovating its infrastructure. The study also discusses the regulatory challenges posed by decentralized systems and the need for balanced frameworks to foster innovation while safeguarding stability. This research concludes that international payments, where traditional and decentralized models seem to coexist.

Keywords: Decentralization, International Payments, Blockchain, SWIFT, Cross-Border Transactions

1. INTRODUCTION

Decentralization in international finance and payments is the process of reducing or eliminating central authority in managing financial resources and operations, which allows participants to interact directly with each other. Traditional financial systems rely on intermediaries such as banks, regulators and government institutions to guarantee the validity and security of transaction (Zhukeyvych and Zhuk, 2023). Decentralization mainly changes this dynamics, minimizing the need for such intermediaries, thus expanding access to financial resources and information (Schär, 2021). By accepting decentralized mechanisms, consumers can get a greater control and transparency in their financial activities, while traditional goalkeepers lose their monopoly on financial transactions.

The key elements of decentralization in international finance include decentralized financing technologies (DeFi), digital currencies and declining reliance on traditional reserve currencies (Petkova, 2025). Defi Platforms use Blockchain technology to allow automated intelligent contracts and partner transactions without centralized management, leading to lower costs and faster transfers (Wer-

ner et al., 2021). In addition, cryptocurrencies such as Bitcoin and Ethereum have introduced decentralized funds for conducting international payments managed by consumer communities instead of governments or banks (Catalini and Gans, 2020). Moreover, decentralization encourages nations and corporations to explore alternative transactions and reserves, striving to reduce its dependence on dominant reserve currencies such as the US dollar (Naby and Berg, 2023).

Despite its advantages, decentralization poses significant regulatory challenges (Suherman et al., 2024). The lack of centralized supervision masters the ability of the authorities to monitor and control cash flows, increasing the risks of financial violations, money laundering and illegal activities (Ganne, 2022). Nevertheless, decentralized systems also improve transparency and security, as transaction data stored in distributed networks are highly resistant to seasoning or compromise. Overall, the decentralization of international finance and payments brings the promise of democratization of the global financial system by increasing the autonomy of participants, reducing transaction costs and improving efficiency - providing that adequate regulatory frameworks are developing to deal with the risks.

The subject of the present research is the process of decentralization in international payments and its impact on the traditional role of SWIFT (Society for Worldwide Interbank Financial Telecommunication). The purpose of this research paper is to examine the extent to which decentralized financial technologies influence transaction efficiency, cost reduction, financial inclusion, and the regulatory landscape, while also evaluating how SWIFT is adapting to these new developments. The research seeks to assess whether decentralized alternatives threaten SWIFT's established position or whether SWIFT is capable of evolving to remain a key player in the international payment ecosystem.

To achieve these goals, the paper provides a theoretical analysis of decentralization trends, conducts an empirical analysis of SWIFT's market share and performance (measured through the average number of messages per day), and examine the technological and regulatory developments affecting the future of international payments. The methodology involves time series analysis, forecasting models based on IBM SPSS and R software, and the decomposition of seasonal and trend components of SWIFT message data from 2014 to 2022.

2. LITERATURE REVIEW

The international payments landscape is in the midst of significant change, spurred by the development of decentralised technologies and the continued need for more efficient, transparent and inclusive financial systems (Scott and Zachariadis, 2013). While traditional systems such as SWIFT have been the default choice for cross-border transactions for many years, their limitations in terms of speed, cost and inclusiveness are now becoming increasingly apparent (Sheela et al., 2023). This has prompted the rise of alternative payment systems, some of which make use of distributed ledger technology, among other novel features, to remedy the limitations of current infrastructure (He, 2017). Banking's capacity to deliver both diversified and secured as well as convertibility-based two-way solutions for dealing with the rest of the world is a crucial ingredient in international currency attractiveness (Narlikar 2005). If access to US dollar becomes more unstable, e.g. because of bank crises, the need for more diversified payment and a desire to use local currencies will increase, with a particular focus on Asia (Narlikar 2005). This change represents both a threat and a possibility for SWIFT, the Society for Worldwide Interbank Financial Telecommunication; that is, the organization that traditionally has been the core of international financial messaging (Scott and Zachariadis, 2013).

SWIFT has established itself as an international payments powerhouse by being not only a network, but also a standardized messaging mechanism and an established brand of security and stability (Barbosa, 2020). But the emergence of decentralized finance and other alternatives for the movement of money are driving a reckoning inside SWIFT about where it adds value and whether it is capable of keeping up with the demands of the changing global financial ecosystem. The cost of the initial investment in SWIFT adoption (hardware, software, services, and IT-literate human resource) can be substantial, but medium-to long-term running costs are expected to fall as banks converge towards the use of newer, more flexible development technologies and maintenance costs of obsolete systems are reduced (Liu, 2021). SWIFT enables financial institutions to exchange pay-

ment instructions, but does not process any of these payments itself, in place using correspondent banking relationships and even other platforms to settle the transactions (Jereni and Sundire, 2023). This dependence on intermediaries results in inefficiencies, delays, increased cost, and the resulting slower and more expensive nature of cross-border payments when compared with domestic payments. SWIFT's constraints have been exposed in the digital economy, where enterprises and consumers demand faster, cheaper, and more transparent payment services.

SWIFT's architecture, while robust, can be seen as a centralized system, subject to geopolitical influences and potential vulnerabilities (Köppel, 2011). The network facilitates financial institutions to securely exchange messages regarding financial transactions (Boz et al., 2020). The US dollar and the Euro have a strong market share in global trade (Narlikar, 2005). Logically, China's currency, which is still subject to relatively stringent exchange controls, notably on non-trade transactions, has a share of world payments significantly lower than its share in world trade (Narlikar, 2005). The increasing use of sanctions and other politically motivated restrictions on access to the SWIFT network has further fuelled the search for alternative payment systems that are less susceptible to external interference. Also, local currency financing and pricing have many advantages in a commercially-integrated zone (Narlikar, 2005). The current systems have inefficiencies originally designed for retail banking and is based on rules and risks (Hamza et al., 2023). Some commentators have argued that part of the reason could be the limited incentives for banks to use it as opposed to their own correspondent banking channels as well as the lack of awareness of its existence among households and corporates (Drakopoulos, 2024).

Decentralized payment systems, particularly those based on blockchain technology, offer a potential alternative to SWIFT by eliminating intermediaries, reducing transaction costs, and enhancing transparency (Owolabi et al., 2024). The introduction of the Euro led to a relatively stable duopoly in currency use over the past decade - albeit there is no market barrier-to-entry preventing another large currency from being supplied and actually having success (Narlikar, 2005). The creation of the euro increased the hierarchy between the main two currencies, and other currencies, in respect of these standards. The main driver of RMB international development is hence for the time being of regulatory nature. By leveraging distributed ledger technology, these systems can facilitate peer-to-peer transactions without the need for a central authority, thereby reducing the risk of censorship and control (Sussangkarn, 2020).

New empirical literature has started to evaluate real-world operational and technological efficiency of DeFi applications. For instance, Adamyk et al. (2025) introduce a utility-based methodology for comparing DeFi transaction tracking platforms using 3 key performance indicators: the ability to perform real-time monitoring, system risk reduction and user trust help. According to their research, although DeFi platforms can outperform traditional systems in transaction transparency and auditability, they still have a problem with fragmentation and the lack of standardized compliance. Including these metrics offers a comparative baseline to indicate the advantages and disadvantages of centralized (SWIFT) vs. decentralized infrastructures.

Digital currencies also diminish reliance on the U.S. dollar-dominated financial system (Pocher and Veneris 2021). The disrupt for global payments isn't simply replacing SWIFT, it's about building a broader and more distributed architecture that includes both traditional systems and open systems like Ripple. It is the worlds' central banks that are driving development and evolution of these digital forms of payment (Prodan et al., 2024).

Advances in distributed ledger technology and digital assets are opening up new possibilities for cross-border payments, but they are also new challenges for regulators and policy makers. Such alternative payment systems could work easily alongside SWIFT, and offer users more choice, as well as ramping up competition in the international payments space. Around the world, central banks are looking at the possibility of issuing a central bank digital currency and some are already experimenting with one (Tan, 2023). Though the development of digital currencies is in an early phase, a well-designed system would lower the cost of domestic and cross-border transactions, improve settlement of payments enabling real time payments, increase access to central bank money, add programmable payments and encourage innovation (Yanagawa and Yamaoka, 2019; Broby, 2021).

CBDCs may also mitigate counterparty credit risk, liquidity risk, and settlement risk. A number of central banks are in the process of conducting work on the possibilities and implications of issuing digital currency and the extent to which these virtual currencies would help in address current challenges of payment systems and improving the degree of financial inclusion (Aysan and Kayani, 2022). The benefits of central bank digital currency are numerous such as ability to provide lower cost transaction fee in comparison to that charged by banks/companies, enhanced cross-border remittances, improved financial inclusion (Ozili, 2022).

3. THE TREND OF DECENTRALIZATION IN INTERNATIONAL PAYMENTS

International finance and payment decentralization is an act of reduction or removal of central authority control on management of financial resources and operations. Individual participants can directly interact without permission of authority. By removing the need for banks, regulators, and other government agencies to act as trusted intermediaries, decentralization enhances participants' access to resources and information. Their autonomy expands by lowering costs and increasing the speed of transactions.

The main drivers of decentralization of the international finance are:

- Decentralized financial technology (DeFi), created with the ability to allow the implementation of automated contracts and transaction networks without any central control. This enables end-to-end user transactions excluding state and bank systems.
- Digital currencies and cryptocurrencies, like Bitcoin and Ethereum, that has introduced new possibilities for conducting international payments. These currencies are decentralized and are managed by the communities who use them, rather than by governments or banks.

3.1. DECENTRALIZED FINANCIAL TECHNOLOGIES (DEFI)

Decentralized finance (DeFi) is not a formal legal or technical term but is widely used to describe the evolving ecosystem of financial services that operate without traditional intermediaries. It typically involves decentralization, distributed ledger technologies (DLT), smart contracts, disintermediation, and open banking (Zetsche, Arner and Buckley, 2020).

Although DeFi projects like Bitcoin are based on DLT and blockchain, decentralization can be attained in other ways. A lot of banks rely on distributed ledgers which are still centrally controlled. Thus, decentralization does not necessarily imply distribution, and disintermediation is sometimes a consequence, rather than a precondition. DeFi ultimately encompasses the delivery of financial services over decentralized infrastructures, technologies, and counter-parties (Walch, 2019).

DeFi, which operates on permissionless blockchains, differs from traditional finance (TradFi), in which there are intermediaries, slower and more expensive settlements, and no public transparency. Through smart contracts, direct peer-to-peer interaction is enabled and since the code is immutable, no one has the ability to change any transactions that were implemented. These attributes build confidence by openness and not by a single controlling source of authority.

DeFi provides lending, saving, trading, insurance, and payment services via Decentralized Applications (dApps) that are built on top of blockchain networks. dApps turn cryptic protocols into easy-to-use financial instruments. Unlike centralized software, they run on censorship-resistant networks and most are open-source, which allows for public auditability and trust.

These blockchains are secured by consensus mechanisms like Proof-of-Work (PoW) and Proof-of-Stake (PoS). dApps reward users with tokens to promote operational quality and transparency. Their global nature means anyone with internet can access DeFi services, transcending obstacles encountered in traditional banking systems.

DeFi platforms serve as user interfaces for decentralized finance, offering exchanges (DEXs), lending, insurance, derivatives, and asset management. One milestone is the development of the Automated Market Makers, which replaced centralized order books with algorithms that adjust prices and execute trades based on liquidity. Decentralized autonomous organizations (DAOs) additionally decentralise governance as they permit communities to govern projects through the use of smart contracts.

This approach improves the efficiency and accessibility of financial services (Schär, 2021). DAOs and open-source protocols promote community-led innovation and governance (Jensen and Ross, 2021). Programmable blockchains such as Ethereum and Solana support diverse services like token swaps, margin trading, and ownership verification of real or digital assets.

The primary benefits of DeFi include accessibility, faster transaction rates, reduced costs, transparency, and faster innovation cycles. Services are international, lowcost, and not bordered by traditional financial systems. Users can see past transactions and join in on influencing platforms through governance by tokens. Furthermore, DeFi allows to quickly launch new financial products. If dissatisfied, communities can fork code to launch their own competing platforms.

DeFi also presents serious risks and challenges. First, the open-source code and the high value of funds involved mean that DeFi protocols are at risk of getting hacked. Second, the lack of regulation can lead to abuse and high market volatility. Third, even for technically proficient users, DeFi services can be complex and difficult to use. Fourth, as an emerging financial concept, DeFi naturally carries risk. A key question concerns responsibility: who is accountable for a user's mistake during a transaction, especially given that blockchain-based actions are irreversible. The technology executes the user's intention, and if incorrect, that will be encoded and automatically enforced by the smart contract embedded in the dApp. Even though many DeFi tokens have already provided high returns, they come with considerable risk and price volatility, often exceeding that of well-established digital assets like Bitcoin and Ethereum. They are also relatively less liquid and therefore more vulnerable to dramatic price movements. The anonymity of DeFi participants makes transactions vulnerable to cyberattacks, hacks, and fraud. This may result in the loss or theft of funds without access to remedial recourse. However, regulatory environments are beginning to mature.

3.2. DIGITAL CURRENCIES AND CRYPTOCURRENCIES

One big aspect of decentralization of international payments is the advent of digital currencies, and cryptocurrencies – e-money that exists solely in digital form, something that is not physical, and in many cases, not controlled by a central body. Though both are digital, digital currencies all can be centralized or decentralized, while cryptocurrencies are based exclusively on decentralized systems and cryptographic security.

These digital currencies are a combination of government-issued Central Bank Digital Currencies (CBDCs) such as China's digital yuan (e-CNY) and decentralized assets. CBDCs represent the value of traditional money, but they only exist in electronic, not physical, form and are accessed through digital wallets and apps. They are used for e-commerce and online payments, and are controlled by institutions such as central banks.

Cryptocurrencies operate independently of state control. They leverage blockchain to record and verify transactions, providing more privacy, lower fees and global accessibility. Transacted over the internet, stored in a specialized type of software called a crypto wallet, the assets are transparent yet anonymous in many cases, which makes them attractive but also vulnerable to cyberattacks, steep price fluctuations and uncertain regulatory status.

Regulatory advancements and a more widespread adoption of CBDCs will define the future of digital currencies. The move towards digital asset management and transactions can also be seen in cryptocurrencies extending into DeFi, NFTs and virtual worlds.

Decentralization can also help nations and companies in reducing reliance on dominant reserve currencies such as the US dollar or euro. Now more than ever this is crucial for developing countries seeking greater independence in the world trading and financial system.

The pace of this trend is likely to accelerate with technological innovations in FinTech (Rutendo Magwedere and Marozva, 2025; Abdo et al., 2025). Innovations such as blockchain-based payments, digital wallets, neobanks, and P2P platforms threaten the domination of centralized systems such as SWIFT by allowing for faster, cheaper, and more secure transfers (Statista, 2023). Recent trends in the worldwide financial services market indicate a radical transformation towards decentralization and digitization. Aquilina, Frost and Schrimpf (2023) explain that the DeFi growth is driving forward the demands for instant settlement, user-driven interfaces, and automation through smart

contracts. These developments reflect broader technological innovations, such as mobile-first platforms, AI-based fraud detection, and embedded finance, which are disrupting traditional financial infrastructure. This trend is a major move toward decentralization that reduces the dependency on traditional, central clearing and settlement systems.

While SWIFT remains a critical backbone for global financial messaging, the growing preference for instant, decentralized payment networks forces it to innovate. For example, SWIFT has been transforming itself through programmes such as its Global Payments Innovation (gpi) initiative, which it is also anchoring within ISO 20022, an effort to increase the speed, transparency and interoperability of payments. These all prove the increasing institution-demand for real-time financial infrastructure, and bring pressure to legacy systems like SWIFT to evolve beyond the traditional batch-processing approach. These technological expectations are coherent with the decentralisation spirit, where speed, automation and user access are the basics.

Central banks around the world are also adjusting their strategies to the decentralization. Distributed ledger technology (DLT), stablecoins, and central bank digital currencies (CBDCs) are among the technological innovations embraced by many central banks to extend financial inclusion and upgrade settlement systems. Tan (2023) observes that CBDCs have the potential to reduce transaction costs, facilitate programmable payments, and increase central bank money in the digital era. Aysan and Kayani (2022) point out the strategic and financial motivations for digital currency issuance, especially when emerging markets are aiming to lower reliance on dominant reserve currencies. These institutional changes signal that CBDC creation is not just about a monetary innovation but also an attempt by central banks to react to the overall decentralization in global payments.

This institutional change indicates a reconstitution of central banks' roles: from being the sole keepers of monetary infrastructure towards becoming collaborative agents in programmable and interoperable payment ecologies. The trial of CBDCs could marginalize SWIFT or push it to serve as a backbone for regulated digital payments. SWIFT's development is one of strategic evolution – SWIFT is already exploring a range of potential solutions for CBDC interoperability and updating its messaging standards to accommodate the decentralised architectures in development. So, while that decentralization is disrupting the world of international payments, SWIFT is also transforming and demonstrating further hybridization where traditional infrastructures coexist and adapt alongside new decentralized systems.

4.METHODOLOGY OF THE STUDY

Stage 1: In the statistical literature, there are several methods for checking the presence of a development trend in each dynamic series. It was used Autocorrelation coefficient. „It is usually considered that time series that have a development trend are autocorrelated, each member of the series depends on the previous one“ (Atanasov, 2018). The coefficient has the form:

$$r_1 = \frac{\sum_{t=2}^N Y_t Y_{t-1} - \frac{1}{N-1} \sum_{t=1}^{N-1} Y_t \sum_{t=2}^N Y_t}{\sqrt{\left[\sum_{t=1}^{N-1} Y_t^2 - \frac{1}{N-1} \left(\sum_{t=1}^{N-1} Y_t \right)^2 \right] \left[\sum_{t=2}^N Y_t^2 - \frac{1}{N-1} \left(\sum_{t=2}^N Y_t \right)^2 \right]}} \quad (1)$$

r_1 - autocorrelation coefficient;

Y_t - average number of SWIFT messages per day in year t ;

N - number of general population.

Stage 2: The seasonal component was examined using the actual to smoothed values method. This was done for the 12-month periodicity, as in the “12-months moving average“ (Macauley, 1931). The formula has the form:

$$\hat{Y}_7 = \frac{\frac{Y_1}{2} + Y_2 + Y_3 + \dots + Y_{12} + \frac{Y_{13}}{2}}{12} \quad (2)$$

Y_i - average number of SWIFT messages per day in year t ;

$\hat{Y}_i$ - estimated amounts of average number of SWIFT messages per day in year t .

Stage 3: For the purposes of the analysis, the dynamic series of the indicator “Average number of SWIFT messages per day” was studied. When model the time series, trends, seasonal and random components were included due to the presence of the trend and the nature of the monthly data. The components of the studied series are represented by the function:

$$Y = f(T, S, \varepsilon) \quad (3)$$

The model following multiplicative form:

$$ANT_t = T_t * S_t * \varepsilon_t \quad (4)$$

ANT_t is average number of transactions per day (in millions);

S_t is the seasonal index;

ε_t is random component;

T_t is tend component, where ($T_t = \beta_0 + \beta_1 * t$);

β_0 is constant;

β_1 is the regression coefficient;

t is time.

Stage 4: Considering the specificity of the data, the exponential smoothing method was used in the forecasting. The estimated amount is presented in the following form:

$$\hat{Y}_{t+1} = \alpha Y_t + \alpha(1 - \alpha)Y_{t-1} + \alpha(1 - \alpha)^2 Y_{t-2} + \dots + \alpha(1 - \alpha)^k Y_{t-k} \quad (5)$$

Y_t - average number of transactions per day (in millions) for t -period;

Y_{t-k} - lag amounts of the studied order average number of transactions per day;

- parameter . The larger the amount, the more weight is given to the last members of the time series.

Limitations of the present research:

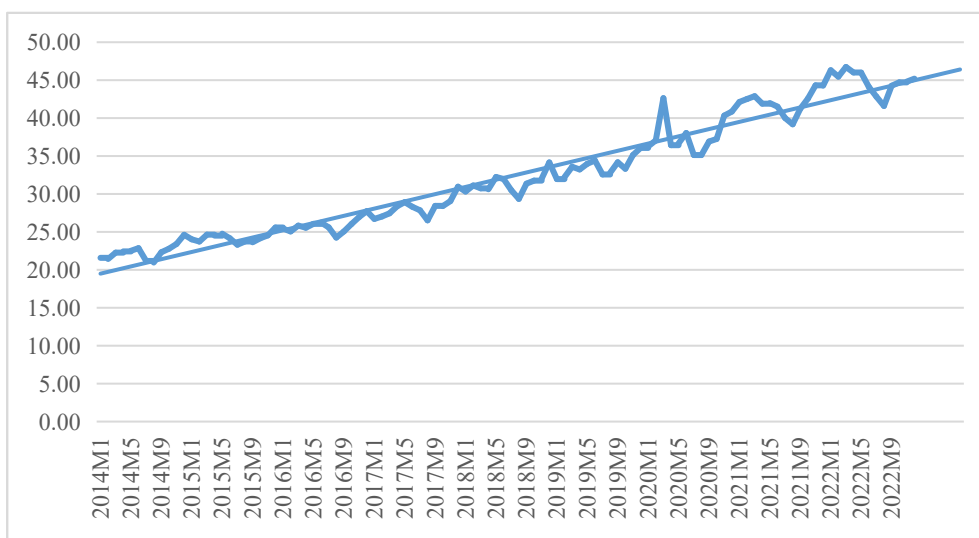
- The analysis is restricted to monthly global data on the average number of SWIFT messages per day between January 2014 and December 2022. Additionally, the research focuses on SWIFT as the central institution of analysis and does not cover every alternative decentralized payment platform in the empirical section.
- Another limitation is that the study forecasts future trends based only on historical data patterns without incorporating disruptive geopolitical, technological, or regulatory shifts beyond the models' assumptions.
- Due to the limitation of the length of the time series, namely 9 years. The forecast is prepared for approximately 20% of the time series. The article presents a forecast for the period from January 2023 to December 2024. The available data for “Average number of SWIFT messages per day” (Statista, 2025) in Statista are for the period January 2014 to December 2022 for the worldwide, therefore the study and analysis is limited to the study of this period. The analysis of the dynamics of Average number of SWIFT messages per day in the article is limited to the study of the permanent development trend and forecasting the future development through an appropriate forecast.
- The specialized statistical software IBM SPSS was used in this study.

The objective of the forecasting exercise is to evaluate whether SWIFT's message volume trends reflect institutional inertia or an active strategic response to decentralization pressures. By modelling future usage, we aim to assess whether SWIFT remains robust amid emerging alternatives.

5. EMPIRICAL ANALYSIS

The data for the variable “Average number of SWIFT messages per day” (Statista, 2025) are presented by months. This is a sufficient indicator to examine development trend and seasonality. The trend is presented in Figure 1.

Figure 1. Average number of SWIFT messages per day – trend line



Source: Authors' contribution based on data by Statista, 2025

The data for “Average number of SWIFT messages per day” are monthly, which defines the dynamic series as periodic. The same recurrence is observed in it. In the same month of August in each year, decreases are observed. In the same months, increases are observed, namely December. This is an indicator of the presence of seasonality. Seasonality is examined in more detail at a later stage, and in addition to a practical approach, it is also studied through an analytical approach. Over time it exhibits an upward development trend. The shapes of the seasonal fluctuations on the graph are not completely identical, which suggests that there is a random component. “The mode of coupling is determined by the amplitude of the seasonality of the phenomenon during the period under consideration” (Bozev, 2014). Undoubtedly, in the current dynamic series, an increase in amplitude is observed at the end of the period, which is why the relationship is defined as multiplicative.

The analytical approach was used to determine the main components. The results of the analysis show that there is a development trend in the dynamic series. In ACF plot the first autocorrelation coefficient (the first pillar) goes beyond the limits of the confidence interval. The average number of SWIFT messages have a periodicity of 12, because the presented data are for each 12 months. This coefficient number also goes beyond the limits of the confidence interval. This shows that there is a clearly expressed seasonality in the average number of SWIFT messages. It can be stated that in the analysed time series there is a permanent development trend, a seasonal and a random component.

Table 1. Trend modelling results

Coefficients	B	Std. error	t	Sig
(Constant)	19,21	0,227	84,63	0,000
t	0,239	0,004	66,76	0,000
F(4376,7)				0,000
R - 0,988				
R Square - 0,976				

Source: Authors' contribution based on data by Statista, 2025

In Table 1 the results of the trend modelling are presented. In studying the trend of the average number of SWIFT messages per day, the linear model was chosen as the best model. Table 1 presents the results of the

analysed model, the estimated model parameters and their statistical significance. 97.6% of the variation in the time series can be explained by the presence of a linear trend in its dynamics. There is a reason to believe that the model is adequate $F(4376.7)$ $\text{Sig}=0.000 < \alpha=0.05$. The results of the model show that there is an average growth in the average number of SWIFT messages per day monthly to the amount of 0.239 million. After performing diagnostics of the studied model, it can be stated that the distribution of the residuals is close to normal. The presence of autocorrelation has been established. As noted earlier, this is an indicator of the presence of a trend in the time series. Therefore, in the study of this series, one of the most common measures has been taken, namely “introducing time as an independent variable in the regression model” (Atanasov, 2018).

Due to the linear form of the model, it has the form:

$$\hat{Y}_t = \beta_0 + \beta_1 t_1 \quad (6)$$

In the study of the seasonal component of the average number of SWIFT messages per day, seasonality indices were established. They are presented in Table 2.

Table 2. Results of the study of the seasonal component (Seasonal Factors)

Period	Seasonal Factor (%)	Index (%)
January	101,7	1,7
February	101,4	1,4
March	103,2	3,2
April	101,3	1,3
May	102,5	2,5
June	101,0	1,0
July	96,2	-3,8
August	93,3	-6,7
September	97,2	-2,8
October	98,0	-2,0
November	100,5	0,5
December	103,5	3,5

Source: Authors' contribution based on data by Statista, 2025

The largest increases in the index were observed in March and December. In March, the average number of SWIFT messages per day was 3.2% higher than the average amount for the period under review. In December, the average number of SWIFT messages per day was 3.5% higher than the average amount for the period under review, which is due to the seasonal nature of the phenomenon. In August, the largest decrease in the index was observed. In August, the average number of SWIFT messages was 6.7% lower than the average.

The seasonal fluctuations, particularly the consistent December peak and August low point, can be linked to the institutional and operational rhythms in the global banking system. The December peak corresponds to an increased financial activity tied to year-end settlements, corporate reporting, and fiscal closures. The August decline reflects widespread holiday periods and reduced institutional throughput in key financial centres. Structurally, the upward trend in SWIFT messages aligns with the network's ongoing modernization, including the Global Payments Innovation initiative and gradual implementation of ISO 20022 standards. These innovations aim to address competition from decentralized systems by improving speed, traceability, and interoperability. As such, the seasonal and structural components of the data do not merely reflect operational patterns but are indicative of SWIFT's adaptive strategies in a shifting financial landscape.

Table 3. Predicted amounts

Time	Forecast	UCL	LCL
Jan 2023	46,22	48,13	44,32
Feb 2023	46,09	48,11	44,08
Mar 2023	47,63	49,75	45,50
Apr 2023	46,29	48,49	44,09
May 2023	46,95	49,25	44,65
Jun 2023	46,75	49,13	44,36
Jul 2023	44,73	47,15	42,31
Aug 2023	43,81	46,29	41,33
Sep 2023	45,92	48,53	43,31
Oct 2023	46,35	49,05	43,66
Nov 2023	47,72	50,54	44,91
Dec 2023	49,08	52,00	46,15
Jan 2024	49,13	52,19	46,06
Feb 2024	48,98	52,09	45,86
Mar 2024	50,59	53,83	47,35
Apr 2024	49,16	52,39	45,92
May 2024	49,84	53,16	46,52
Jun 2024	49,61	52,97	46,24
Jul 2024	47,46	50,78	44,13
Aug 2024	46,47	49,80	43,14
Sep 2024	48,69	52,18	45,20
Oct 2024	49,14	52,70	45,57
Nov 2024	50,57	54,26	46,89
Dec 2024	51,99	55,80	48,19

Source: Authors' contribution based on data by Statista, 2025

Table 3 and Figure 2 present the monthly forecasted values and their respective confidence intervals (UCL and LCL) for the years 2023 and 2024. A clear upward trend is observed: the predicted values for each month in 2024 are consistently higher than those for the same month in 2023. In both years, the month of August shows the lowest forecasted value within the respective year, indicating a seasonal dip.

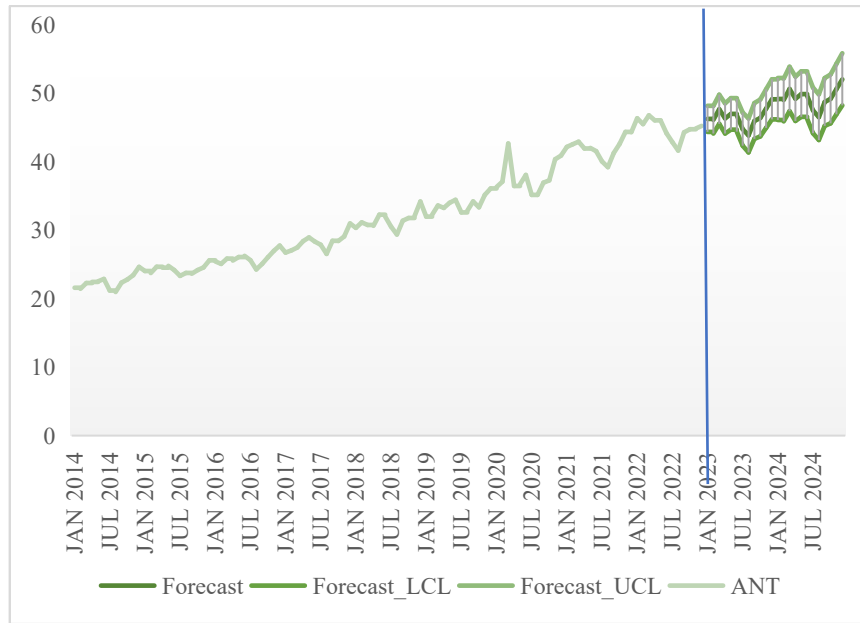
For August 2023, the model predicts that the average number of SWIFT messages per day will be 43.81 million. With a 95% confidence level, the actual amount for August 2023 will be between 41.33 and 46.29 million.

For December 2023, the model predicts that the average number of SWIFT messages per day will be 49.08 million. With a 95% confidence level, the actual amount for December 2023 will be between 46.15 and 52.00 million.

For August 2024, the model predicts that the average number of SWIFT messages per day will be 46.47 million. With a 95% confidence level, the actual amount for August 2024 will be between 43.14 and 49.80 million.

For December 2024 the model predicts that the average number of SWIFT messages per day will be 51.99 million. With a 95% confidence level, the actual amount for December 2024 will be between 48.19 and 55.80 million.

Figure 2. Forecast of average number of SWIFT messages per day



Source: Authors' contribution based on data by Statista, 2025

In the considered dynamic series of average number of SWIFT messages per day, an upward trend of development is observed, as average growth of average number of SWIFT messages per day monthly in the amount of 0.239 million is observed. In addition to the trend, a seasonal component is observed in the analysed dynamic series. In August, the largest decreases in the SWIFT indicator are observed, as the average number of SWIFT messages was 6.7% lower than the average amount. This decrease is expected due to the nature of the summer month of August. In December, the largest increases in the SWIFT indicator are observed, as the average number of SWIFT messages per day was 3.5% higher than the average amount for the period. From the forecast made, for 2023 and 2024, an upward trend is expected to preserve. Depending on which of the limits of the interval the actual number of SWIFT messages per day will be, lower average growth rates may be expected.

The empirical analysis of the average number of SWIFT messages per day between 2014 and 2022 reveals a consistent upward trend, indicating a steady growth in the use of SWIFT's services despite the rise of decentralized alternatives. The time series decomposition confirms the presence of both a significant linear trend and seasonal fluctuations, with peak activity typically occurring in March and December, and notable declines in August. The trend modelling shows that SWIFT's traffic increases by approximately 0.239 million messages per month on average, reflecting its continuing central role in international payments. Forecasting results for 2023 and 2024 project further growth, reinforcing SWIFT's resilience and adaptability amid the broader shift toward decentralization. These findings suggest that while decentralized payment systems are gaining ground, SWIFT remains a critical and evolving infrastructure in the global financial ecosystem.

6. DISCUSSION

6.1. IN TERMS OF REGULATORY FRAMEWORKS

In terms of regulations, there are deep regulatory challenges with decentralized finance and cryptocurrencies. Such financial innovations frequently work outside conventional legal rules and supervisory systems. The decentralized nature of these platforms as well as the anonymity of users deviate the discourse from the usual one-size-fits-all narrative that typically applies to centralized intermediaries (Rangapriya and Lokhande, 2022). As a peer to peer intermediary-free technology, block chain makes it quite impractical to enforce KYC and AML rules (Saleh, 2024). This makes it more difficult to trace transactions, the parties involved and irregular activities such as money laundering and terrorist financing (Zhuk, 2024).

Another level of complexity arises due to the worldwide reach of blockchain networks. Unclear jurisdictions As borders blur, the application of legal frameworks is not clearcut, in particular when service users cannot be limited by borders to the same platform (Coelho, Fishman and Ocampo, 2021). This legal ambiguity gives room to regulatory arbitrage, the practice of gaming the different legal setup of countries (Kayani and Hasan, 2024). Therefore, international regulatory cooperation is of great importance to homogenize standards and to fill any gaps (Xiong, and Luo 2024).

Also, jurisdictions on what cryptocurrency is vary: some see it as a property, while others see it as a security or a commodity. The lack of uniformity in standards impedes the emergence of a set of world-wide standards. The fast pace of development in the space adds a sense of urgency - new forms are consistently developed and paternalistic legal systems must adapt (Grennan, 2022; Blandin et al., 2019). With the exponential increase of influence of the crypto sector on traditional finance markets (Coindesk, 2023), the downfall of large platforms such as FTX makes it clear the need for strong regulation (Frediani, 2024), especially in a financial services oversight endeavor (Vidal-Tomás, Briola and Aste, 2023).

6.2. IN TERMS OF INSTITUTIONAL RESPONSES

Institutions have begun to adapt their regulatory strategies to meet the challenges posed by DeFi and cryptocurrencies. A shift is underway from entity-based regulation (focused on institutions) to activity-based regulation, which targets financial functions regardless of who performs them (Alam, Gupta and Zameni, 2019). This model better suits decentralized systems, where algorithms, not entities, execute transactions. Regulatory sandboxes, which allow controlled testing of new financial innovations, offer a flexible way for authorities to experiment with tailored oversight mechanisms (AllahRakha, 2023).

Financial regulators must balance innovation and stability (Topić – Pavković, 2024). Overly strict rules may drive innovation abroad, while lax regulation can lead to systemic risks and consumer harm (Yadav and Brummer, 2019). A flexible regulatory approach is needed, which evolves alongside the technology and ensures market integrity without impeding growth (Koker, Morris and Jaffer, 2020). Moreover, harmonizing regulations internationally remains a strategic priority to prevent fragmentation and arbitrage.

While SWIFT relies on standardized, institutionally mediated messaging protocols, DeFi ecosystems utilize radically different transaction-tracking mechanisms such as public block explorers (e.g., Etherscan), on-chain analytics tools (e.g., Nansen, DeFi Llama), and protocol-specific dashboards. These tools allow for near-instantaneous visibility into asset flows, contract activity, and user behavior - capabilities largely absent in traditional finance. Including such decentralized tracking technologies in the comparative analysis underscores the distinct paradigms at play, while also hinting at a potential convergence where institutional systems like SWIFT may incorporate or adapt similar transparency-enhancing mechanisms in future iterations.

In line with these institutional challenges, Adamyk et al. (2025) propose that future oversight mechanisms may benefit from adopting DeFi-native metrics (f.e. protocol-level transparency, user-driven governance models, and automated auditing tools) as part of cross-jurisdictional supervisory strategies. Such empirical insights can inform how centralized institutions like SWIFT might integrate decentralized monitoring architectures into their evolving systems.

The forecasting results project a continued upward trend in SWIFT message volumes through 2024, suggesting that despite the emergence of decentralized payment alternatives, institutions remain deeply integrated with SWIFT's infrastructure. This upward trend, confirmed by robust time series modelling, supports the paper's main conclusion that the SWIFT is not in decline but rather it is actively evolving. The network's strategic adaptations - such as its Global Payments Innovation (gpi) program and ISO 20022 compliance - position it not merely as a legacy institution but as a competitive player responding to the pressures from decentralization through a structural modernization. This resilience implies that decentralization does not automatically lead to disintermediation of legacy infrastructures. Instead, SWIFT's adaptability suggests a hybrid path where institutional systems absorb or align with decentralized innovations rather than being displaced.

The results of the forecast, which indicate a sustained upward trend in SWIFT traffic, reinforce the argument that traditional infrastructures are not being displaced but are instead adapting. Rather than showing decline, the data support the view that SWIFT is absorbing pressure from decentralization through innovation and modernization. These projections substantiate the study's thesis that SWIFT's resilience is not incidental but structurally embedded, reflecting the network's capacity to coexist with and even complement decentralized systems.

6.3. IN TERMS OF CONSUMER PROTECTION

The rapid proliferation of DeFi and crypto platforms has exposed consumers to novel and often severe risks. Users face fraud, scams, market manipulation, and technical vulnerabilities. Many lack the financial literacy required to understand these risks, making them especially vulnerable (Ahlström, Chang and Cheung, 2019). Existing consumer protection laws, designed for traditional markets, may not be directly applicable in the digital finance space (Frediani, 2024).

Regulatory bodies frequently lag behind technological change. A more proactive stance, such as funding academic research and hosting international symposia, could help close this gap (Walton, 2014). Additionally, public education campaigns and effective grievance redressal mechanisms must be developed to ensure that retail participants are informed and protected (Momčilović and Ninković, 2024).

Ultimately, consumer protection must be a cornerstone of crypto regulation. As financial technology continues to evolve, safeguarding retail users will be essential for building trust and fostering sustainable growth in digital finance (Aquilina, Frost and Schrimpf, 2023; Smoleńska, Ganderson and Héritier, 2020).

7. CONCLUSION

Decentralization in international finance and payments has the potential to democratize the financial system by granting greater autonomy to participants, reducing costs, and increasing transaction efficiency. Decentralized financial technologies may reshape the financial system by offering users more control and independence while managing risks and challenges.

At the same time, digital currencies and cryptocurrencies are already offering alternatives to traditional financial infrastructure, transforming how people make payments and manage their assets. Reducing dependence on reserve currencies may also lead to fundamental changes in the global financial system, opening new opportunities for economic development and innovation, especially for emerging economies seeking greater independence and resilience.

Decentralizing of global payments, advancing blockchain technology, DeFi, cryptocurrencies, and CBDCs are fundamentally transforming the world financial system. Such changes bring about improved transactional utility, cost reductions, and broadens financial inclusivity in contrast to conventional centralized architectures. However, the empirical analysis of SWIFT's message volumes from 2014 to 2022 indicates a consistent upward trend, with notable seasonal fluctuations. The projected growth in SWIFT message volume underscores the network's continued centrality in international payments. This empirical resilience supports the argument that SWIFT is not being displaced by decentralised platforms but is instead evolving. Thus, the modelling results substantiate the broader claim that hybridization - rather than a full displacement of centralized systems - is defining the future of international payments infrastructure.

This suggests a financial ecosystem in transition, where emerging decentralized platforms coexist with established centralized infrastructures. While decentralized systems address specific inefficiencies and cater to evolving user demands, SWIFT's adaptability – evident in initiatives like the Global Payments Innovation (gpi) and alignment with ISO 20022 standards - demonstrates its commitment to modernization. The future of international payments is likely to be characterized by a hybrid model, integrating the strengths of both centralized and decentralized systems.

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THEORETICAL AND METHODOLOGICAL PRINCIPLES OF APPLICATION OF AGENT-ORIENTED APPROACH TO MODELING PROCESSES OF LOCAL HROMADAS

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ABSTRACT

This article presents a theoretical and methodological framework for applying a multi-agent systems (MAS) approach to modeling the budgeting processes of local hromadas. MAS-based modeling enables consideration of agents' heterogeneity, bounded rationality, and dynamic interaction structures, which traditional models typically overlook. These features allow for a more realistic reproduction of economic processes at the hromada level. The study explores the potential of MAS in solving practical problems such as resource allocation optimization, strategic planning for sustainable development, and strengthening resilience to crises. Particular attention is paid to the development of a budget auction model based on game theory, where economic actors - including local government, enterprises, and residents - engage in a structured competition for resource distribution. The auction mechanism identifies production functions and utility values for each actor, enabling iterative optimization based on predefined efficiency criteria. A proposed simulation framework combines the auction logic with reinforcement learning methods (MARL), where agents improve their strategies through interaction and feedback. The article also outlines a multi-step algorithm for modeling decision-making and coordination processes within the decentralized budget structure. Ultimately, the approach offers tools for more transparent, participatory, and efficiency-driven public finance management. Its implementation can support the digital transformation of local governance, aligning resource distribution with sustainable development goals. The proposed methodology is particularly relevant in the context of Ukraine's decentralization reform and post-war recovery challenges, and it may serve as a foundation for the development of intelligent public finance systems in local hromadas.

Keywords: multi-agent systems, local hromadas, sustainable development, horizontal alignment, resource allocation

1. INTRODUCTION

The decentralization reform that began in Ukraine in 2014 has radically changed the system of local self-government and territorial organization of power. This large-scale transformation, based on the principles of the European Charter of Local Self-Government, aimed to transfer significant powers and resources from state bodies to local hromadas. Analyzing the path taken, we can note a number of significant achievements and certain problematic aspects that determined the results of the reform for local hromadas (Kotukh, 2020). The most obvious achievement of decentralization was a significant strengthening of the financial capacity of local hromadas. As a result of changes to the budget and tax legislation, hromadas received stable sources of revenue in the form of local taxes and fees, as well as a share of national taxes. Thanks to financial decentralization, the own revenues of local budgets increased several times compared to the pre-reform period. In particular, local bud-

gets began to receive a significant part of the personal income tax, excise tax, single tax and other revenues. This allowed local authorities to expand financial opportunities to solve urgent problems of hromadas and invest in local development.

A key element of the reform was the formation of a new spatial basis for local self-government through the creation of capable territorial hromadas. The process of voluntary unification of territorial hromadas, and subsequently the completion of the administrative-territorial reform in 2020, led to the formation of 1,470 territorial hromadas instead of more than 11,000 small and mostly financially insolvent local councils. The consolidation of administrative-territorial units allowed to optimize the system of territorial management and increase the efficiency of resource use. This created the basis for a more rational organization of the provision of public services at the local level (Riabokin, Hordei, Novytska, Kotukh, & Kozii, 2022).

The increase in the financial capabilities of hromadas contributed to the intensification of infrastructure development at the local level. A significant number of infrastructure projects were implemented in many hromadas: repair of roads and streets, modernization of lighting and water supply systems, renovation of educational, health and cultural institutions. State support in the form of a subvention for the development of the infrastructure of united territorial hromadas, as well as funds from the State Fund for Regional Development contributed to the implementation of numerous projects that improved the quality of life in many settlements of Ukraine. Decentralization also contributed to the strengthening of local democracy and public participation in solving local issues. The expansion of local self-government powers increased the role of citizens in decision-making at the local level. In many hromadas, mechanisms for participatory budgeting, public hearings, electronic petitions and other forms of public participation were introduced. This contributed to the increase in the accountability of local authorities to citizens and the strengthening of public control over the activities of local self-government bodies. In fact, this changed the paradigm of local self-government in the financial sphere, participants in the budget process in the past became actors and subjects of the budget process.

At the same time, along with positive results, decentralization has also revealed a number of problematic aspects. The problem of managerial capacity has determined the results of decentralization for many hromadas. The shortage of qualified personnel, especially in rural and remote hromadas, limits the possibilities of strategic planning, attracting external resources and effective management. The lack of employees with project management experience, legal and economic education often does not allow to fully use the opportunities that have opened up to hromadas as a result of the reform.

The institutional incompleteness of the reform also affected its results. The unresolved issues of a clear division of powers between different levels of government, especially in the education, healthcare and social protection sectors, create additional challenges for hromadas. Often, hromadas receive new powers without appropriate financial support, which makes it difficult for them to perform their functions. The problem of harmonizing sectoral reforms (educational, medical, and administrative) with the decentralization process remains relevant for the further development of local self-government.

The financial dependence of many hromadas on transfers from the state budget is also a challenge for full decentralization. Despite the increase in their own revenues, a significant part of hromadas remains dependent on subventions and subsidies from the state budget, especially in the areas of education and healthcare. This limits the autonomy of local government and creates risks in the event of economic or political instability at the national level. Reforming the network of educational, healthcare, and cultural institutions in the context of decentralization has also proven to be a difficult task for many hromadas. The need to optimize the network of institutions, which is often accompanied by unpopular decisions to close or reorganize institutions, creates additional social tensions in hromadas. Limited resources do not allow many hromadas to provide the proper quality of services in these areas without significant state support. At the same time, the reform has revealed structural problems of regional development and deepened inequalities between different types of hromadas. To ensure comprehensive success, it is necessary to further improve inter-budgetary relations, strengthen the institutional capacity of hromadas, and continue sectoral reforms. Finding a balance between hromada autonomy and ensuring uniform standards of public service provision throughout Ukraine remains

particularly relevant, especially in the context of the war, which has created an additional burden on local budgets and exacerbated regional disparities. Despite the challenges, decentralization remains one of the most successful reforms in modern Ukraine, significantly bringing the country closer to European standards of local self-government and territorial organization of power.

One of the most obvious problems was the uneven development of hromadas. Financial decentralization led to significant differentiation of hromadas in terms of budget security. Hromadas with developed industry, large enterprises or located near regional centers received significantly greater financial opportunities compared to peripheral, rural hromadas. The existing distribution mechanism seeks to completely equalize budget security, but only smoothes out the largest disparities, preserving the difference between „rich“ and „poor“ territories, is carried out according to a clear formula, is based on only one tax, which simplifies the system and does not allow taking into account many factors and aspects in the development of hromadas. Despite the mechanisms of horizontal equalization (basic and reverse subsidies), significant disparities in the development of territories remain an urgent problem. The digitalization of the state's financial sector, the introduction of the latest financial technologies, the accumulation and ability to process huge amounts of data, as well as artificial intelligence technologies have created the prerequisites for changing approaches and improving planning and implementation mechanisms in the budget process.

Thus, an urgent scientific and practical task is to study the possibilities of an innovative approach to modeling the economy of local hromadas, based on the use of multi-agent systems (MAS). Unlike traditional economic models, MAS allow us to take into account the heterogeneity of agents, their bounded rationality, and complex interaction networks. This provides a more realistic and detailed reproduction of economic processes at the hromada level ([Muyambiri, 2025](#)).

The aim of this study is to develop theoretical and methodological foundations for the use of multi-agent systems for modeling the budgeting process of local hromadas. The most promising applied approach in this regard is the use of game theory and the proposal of a business game in the auction format.

2. LITERATURE REVIEW

The application of agent-oriented approaches to modeling local hromada processes represents an emerging interdisciplinary field combining computer science, economics, public administration, and sustainability studies. Multi-agent systems (MAS) have emerged as powerful tools for addressing complex resource allocation problems in distributed environments. Zhang et al. (2019) provide a selective overview of multi-agent reinforcement learning (MARL), highlighting that most successful reinforcement learning applications involve multiple agents. Research demonstrates that MAS can decentralize traditional centralized resource allocation, enabling more efficient distribution across complex networks.

Studies show that multi-agent systems provide promising platforms for decentralizing resource allocation, particularly where economic dispatch and unit commitment play critical roles in system operation. Efficient resource allocation mechanisms enable proper use of limited resources to achieve optimal objectives, with game theory providing mathematical foundations for analyzing interactive behavior. Current studies indicate that MARL faces challenges including computational complexity, non-stationarity, coordination, and performance evaluation, requiring solutions for scalability and trustworthiness for practical implementation.

Participatory budgeting represents one of the most ambitious participatory innovations of recent decades, enabling hromada members to collectively decide budget allocation. Systematic literature reviews reveal that PB has evolved through various phases, focusing on democratic governance, citizen engagement, and resource allocation efficiency. Research utilizing Korean local government data demonstrates strong evidence that public participation in budgetary processes significantly affects fiscal outcomes. Studies indicate that meaningful citizen participation requires two-way dialogue between government and citizens, with public managers' perceptions significantly influencing PB process success.

Game theory has made important contributions to public economics, particularly where standard competitive models provide inadequate analytical frameworks. The Public Goods Game serves as a standard experiment for analyzing tension between individual incentives and collective benefits. Game-theoretic

techniques explain various financial phenomena, including capital structure decisions and resource distribution mechanisms. Research demonstrates that rational individuals in public goods games tend to contribute fewer resources, highlighting free-rider problems in public resource allocation.

Recent advances in reinforcement learning have led to significant progress in multi-agent applications, though theoretical foundations for MARL remain relatively limited. MARL has been applied to resource allocation problems including computation offloading, energy management, and network resource distribution, with challenges remaining regarding non-stationarity and partial observability. Theoretical arguments suggest that decentralization can make government more accountable and responsive to citizens. Research indicates that centralization and decentralization represent compatible governance concepts, with public administrators driven by values such as accountability, efficiency, responsiveness, and innovation.

Various optimization mathematical models are used to model the cost allocation process. The choice of the appropriate model depends on the specifics, strategic goals, and the level of interaction between participants in financial processes. In (Kotukh & Riabokin, 2025), a comparative analysis of common models used for the allocation of investment resources and subsidies was carried out.

One of the newest and innovative approaches is multi-agent reinforcement learning (Zhou, Zhang, & Luo, 2023), which is able to adapt subsidy policies in real time based on market reactions. The use of artificial intelligence enables dynamic analysis of the optimal allocation of financial resources, but this method requires large amounts of data and complex computing resources. It is relevant in the areas of dynamic allocation of subsidies to maintain stable prices for agricultural products. Combining the capabilities of multi-agent systems (MAS) with game theory will provide hromadas with promising budgeting tools. In the context of the involvement of territorial hromadas, it can provide significant advantages when planning the involvement of new innovative approaches in investing in sustainable development projects (Riabokin & Kotukh, 2025a).

Studies demonstrate that governance quality significantly impacts public sector efficiency, with human resources, democracy, corruption, and digitalization affecting performance. Research on local government efficiency reveals significant variations in service delivery costs, with privatization and public sector reforms showing potential for cost savings. Recent approaches to public sector productivity emphasize moving beyond cost-efficiency focus toward innovation-enhancing measures and digital transformation (Lemaallem & Saadi, 2025).

Research on SDG 11 emphasizes creating inclusive, safe, resilient and sustainable cities and hromadas, with local action essential for achieving sustainable development goals. Studies demonstrate that local action can accomplish things other governance levels cannot, with proximity to problems enhancing collective motivation for sustainable solutions. Research explores how citizen-generated data can support local environmental SDG monitoring, emphasizing community participation importance in sustainability initiatives.

Current literature reveals gaps in integrating multi-agent systems with participatory governance mechanisms. While individual components have been extensively studied, limited research examines the intersection of MAS, game theory, and participatory budgeting in local hromada contexts. Research suggests that achieving SDGs requires alignment between conceptualization, implementation, and evaluation, with transformative learning and robust partnerships across sectors. Future studies should focus on empirical validation of theoretical models in real-world local governance settings and examine how digital transformation can enhance participatory processes while maintaining democratic legitimacy and hromada ownership.

The literature reveals growing recognition of agent-based approaches' potential for enhancing local hromada resource allocation. While significant theoretical foundations exist across multiple disciplines, empirical evidence for integrated approaches remains limited. Future research should focus on developing and testing comprehensive frameworks that combine multi-agent systems, participatory governance, and sustainable development objectives in local hromada contexts.

3. MATERIALS AND METHODS

The result of the functioning of the economy is the production and distribution of goods that form product flows. The annual period of economic planning for most economic actors is determined by a number of historical, legal, organizational and psychological factors. First of all, the legal and fiscal system in most countries of the world, including Ukraine, is built on the annual budget cycle. The fiscal year as the basis of budget planning and reporting sets the time frame for state bodies, which are subsequently projected onto other economic actors. Tax reporting and obligations associated with fiscal periods encourage enterprises and organizations to synchronize their own planning cycles with the budget year. It is obvious that budget processes are continuously linked to economic processes and relations.

One of the most important characteristics that determine the economic potential and capabilities of an enterprise is its production function. The production function hereinafter refers to the relationship between the quantity of products produced of a given quality and the resources spent on their production. It is determined by both endogenous and exogenous factors that control the production process. Endogenous factors include: equipment with basic equipment and organization of the technological process, which ensures the efficient use of equipment for processing incoming resources, and availability of production personnel. Exogenous factors include the demand for products, prices for products and resources, which are determined by market conditions, as well as the tax policy of the state, and in exceptional cases, a government order, which is usually distributed on a competitive basis.

Each change in the model of manufactured products causes a change in the internal environment of the enterprise. These changes are accompanied by social processes of a local nature, which are projected on the market as a whole. Usually, the market's reaction to these changes has local significance. The entire market, due to its great inertia, cannot adequately respond to rapid changes. Only a change in product generations, which affects the production activities of entire industries, is reflected in the market situation, since the creation of a new generation of products in any industry is correlated with a radical restructuring of enterprises. It is accompanied by a change in the main production equipment, in which new generation products are manufactured. The production of new types of main equipment stimulates changes in the activities of industries that produce equipment. Therefore, the social consequences of changes in the production of goods caused by the creation of new generations of products affect market processes, affect the interests of wide circles of the population and provoke industrial crises.

The changes brought about by the production of products for new purposes in a number of industries are affecting the activities of many enterprises and the economies of states. They affect the entire infrastructure of industry and inspire changes in the lives of people. The crisis caused by the restructuring of the country's economic infrastructure in wartime conditions is spreading to the life of territorial hromadas. There are changes in the way of life of hromadas hosting IDPs and enterprises, where new production sectors are being created, the transport system and communication system are changing, and living standards are changing. Correlated changes in industrial production of economic blocs are reflected in the development of production relations on a state scale. The destruction of established economic and social relations causes serious upheavals in the economies of countries. There is a redistribution of spheres of influence and accumulated wealth. Population migration is accelerating. Usually, under conditions of total destruction of the economic potential of certain regions, also associated with the destruction of the old way of life and production, the change in the energy base of the economy is accelerating. Restructuring, accompanied by the rise and fall of production, determines new laws of social development. All contradictions caused by changes in the economic potential of hromadas are reflected in the market. All contradictions are focused in market processes. Their diversity is dictated by the strict laws of economics.

Modern democratic processes put forward new requirements for local governance, and one of the key tools for transforming local government is participation. Participation (or participatory democracy) in local government and budget relations is an important mechanism for involving citizens in decision-making processes at the local level. This is a complex socio-political phenomenon that

involves the active involvement of citizens in decision-making processes, in particular in the field of budget relations. Participation in local government is not only a management tool, but also an important step towards the development of civil society, increasing the efficiency of local government and strengthening democratic values.

The main forms of participation include several key practices. First of all, this is participatory budgeting - an innovative mechanism that allows residents to directly influence the distribution of part of the local budget. No less important are public hearings - public meetings during which residents have the opportunity to directly communicate with representatives of local authorities, discuss budget proposals and provide their own feedback. In Ukrainian realities, the legal basis for the development of participation is laid by a number of legislative acts, in particular the Law of Ukraine „On Local Self-Government“, the Budget Code and methodological recommendations of the Ministry of Regional Development. The true effectiveness of participation depends on the readiness of both authorities and citizens for constructive cooperation.

Participation in budgetary relations is a modern and important element of patronizing the development of leading industries of local hromadas and concentrating in the hands of the authorities funds sufficient to meet the socio-economic needs of the community. Such a task is usually solved with the involvement of a certain circle of public experts. The competition of opinions and visions of community development of experts with the vision of representatives of local self-government bodies motivates to look at this process from the position of modeling a business game, an auction of proposals, as an optimization problem. It is in this vein that it makes sense to introduce the concept of an actor of economic relations, which are individuals (citizens) living in a local hromada, legal entities (enterprises) registered in the territory of the hromada - responsible for paying taxes on the results of their activities, as a result of the production of public goods, as well as local self-government bodies responsible for the distribution of public goods (taxes) and management of community property for the provision of public services. It is using the example of financial bodies of local hromadas that we will further explore the involvement of actors in modeling using the game.

The goal of the auction is to allocate subsidies and investments in a typical link in such a way that the efficiency of using funds that have the center of the link is maximized. This means that, taking into account the utility and limited cost of the goods (products and services) produced, the efficiency is maximized.

The calculation is carried out using the game module „auction“, which is used to coordinate the interests of players and the center of any link in the expenditure part of the budget structure.

The central link organizing the game has some resource that it must distribute among the players. Each of the players is characterized by its production function, on which we are particularly interested in two points that reflect the regimes in which production volumes are minimal and maximal. In real conditions, the player's production function is unknown to the partners. It is hidden by the player from the rest of the process participants, including the center. Therefore, at the initial stage of the game, the center must identify it for all players who represent the units involved in the distribution. (Often, the analytical expression of this function is unknown even to the players who represent this element).

In the context of the local hromada economy, the production function can be considered as a mathematical model of the relationship between the volume of public goods/services provided and the budget resources spent. We formulate the production functions of the local hromada according to the following criteria (See Table 1).

In the work (Riabokin & Kotukh, 2025b), an analysis of the compliance of the production functions of local hromadas with the goals of sustainable development was conducted. At this stage, it is advisable to introduce the concept of public product as an integrated indicator of hromada utility.

In the future, for theoretical justification by modeling the optimization of the allocation of budget funds, assessing the effectiveness of expenditures and planning hromada development, we will use this integral indicator of the above functions. However, it is quite clear that in practical application, actors of economic relations can optimize funds in terms of sustainable development goals and,

under such circumstances, production functions should be considered separately, by direction, and then there will be a municipal public product, an administrative public product, an investment, a social, etc.

Table 1 - Production functions of local hromada

Function	Function description
The function of providing municipal services	the relationship between spending on a particular area and the quantity/quality of services provided.
Administrative production function	the efficiency of local government depending on administrative costs
Investment function	the relationship between capital expenditures and the infrastructure/ fixed assets created
Social production function	the relationship between social spending and social indicators (e.g., poverty level, availability of services).
Ecological function	the relationship between environmental expenditures and ecological indicators/outcomes

Source: developed by the authors

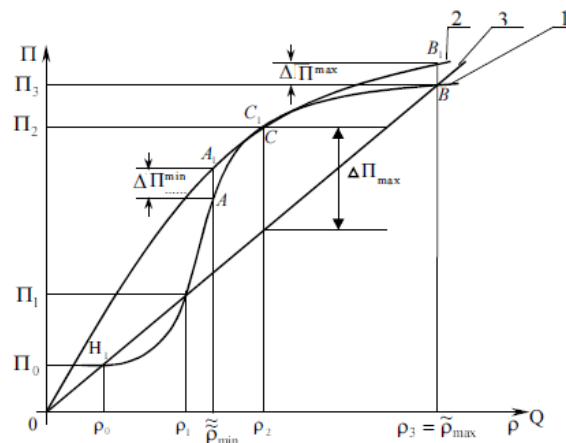
Thus, we conduct the simulation considering the local hromada as an economic actor with a single public product, where the price of all working capital is taken as a single resource. This, of course, will not give efficiency in optimization, but will provide an opportunity to consider the approach in general terms. Our approach is based on the proposal being considered in (Dabagyan, 2000).

In economics, the relationship between the cost of production and the price of the consumed gener-

alized resource is expressed by the relationship $\Pi = \frac{k_1}{1 + k_2 e^{-k_3 P}}$,

where P - current cost of the product; P - cost of the resource; $k_i, i = 1, 2, 3$ - constant coefficients.

Figure 1 – Graph of the function of the dependence of the cost of production and the price of the product*



*Source: developed by the authors

The graph of the function is presented in Fig. 1. In Fig. P 0 – minimum integral indicator of product cost, P 1 – basic integral indicator of product cost, P 2 – optimal product cost; P 3 – maximum product cost;

The corresponding values of the price of resources for the production of the product are plotted on the x-axis. With sufficient accuracy for approximate calculations at the system design stage, in the operating mode of local government functioning according to production functions, the schedule can be approximated by a power function.

When implementing the auction process, it is necessary to take into account that the volume of the public product is determined by a public resource, which can be dated from the state budget but also from the local hromadas own public funds. Therefore, the volume of the public product is a function of these sources. In gen-

eral form, we present it as $\Pi = f(\rho_{\text{дотаций}} + \rho_{\text{власний фонд}})$, where $\rho_{\text{дотаций}}$ - the amount of subsidies, $\rho_{\text{власний фонд}}$ - the cost of own funds used for the production of the public product. In this function, the weight of $\rho_{\text{дотаций}}$ can vary from zero to 100%. Since when distributing subsidies we are interested in the efficiency of the subsidies allocated to the actor, when determining the production function, $\rho_{\text{власний фонд}}$ we will consider the value as a

constant parameter. Then the value of the public product can be represented as a function $\Pi = F(\rho_{\text{дотаций}})$, where P - the cost of the produced product, $\rho_{\text{дотаций}}$ - the amount of subsidies.

The auction game consists of two components – identification of the production functions of the actors by the center, which are refined with each step, and multi-step solution of the optimal distribution problem. By the center we mean the conditional arbiter of the game, which establishes the rules and compliance of actions with the rules. First, the initial identification of the production function for each actor

is carried out in the form of a working section of its analytical expression, given by the formula $\Pi_{ij} = s_{ij} \rho_{ij}^{\alpha_{ij}}$, where Π_{ij} - the cost of production produced by the j -th player of the i -ro level, ρ_{ij} - the amount of subsidy allocated to the j -ro actor of the i -ro level, s_{ij} and α_{ij} - the parameters of the production function. To highlight a working area on the production function, experts of the corresponding element of the system indicate two points where the value of the produced goods is equal to $\Pi_{ij \min}$ and $\Pi_{ij \max}$. For each value we can compose

equalities $\Pi_{ij \min} = s_{ij} \rho_{ij \min}^{\alpha_{ij}}$ and $\Pi_{ij \max} = s_{ij} \rho_{ij \max}^{\alpha_{ij}}$. In this case, the parameters of the production function s_{ij} and α_{ij} are unknown

and must be determined. By taking the logarithm of the ratio $\Pi_{ij \min} = s_{ij} \rho_{ij \min}^{\alpha_{ij}}$ and $\Pi_{ij \max} = s_{ij} \rho_{ij \max}^{\alpha_{ij}}$ it is necessary to determine the function for each element $\Pi_{ij} = s_{ij} \rho_{ij}^{\alpha_{ij}}$. To approximate the production function on the working area $\Pi_{ij \min} - \Pi_{ij \max}$ by the expression $\Pi_{ij} = s_{ij} \rho_{ij}^{\alpha_{ij}}$, it is necessary that the angular coefficients of the points with coordinates $\Pi_{\min}$, $\Pi_{\max}$, $\rho_{\min}$, $\rho_{\max}$ satisfy the condition $\frac{\Pi_{\min}}{\rho_{ij}} > \frac{\Pi_{\max}}{\rho_{ij}}$. Secondly, based on the parameters

determined s_{ij} and α_{ij} for all, j the optimal value of the functional is determined $E_i = \frac{\sum_{j=1}^{m_{ij}} s_{ij} \rho_{ij}^{\alpha_{ij}}}{P_i^0} \rightarrow \max$, where $P_i^0 = \sum_{j=1}^{m_{ij}} \rho_{ij}$. Here E_i is the efficiency of the node, which is determined by the production function, which is maximized under the constraints defined for each actor in the form of inequalities $\rho_{ij \min} \leq \rho_{ij} \leq \rho_{ij \max}$ specified by the actor in the process of identifying the production function. Another constraint is the inequality $P_i^0 = \sum_{j=1}^{m_{ij}} \rho_{ij}$ given to the center after the iteration of the game in the past. Let us write the functional in the following form using the Lagrange multiplier method:

$$\sum_{j=1}^{m_{ij}} s_{ij} \rho_{ij}^{\alpha_{ij}} + \lambda \left(m_i^0 - \sum_{j=1}^{m_{ij}} \rho_{ij} \right) \rightarrow \max, \text{ where } \rho_{ij} \Big|_{\min} < \rho_{ij} \leq \rho_{ij} \Big|_{\max} \text{ and } P_i^0 = \sum_{j=1}^{m_{ij}} \rho_{ij} \quad (1)$$

At this stage, resource normalization is performed and therefore we assume that $D^0 = 1$. Under

these conditions, the Lagrange function is defined as follows $\sum_{j=1}^{m_{ij}} s_{ij} \rho_{ij}^{\alpha_{ij}} + \lambda \left(1 - \sum_{j=1}^{m_{ij}} \rho_{ij} \right) \rightarrow \max$, where

ρ_{ij} - in this expression the values of resources are already normalized. Differentiating this function by ρ_{ij} we get ${}_0\alpha_{ij} s_{ij} \rho_{ij}^{{}_0\alpha_{ij}-1} - \lambda = 0$, where $j = \overline{1, n_i}$ and therefore $\rho_{ij} = \left(\frac{\lambda}{{}_0\alpha_{ij} s_{ij}} \right)^{1/{}_0\alpha_{ij}}$, where $i = \overline{1, n_i}$ and ${}_0\sigma_{ij} = {}_0\alpha_{ij} - 1$. From the condition $\sum_{j=1}^{m_{ij}} \rho_{ij} = 1$ we have $\sum_{j=1}^{m_{ij}} \left(\frac{\lambda}{{}_0\alpha_{ij} s_{ij}} \right)^{1/{}_0\sigma_{ij}} = 1$. Having solved this equation

with respect to λ , we will find a solution that satisfies us, which we will substitute into ${}_0\alpha_{ij} s_{ij} \rho_{ij}^{{}_0\alpha_{ij}-1} - \lambda = 0$ and determine the values of the resource allocation plans D^0 . The solution does not satisfy the constraint $\rho_{ij \min} \leq \rho_{ij} \leq \rho_{ij \max}$. To satisfy the constraint, we will compose the sets

${}^0K_1 = \{ \rho \mid \bar{\rho}_{ij} > \tilde{\rho}_{ij} \}$, ${}^0N_1 = \{ \rho \mid \tilde{\rho}_{ij} \leq \tilde{\rho}_{ij} \leq \tilde{\rho}_{ij} \}$, ${}^0K_{11} = \{ \rho \mid \tilde{\rho}_{ij} > \rho_{ij} \}$ and ${}^0N = {}^0K_1 + {}^0N_1 + {}^0K_{11}$, where $\tilde{\rho}_{ij} = (\rho_{ij})_{\min}$, $\bar{\rho}_{ij} = (\rho_{ij})_{\max}$, ${}^0N$ - the total number of actors of the i -th link. In order to take into account, the constraints center must first satisfy the requests of the actors included in the set ${}^0K_1$. We define a resource for the actors from this set $\hat{\rho}_{ij} = \tilde{\rho}_{ij}, \forall i \in {}^0K_1$ and then for the remaining requests actors the

constraint has the following form: $\sum_{\forall j \in N \setminus K_1^0} \left(\frac{\lambda}{\alpha_{ij} s_{ij}} \right)^{1/\sigma_{ij}} = {}^1P = P^0 - \sum_{\forall j \in K_1^0} \rho_{ij}$, where K_1^0 is the set of actors who received the maximum permissible amount of resources $\rho_{ij} = \tilde{\rho}$. Let's solve the simplified problem of optimal distribution for actors from the set $\notin K_1$. It is simplified after satisfying the requests of actors from the set K_1 . The new distribution, in addition to the actors included in the set ${}^0K_1$, will contain an additional number of actors who need to be given resources in the amount of $\tilde{\rho}_{ij}$. Having satisfied all the performers who $\tilde{\rho}_{ij} < \rho_{ij}^{\max}$, we will compose the sets ${}^1K_1, {}^1N_1$, where ${}^1K = {}^0K_1 + \Delta {}^0K_1$, and are $\Delta {}^0K_1$ the actors who reached the constraint after solving the previous problem. Repeating the approximation for the requests included in the set ${}^1K_1$, we will achieve that on the q-th approximation $\Delta {}^qK_1 = 0$, if under these conditions the set ${}^qK_1 \in \emptyset$, then the problem is solved. If, ${}^qK_1 \neq \emptyset$, then the problem arises, either to exclude actors from further iterations, ${}^q\rho_{ij} < \tilde{\rho}_{ij}$ or to allocate them additional resources (from the reserve fund of the center) in the amount $\tilde{\rho}_{ij}$ and continue the iterations of successive approximations. This dilemma, in our opinion, is outside the modeling process and belongs to the problems in the field of financial policy and therefore, in our opinion, is solved outside the proposed model, therefore it is not considered at this stage. Approximation iterations continue until all resources are allocated.

4. RESEARCH RESULTS

Before we consider the algorithm of the multi-agent model, let us summarize the process of the budget auction. The process of the budget auction begins with the announcement by the center of the starting values of the parameters of all actors. Then the center assigns a queue according to which it will conduct bargaining with the actors, and invites the j-th player in the queue to name new values of his parameters $\rho_{ij}, \prod_{ij}$, which, according to the strategy of the next, j-th player, should improve his state in terms of resource allocation. Before announcing a new plan, the actor estimates his capabilities. A generally accepted approach to the estimation is to calculate the production function. To determine the parameters of $\alpha_{ij} s_{ij}$ the next approximation q in $\prod_{ij \min} = s_{ij} \rho_{ij \min}^{\alpha_{ij}}$ and $\prod_{ij \max} = s_{ij} \rho_{ij \max}^{\alpha_{ij}}$ instead of $\prod_{\min}, \rho_{\min}, \prod_{\max}, \rho_{\max}$ iteratively substituted values

$\left(\prod_{ij}^{q-1} \right)_{\min}, (\rho_{ij}^{q-1})_{\min}$ and new proposals of the actor $\prod_{ij}^q, \rho_{ij}^q$. After that, the center calculates the next, optimal distribution. If the proposal of the j-th player increases the efficiency of the system by an amount greater than some predetermined amount δ , then the proposal of the y-th player is accepted. From this iteration, the plans

$\prod_{ik}^q = f(\rho_{ik}^q), k \in \{1, \overline{m_{ij}}\} \setminus j$ of the other actors are adjusted according to the new optimal solution. If the new plan does not improve the efficiency of the system, the actor is offered to make the next attempt. However, the actor is free to announce any new plan that does not go beyond the working area of the characteristic and to demand the corresponding value of the resource. After a certain (pre-agreed) number of attempts, the center stops the dialogue with the j-th actor and announces the results of the auction. There are two possible options for the center's decision: the actor's proposal is rejected, since it does not increase the functionality of the center, or it is accepted. In this case, the distribution, which is made taking into account the new values of the parameters of the j-th player, is reported to all actors. Then the center passes the move to the next actor. After completing the first round of negotiations with all actors and correcting the plan according to acceptable amendments, the center continues the game with performers who wish to further improve the plan. Iterations continue until all actors leave the auction. After the auction ends, the center announces the agreed decision. In a single-resource problem, when only cost is considered, the change in the situation is depicted in Fig. 2, where curve 2 corresponds to the original production function of the actor. That is, the proposed solution assumes that the utility of the goods produced by all its actors is determined by their monetary value. But in reality, the utility and cost of goods may not coincide. This is easy to prove by analyzing only stable cases.

For example, Public natural resources: Forests, lakes, parks have high utility for the hromada (recreational value, ecological services, quality of life), but their market value often only takes into account potential commercial exploitation.

Historical and cultural sites: Old buildings, monuments, or local traditional practices may have relatively low market value but extremely high utility as a source of hromada identity and social cohesion.

Infrastructure with externalities: Schools, hospitals, community centers create positive externalities (better education, health, social capital) that are not fully reflected in their market valuation.

Non-profit utilities: Water systems, local transportation may have low profitability (cost), but are critical utilities for the functioning of the hromada.

Public Land: The value of common lands for grazing, local festivals, or community gatherings is difficult to quantify monetarily, although their utility for social cohesion can be high.

Public goods with time inconsistency: Investments in sustainable development, renewable energy may have low current commercial value, but high long-term utility for future generations.

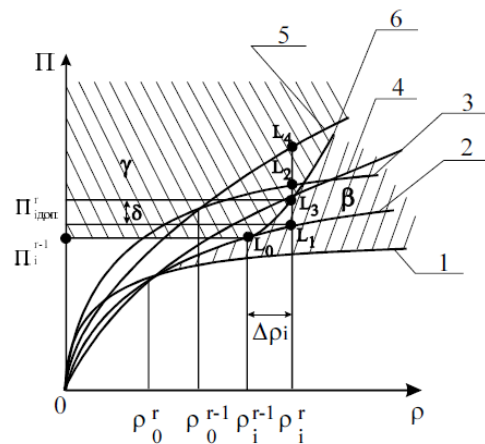
Traditional land use practices: In many hromadas, traditional forms of land use exist with low market efficiency but high socio-cultural value and environmental sustainability.

Hromada digital and information assets: Local databases, archives, and information exchange systems have high functional value, but are difficult to commercially value.

General utility theory was developed by Von Neumann allows us to model these differences through the concept of expected utility and subjective preferences, but it is important for hromadas to develop their own assessment mechanisms that take into account both economic and social, cultural and environmental dimensions of „utility“. An interesting direction for future research is the methodology for determining weighting factors that would allow us to take utility into account when conducting an auction.

Fig. 2 shows a graphical representation of the proposed scenario, where γ is the permissible and β is the forbidden regions of the scenario. Point L_0 depicts the plan proposed to the j th actor as a result of the previous solution of the optimization problem. The new proposal will change the position of the representation point: it will either remain on the old production function, or be located below or above this curve. In the first two cases, the center immediately rejects the proposed plan, since it cannot be better than the optimal one determined after the previous move (i.e., the result is either already known or belongs to the forbidden region). If the point is located above the curve, it will make a new calculation of the optimal plan for the entire system. If the calculation shows that increasing the player's plan will not lead to an improvement in the center's functional by a predetermined amount ($\delta > 0$), the proposal will be rejected. If the functional increases by an amount greater than δ , the proposal will be accepted. Depending on which of the parameters of the production function α_{ij} or s_{ij} changes in connection with the proposal of a new plan by the j -th actor, its representation point will move to one of the characteristics depicted in Fig. 2 as curves. The transition to curve 4 (point L_3) will occur with an increase in parameter s_{ij} , the point L_2 on curve 3 — with a decrease in the value of parameter α_{ij} . If it moves to curve 5 (point L_4), then both parameters will change. But even in these cases, the center can agree to a change in the plan if its functionality increases by a value greater than δ . Thus, a change in the plan acceptable to the center can occur only if the condition is met with the redistribution of the resource $0 < \delta < \delta_{ij} - \Delta_i$, where δ_{ij} is an increase in the plan of the j -th player, and Δ_i is the total decrease in the plans of the players from the set $\{j_i\} \setminus j$. In Fig. 2, such a redistribution corresponds to the representation point lying above curve 6.

Figure 2 – Graphical representation of the proposed scenario



Source: developed by the authors

Curve 6 is the locus of points dividing the entire region into two parts. It is obvious that only plans corresponding to points lying in the region above curve 6 are acceptable to the center. After the game

is over, the center will determine the refined parameter values $\prod_{ij}(\rho_{ij}), \rho_{ij}$ and make a resource allocation consistent with the capabilities of all actors.

Combining the described auction algorithm with multi-agent reinforced learning methods (Multi-Agent Reinforcement Learning (MARL)) could create a powerful adaptive resource allocation system. Each actor (agent performer) is implemented as a reinforcement learning agent. The center is also implemented as a center agent that optimizes the allocation rules. Agents learn to optimize their bid strategies over time. Thus, we formalize the environment and rewards through:

State – current resource allocation, requests from other agents, history of previous iterations

Action – creating a request for resources.

Reward is a combination of resources received and the implemented plan, taking into account the utility function.

In the practical part of the study, it is proposed to consider practical approaches to implementation, namely:

1. Decentralized approach (Independent Learners). In this approach, each agent autonomously learns to optimize its application strategy. This would have advantages in ease of implementation and scalability, but there may be disadvantages with learning and coordination.
2. Centralized learning, decentralized execution. Under this approach, agent training occurs centrally using complete information, and during the auction, agents act autonomously using the learned strategies. Such a solution is proposed to be built using the MADDPG, QMIX, COMA methods.

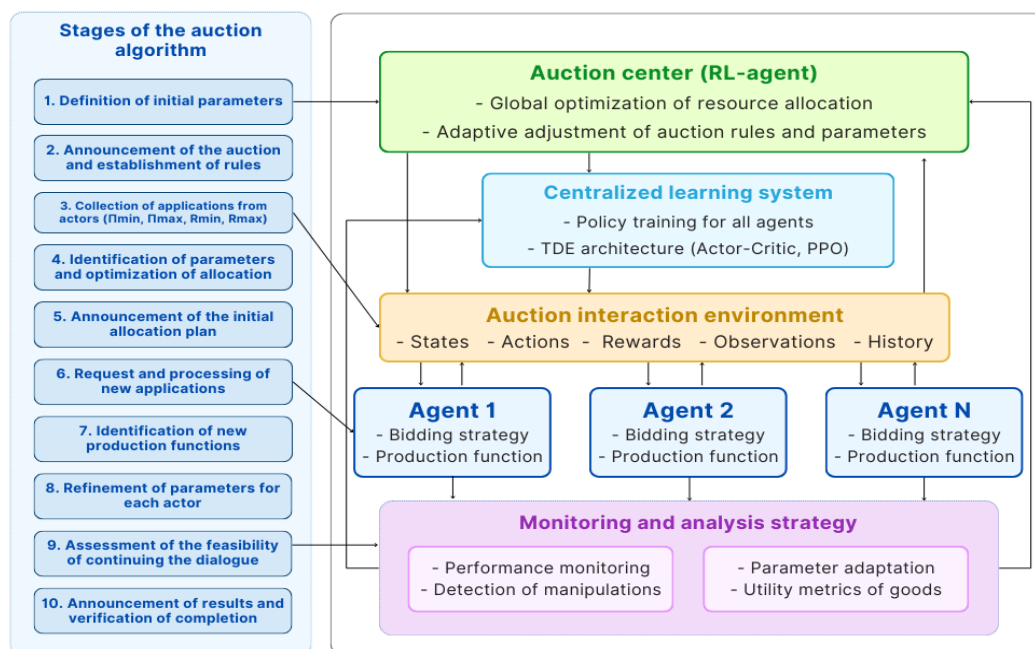
Below we present the budget auction algorithm directly. (Fig. 3). The algorithm is designed to be executed in the topology of a multi-agent system model. The role of actors here is played by the agents-executors, and the agent-center performs the functions of the center.

The dialogues of the executing agents with the agent-center begin with determining the initial parameters for the budget auction and agreeing on the cost of the goods. After that, the agent-center:

1. Announces the start of the budget auction, indicating the amount of the allocated resource.
2. Warns about the rules of the game and reminds of the penalties imposed in case of their violation.
3. Assigns a queue of dialogues with performing agents.
4. Asks, in turn, each executing agent to name the limiting values of the optimal plans for the players $\prod_{\min}, \prod_{\max}$ and the corresponding values of the required resources $\rho_{\min}, \rho_{\max}$.
5. Identifies for each agent-executor the values of the parameters ${}^0\alpha_{ij}$ and ${}^0s_{ij}$ and the boundaries of the working area of the characteristic.

6. Optimizes the production plan and resource allocation based on these values.
7. Announces these values of the initial distribution plan to the executing agents, specifying the initial values of ${}^0\prod_{ij}$ and ${}^0\rho_{ij}$.
8. The agent center informs the executing agents of the planned indicators obtained at the previous stage of the procedure and invites the next executing agent to the budget auction.
9. Request from the center agent about the feasibility of changing the plan.
10. If no changes are needed, go to 13, otherwise return to 4.
11. Request from the center agent about the amount of the request for the resource.
12. Input by the jth agent-executor of his request for the resource.
13. Identification of a new production function of the agent -executor passing through the point where $\prod_i = \prod_{i_{\min}}$, $\rho_i = \rho_{i_{\min}}$ and a new point proposed by the agent -executor.
14. Calculation of the permissible production volume by the center j-th executive agent.
15. Notification by the center agent to the j-th execution agent about the possibility or impossibility of satisfying its request.
16. Request from the executing agent for an acceptable plan.
17. Notification of the agent to the center about the minimum permissible production volume j- th the agent -executor corresponding to the previously entered request for the resource.
18. Request from the center agent about the advisability of continuing the dialogue.
19. If continuation is required, go to 4, otherwise go to 13.
20. Request from the center agent about the appropriateness of refusing to choose to continue the steps and returning to the plan of the previous step.
21. Announcing the result of the game with the j-th agent-executor.
22. Transition to dialogue with j+1-th agent-executor and transition to 8.

Figure 3 – Budget auction algorithm based on a multi-agent model



Source: developed by the authors

The budget auction ends when none of the implementing agents expresses a desire to change their planned indicators for the next, full cycle. The resulting structure of budget allocation is optimal to the extent that the control figures and restrictions determined by experts, the upper level of the resource allocation subgraph, and the acceptability of the agreed boundaries of the working areas of the production characteristics of the elements are optimal. In order for the allocation in the local budget system to be optimal, it is necessary that all actors at all levels of budgeting be represented by agents and participate in the budget auction. Obviously, it is necessary to methodologically and

programmatically ensure the lowest level of actors (the village represented by the village headman and the village community), although now most small settlements no longer have their own budget. It is also necessary to work out production functions that correspond to different sustainable development goals separately. This will make it possible to measure the results obtained at the stage of budget implementation and compare them directly with the sustainable development goals. In this way, the distribution of subsidies and investments is optimized, which forces all elements of the link to work in such a way that their efforts are aimed at maximizing the functionality of the center, taking into account the usefulness for the center of the goods produced by the actors.

5. DISCUSSION

The theoretical framework and methodological foundations presented in this study establish a solid foundation for the application of multi-agent systems to local hromada budgeting processes. However, several critical areas require further development to translate these theoretical concepts into practical, implementable solutions. The most immediate priority for future work involves the empirical validation of the proposed multi-agent budget auction model through controlled pilot implementations. We propose conducting pilot studies in one or two Ukrainian local hromadas that demonstrate varying characteristics in terms of population size, economic development level, and administrative capacity. The selection criteria for pilot hromadas should include willingness to participate in innovative governance experiments, sufficient administrative infrastructure to support data collection, and representative socio-economic profiles that reflect the broader Ukrainian local government landscape.

The pilot testing phase will serve multiple objectives, providing empirical data on the practical feasibility of implementing the multi-agent auction mechanism in real budgeting scenarios, allowing for the collection of performance metrics that can validate the theoretical assumptions underlying the model, and revealing practical challenges and opportunities for model refinement that cannot be anticipated through theoretical analysis alone. The pilot studies should be designed as controlled experiments with clear baseline measurements, intervention protocols, and outcome evaluation frameworks. Data collection should encompass both quantitative metrics such as budget allocation efficiency, participant satisfaction scores, and time-to-decision measurements, as well as qualitative assessments including stakeholder feedback, process observations, and administrative burden evaluations. This empirical evidence will be crucial for refining the model parameters, validating the production function specifications, and demonstrating the practical value proposition of the multi-agent approach.

Recognizing the significant variation in digital capacity and technical expertise across Ukrainian local hromadas, future work must prioritize the development of scaled-down and modular versions of the proposed model. This adaptation strategy acknowledges that while the full multi-agent implementation may be optimal for hromadas with advanced technical infrastructure, many local governments require more accessible entry points to participatory budgeting innovation. The simplified version should maintain the core theoretical principles of the multi-agent auction while reducing computational complexity and technical requirements. This could involve developing preset agent strategies that eliminate the need for complex machine learning algorithms, implementing rule-based decision support systems that can operate with minimal computational resources, and creating standardized templates for production function estimation that require basic input data readily available in most hromadas.

The modular approach should allow hromadas to implement components of the system incrementally, beginning with basic participatory mechanisms and gradually incorporating more sophisticated multi-agent features as their capacity develops. This progression model should include clear upgrade pathways, compatibility standards between modules, and comprehensive training materials that enable local administrators to manage the system independently. Future research should also explore hybrid implementation models that combine digital multi-agent tools with traditional participatory methods, ensuring that hromadas with limited digital infrastructure can still benefit from the improved decision-making processes that the model facilitates.

The complexity of multi-agent systems and auction mechanisms presents significant communication challenges that must be addressed to ensure broad adoption and stakeholder understanding.

Future work should prioritize the development of intuitive visualization tools that make the algorithmic processes transparent and accessible to non-technical stakeholders, including community members, local officials, and oversight bodies. The visualization framework should include interactive dashboards that allow real-time monitoring of the auction process, clear flowcharts that explain the decision-making logic in accessible language, and simulation interfaces that enable stakeholders to explore different scenarios and their outcomes. Particular attention should be paid to visualizing the production function identification process, the resource allocation optimization, and the feedback mechanisms that drive system learning and adaptation.

Additionally, future work should develop comprehensive communication strategies that explain the benefits and mechanisms of the multi-agent approach to diverse audiences. This includes creating educational materials for community members, training protocols for local administrators, and policy briefs for regional and national government officials. The goal is to build broad understanding and support for the innovative approach while addressing potential concerns about complexity and technological dependence.

To demonstrate the practical value and robustness of the proposed model, future research must develop comprehensive performance measurement frameworks and conduct extensive scenario analysis. The performance metrics should encompass multiple dimensions of public budgeting effectiveness, including allocative efficiency in terms of how well resources are distributed according to community priorities, dynamic efficiency regarding how quickly the system adapts to changing circumstances, democratic legitimacy measuring the extent to which all stakeholders feel adequately represented, and administrative efficiency evaluating the cost and complexity of operating the system. Key Performance Indicators should be developed for each component of the multi-agent system, including agent learning rates, auction convergence times, stakeholder satisfaction levels, and budget outcome quality measures. These metrics should be benchmarked against traditional budgeting approaches to provide clear evidence of the model's value proposition.

The scenario analysis framework should examine system performance under various socio-economic conditions, including economic crisis situations, demographic changes, infrastructure disruptions, and varying levels of stakeholder participation. This analysis will be crucial for understanding the model's robustness and identifying potential failure modes or adaptation requirements. Future work should also develop stress-testing protocols that evaluate system performance under extreme conditions, such as sudden population changes due to conflict-related displacement, economic shocks that dramatically alter resource availability, or technological failures that compromise system functionality.

6. CONCLUSION

To position the proposed multi-agent approach within the broader landscape of participatory governance innovation, future research should conduct comprehensive comparative analyses with existing international frameworks for participatory budgeting and resource allocation. The comparative analysis should examine successful participatory budgeting implementations in countries with similar development profiles to Ukraine, innovative digital governance initiatives that have achieved scale in European contexts, and multi-agent system applications in public administration from global best practice examples.

This comparative work should also explore opportunities for international collaboration and knowledge exchange, potentially developing networks of local governments that are experimenting with similar approaches. Such collaboration could accelerate learning, reduce implementation costs, and build broader momentum for participatory governance innovation. Future research should explicitly develop the connections between the multi-agent budgeting model and the United Nations Sustainable Development Goals, particularly those related to sustainable cities and communities, reduced inequalities, and partnerships for the goals. This integration requires developing specific methodologies for incorporating SDG indicators into the production function specifications and auction mechanisms, including monitoring frameworks that track how budget allocations contribute to sustainable development outcomes, creating incentive structures that reward decisions aligned with

sustainability objectives, and establishing reporting mechanisms that demonstrate local contributions to global development goals.

The successful completion of this comprehensive research agenda will transform the theoretical contributions of this study into practical tools for enhancing democratic governance and resource allocation efficiency in Ukrainian local hromadas. The phased approach, beginning with pilot testing and progressing through model refinement, visualization enhancement, performance validation, and international comparison, provides a clear pathway for advancing both theoretical understanding and practical application of multi-agent systems in public administration. The lessons learned and tools developed through this work have the potential to influence participatory governance innovation far beyond the Ukrainian context, contributing to more effective, democratic, and sustainable public administration worldwide.

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THE ROLE OF DIGITAL SKILLS AND DIGITALISATION IN ENHANCING LABOUR PRODUCTIVITY IN THE EU

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ABSTRACT

Digitalisation and digital skills are often considered key factors shaping labour productivity and international competitiveness. The paper aims to examine the potential relationship between the level of digital skills and labour productivity. It explores the interdependence between the level of digital skills and labour productivity while considering the possible effects of business digitalisation. Using the Granger causality tests and panel data regression, we get several novel results. The results indicate a bidirectional causal relationship between productivity and digital skills, albeit with a two-year lag for e-commerce. Panel fixed-effects regressions and Generalised methods of moments (GMM) have been further used to get more detailed and robust results. Panel regression analysis confirms the positive effect of general digital skills on labour productivity, while this effect was not found in the case of advanced digital skills and R&D expenditure. This research brought new knowledge regarding the economic impact of using digital technology. Our findings highlight the importance of general digital skills in the population. The relationship between digital transformation and labour productivity depends on the type of skills and ability of employees to adapt to new technologies. From the perspective of increasing the country's international competitiveness, programs to improve digital skills across the population and different socio-economic groups are the key issue

Keywords: *digital skills, digitalisation, labour productivity, digital economy, international competitiveness*

1. INTRODUCTION

Digitalisation is one of the key drivers of economic growth. Investments in digital infrastructure and technological innovation play a crucial role in boosting economic growth, as found, for example, by [Mura & Donath \(2023\)](#) and [Arsic \(2020\)](#). Despite the potential of digital technology to substitute some jobs, it also helps to gain new skills and enhance the productivity of organisations ([Daher & Ziade, 2024](#)). The successful adoption of digital technology often requires the development of transferable human skills ([Daher & Ziade, 2024](#)). Several previous studies have shown that the lack of available skills appears to be one of the key problems when adopting new technology in a company ([Bello et al., 2021](#); [Kamble et al., 2018](#)). Especially advanced digital technologies require trained professionals with adequate digital skills to thrive in the new digital environment ([Hernandez-de-Mendez et al., 2020](#)). The availability of digital skills is, therefore, significantly affecting the adoption of advanced digital technologies, such as artificial intelligence systems ([Kinkel et al., 2022](#)). Digital skills, therefore, play a crucial role in the adoption and utilisation of digital technology within companies. The lack of digital skills can reduce productivity due to the limited adoption of new digital technology ([Priambodo et al., 2025](#)). Moreover, there could also be direct effects of digital skills on

productivity. The relative scarcity of skilled employees increases the natural rate of unemployment and reduces productivity (Abbritti & Consolo, 2024). Despite several studies focused on the adoption of digital technology and the potential effect of digital skills, there is currently a limited number of studies examining the relationship between digital skills and labour productivity.

This paper aims to bridge the research gap by examining the potential relationship, while also considering the potential effects of digital technology and e-commerce. Our study makes several contributions to the literature. First, our approach distinguishes between the direct effect of digital skills and the possible indirect effects through the adoption of digital technologies and e-commerce. Second, we also used two different variables of digital skills. While the first variable captures the set of general digital skills, the second variable represents ICT specialists. This approach allows us to distinguish between general and advanced skills and their potential effects on labour productivity. Third, our approach is combining three different methods to ensure robust results. Fourth, our data is not limited to one specific country or region. Hence, the results can be applied generally to EU countries, and they also allow us to make recommendations for EU policies. This paper aims to examine the potential relationship between variables capturing digital transformation and labour productivity. The research is based on the qualitative analysis of available secondary data for EU countries. The next section outlines the theoretical background and presents a comprehensive literature review. The methodology section discusses the formulation of the research questions and describes the methodological approaches and data used in the analysis. The main methods include Granger causality, which enables us to determine how digital skills (both general and advanced) impact work productivity and whether there is a bidirectional causal relationship between them. Moreover, it also uses the panel regression analysis (fixed effects and GMM models), through which we identify the potential causal effect of digital skills on labour productivity. The results are described and discussed, with a focus on their relevance to the stated research questions. The results provide important insights for more effective policymaking to support innovation and growth in labour productivity. The final section summarises the main research findings, suggests measures to improve innovation policies, and highlights the limitations of the data and methods analysed.

2. LITERATURE REVIEW AND SPECIFICATION OF RESEARCH QUESTIONS

Regional differences in digitalisation among EU countries are one of the relatively well-researched research problems. Hunady et al. (2022) found significant differences in digital readiness between northern and southern EU countries. Grichchenko (2024) found robust geographical heterogeneity and consistent spatial patterns in digital skills in the EU. Hurduzeu et al. (2022) identified differential impacts of digitalisation on the competitiveness between Central and Eastern Europe and Western Europe. Considering their findings, some authors advocate for diversity in digital skills policy within the EU (Grichchenko, 2024), while others argue in favour of harmonised digital strategies across the EU (Mura & Donath, 2023).

Digital development, as measured by the DESI, is growing along with GDP per capita, with a widening gap between digitally advanced and less advanced EU countries (Török, 2024). The positive correlation between economic growth and digital technology has also been empirically confirmed by Olczyk & Kuc-Czarnecka (2022). They identified a positive and statistically significant impact of DESI on GDP per capita and emphasised the importance of investing in digital infrastructure and education in EU countries.

Differences in digitalisation levels related to variations in economic performance (Kakizhanova et al., 2025). Moreover, the digital economy contributes not only to economic growth but also to social inclusion (Sahi, 2022). Skare et al. (2020) showed that digital transformation promotes countries' competitiveness through productivity and efficiency gains. Enhancing digital capabilities and infrastructure enables countries to respond more quickly to shifting economic conditions and promote innovation.

On the other hand, Chiemeke & Imafidor (2020) found mixed evidence and argued that the effect of digital technology on economic growth and productivity is adverse in the short term. In line with the

results of previous studies, we also use digital technology in firms as one of the independent variables, which allows us to explain the mentioned contradictions in the existing literature.

While most previous studies have found that higher levels of digitalisation can lead to better economic outcomes, the exact cause is not often explained. Several studies suggest that improvements in skills and infrastructure are two potential ways in which digitalisation affects economic performance. As reported by [Boikova et al. \(2021\)](#) and [Kleszcz & Nowak \(2020\)](#), investments in digital skills and digital infrastructure are playing a crucial role. [Miethlich et al. \(2020\)](#) also emphasised the importance of developing digital literacy as well as enhancing cybersecurity to improve digital competitiveness. Since digital transformation promotes e-commerce mentioned findings can also be applied to e-commerce and e-business ([Criveanu, 2023](#); [Anastasiei & Georgescu, 2021](#)). Since e-commerce activities have the potential to increase labour productivity ([Kiani & Ahmed, 2013](#)), our analysis also considers variables related to e-commerce activities.

Although the direct effect of digital skills on labour productivity has been out of focus in previous studies, some of them have examined similar effects of digitalisation. [Basol & Yalcin \(2021\)](#) identified the positive impact of DESI on employment and personal income, and [Balashova \(2023\)](#) highlighted the impact of digitalisation on productivity growth.

Several previous studies have also looked at the impact of specific digital technologies. [Magoutas et al. \(2024\)](#) found that information and communication technology (ICT) has a positive impact on GDP, with human capital being a key driver of economic growth. [Morou \(2024\)](#) found that the increasing role of technologies such as cloud computing and big data is evident in developed European countries. Overall, research confirms that digitalisation plays a crucial role in driving economic growth and enhancing international competitiveness. Its success depends on targeted support for infrastructure, skills, and technological innovation.

Despite the lack of empirical evidence regarding the productivity effects of digitalisation, there is a consensus in the literature that research and development (R&D) and innovation enhance productivity at the national level ([Blanco et al., 2015](#); [Nekrep et al., 2018](#)). As well as at the firm level ([Hunady et al., 2020](#); [Pieri et al., 2018](#)). [Hall et al. \(2013\)](#) argue that R&D and investment in ICT are both associated with changes in productivity. However, ICT expenditure is even more important for productivity compared to R&D. Since R&D expenditure is considered one of the main drivers of labour productivity, we used this indicator as a control variable in our regression models.

Two previous studies conducted at the country level yielded contradictory results. [Varlamova & Lari-on \(2020\)](#) demonstrate that the digitalisation of business processes and an increase in organisations utilising the Internet result in a rise in labour productivity, as shown in data from Russia. On the contrary, [Chiemeke & Imafidor \(2020\)](#) argue that there is an adverse effect of digital technology on labour productivity in the short term, which turns out to be positive in the long term. Due to a lack of studies directly examining the effect of digital skills on labour productivity on larger datasets, the problem remains unclear. Our paper aims to fill this gap with the result of empirical analysis. Based on the results of previous studies, the following four research questions (RQ) have been formulated:

1. Are there any relationships between general digital skills, advanced digital skills, usage of digital technology in firms, and e-commerce?
2. Does the usage of digital technology in firms significantly affect labour productivity?
3. Do general digital skills directly affect labour productivity (while considering the potential effect of digital technology and e-commerce)?
4. Do advances directly affect labour productivity (while considering the potential effect of digital technology and e-commerce)?

All research questions relate to the relationship between digitalisation and labour productivity, with a focus on digital skills. Answering these research questions allows for a deeper understanding of the potential effects of digital skills, digital technology, and e-commerce in the EU.

3. METHODOLOGY

The empirical research is based on panel data for EU countries. Since our main aim is to examine the potential effect of digital skills on labour productivity, labour productivity represents our primary dependent variable. This variable is calculated as labour productivity per person employed and number of hours worked. Labour productivity is expressed in relative terms as a percentage of the EU27 average in 2020. This approach enables us to compare the efficiency with which countries utilise labour, considering differences in the number of hours worked.

Labour productivity per person employed and hours worked is an essential indicator of economic activity. It is defined as the value of all goods and services produced less than the value of inputs used in their production. This indicator is shown as an index, where a value above 100 indicates that the GDP per person employed in each country exceeds the EU27 average for 2020, and a value below 100 indicates a lower level.

Input data are calculated in the Purchasing Power Standard (PPS), which eliminates price level differences between countries. The measurement of labour productivity per hour worked eliminates differences due to the structure of the labour force, specifically the split between full-time and part-time work, and considers changes within a given year. This approach provides a more accurate and reliable picture of productivity developments in the economy. We have chosen this indicator based on the assumption that a competitive country can produce output efficiently in terms of both time and labour. Combined with the selected variables of DESI, this indicator offers insight into how digitalisation impacts economic performance and contributes to economic growth. At the same time, countries with higher levels of labour productivity show a greater ability to compete in global markets.

Four main dependent variables captured the digital skills and digitalisation. These variables were constructed based on the Digital Economy and Society Index (DESI) methodology. DESI represents a composite indicator established by the European Commission to measure the digital performance of European Union member states ([Konc, 2025](#)). Since 2023, DESI has also served as a monitoring tool for progress towards the targets set in the Digital Decade Policy Program 2030 ([European Commission, 2024](#)).

Considering our primary aim and the results of previous studies, the values of four DESI subindices have been used as independent variables in our analysis. These variables capture four different areas of digitalisation: General digital skills, advanced digital skills, digital technology and e-commerce. The general digital skills subindex/variable assesses the overall level of basic and advanced digital skills and internet usage. The advanced digital skills subindex is calculated based on the share of ICT specialists, ICT graduates, and the share of enterprises providing ICT training. The digital technology subindex encompasses a diverse range of indicators related to the utilisation of digital technology in businesses. It includes the share of enterprises using AI, big data analytics, cloud computing, electronic information sharing, social media, and e-invoices. Finally, the e-commerce subindex comprises the share of SMEs selling online, the share of businesses having turnover from E-commerce and those selling their products online cross-border. All variables have equal weights for the calculation of subindices.

The paper examines the period between 2016 and 2023; however, due to rapid changes in digital technologies, not all the variables, such as cloud, AI, or e-invoices, were consistently applicable throughout the entire timeframe. A comprehensive description of variables is provided in Appendix 1. Using the mentioned variables, we analysed the potential causality between different areas of digitalisation and labour productivity. In the first part, we used the panel Granger causality tests, which require testing for stationarity. This fundamental assumption of the Granger causality test was tested by the panel unit-root tests (Levin-Lin-Chu test: LLC test).

The second part of the analysis focuses on examining the potential effects of digital skills on labour productivity by using panel regression analysis. This approach enables us to provide more in-depth insights into the problem and capture the possible causal effects, along with their statistical significance. Two different regression techniques (fixed effects panel regression and GMM panel regression) have been used to analyse the research problem. Fixed effects regression is commonly used in previous studies. The Generalised Method of Moments (GMM) is also popular in economic research

due to its several advantages. The combination of both methods was primarily used to compare results and enhance their robustness. A similar approach has been previously used, for example, by [Hunady et al. \(2023\)](#). The initial GMM model was first introduced in finance by [Hansen and Hodrick \(1980\)](#), and a system GMM estimator was proposed by [Arellano and Bover \(1995\)](#) as well as by [Blundell and Bond \(1998\)](#). The GMM usually produces less biased and more consistent results compared to standard OLS (such as fixed-effects regression). It also eliminates problems with endogeneity ([Nickell, 1981](#)). The GMM estimator is consistent if the condition of no serial correlation between error terms and instruments is met. This condition is, in our case, tested using [Arellano & Bond \(1991\)](#) approach.

4.RESULTS

Firstly, the analysis summarises the descriptive statistics of the main independent variables and dependent variables, which are presented in Table 1. The results are shown for both cross-sectional and panel data. While the correlation analysis utilises cross-sectional data, other methods used in the study are based on panel data for 25 EU countries (Malta and France were excluded due to data unavailability) during the period between 2016 and 2023.

Table 1. Overview of descriptive statistics for cross-sectional data and panel data

Cross-sectional data/ Panel data	Observations (Cross-sectional data / Panel data)	Mean (Cross-sectional data / Panel data)	Standard deviation (Cross-sectional data / Panel data)	Median (Cross-sectional data / Panel data)
General digital skills	25 / 200	51.03 / 50.83	8.81 / 11.53	50.28 / 51.2
Advanced digital skills	25 / 200	12.53 / 12.50	2.34 / 2.52	12.20 / 12.3
Digital technology	25 / 200	26.53 / 26.45	7.86 / 9.78	26.04 / 25.7
e-Commerce	25 / 200	13.36 / 13.36	5.17 / 5.63	13.57 / 12.7
Labour productivity	25 / 200	93.56 / 94.69	36.93	77.17 / 78.5

Source: Authors

The standard deviation is higher in the case of variables capturing general digital skills, digital technology and labour productivity. This fact implies that these variables vary more across EU countries. There is also a slight rightward skew in variables capturing digital skills and digital technology, suggesting that some countries have significantly higher levels of digital skills and adoption of digital technology compared to others. For the general digital skills indicator, the highest average value was recorded in the Netherlands. At the same time, other Western and Northern European countries such as Finland, Denmark, and Luxembourg also achieved high values.

On the other hand, the lowest level of general digital skills was found in Bulgaria. Finland scored best for the advanced digital skills and digitalisation of business. Italy and Bulgaria were at the other end of the ranking. Ireland dominated in e-commerce usage and labour productivity, with Bulgaria again coming last on both indicators.

The correlation matrix in Table 2 reveals a strong positive correlation between digital skills and business digitisation, suggesting that countries with higher general digital skills in their population also tend to have more digitised businesses. Advanced digital skills and enterprise digitisation exhibit a positive linear correlation, indicating that advanced digital skills are associated with higher levels of enterprise digitisation. Based on the positive linear correlation, countries with higher levels of digital skills tend to have higher labour productivity. The correlation between advanced skills and labour productivity is slightly lower. We also observe a moderate correlation between the level of digitalisation of enterprises and labour productivity. E-commerce has lower correlations with the other variables. Results suggest that the use of e-commerce may not be directly related to the level of digital skills or labour productivity.

Table 2. Correlation analysis based on the cross-sectional data for EU countries

	General digital skills	Advanced digital skills	Digital technology	e-Commerce	Labour productivity
General digital skills	1.00	0.71	0.77	0.49	0.67
Advanced digital skills	0.71	1.00	0.74	0.45	0.63
Digital technology	0.77	0.74	1.00	0.47	0.58
E-commerce	0.49	0.45	0.47	1.00	0.47
Labour productivity	0.67	0.63	0.58	0.47	1.00

Source: Authors

The previous results of the correlation analysis provided the foundation for applying the panel Granger causality test, which requires time series to be stationary. Failure to ensure stationarity can lead to incorrect results and misinterpretations of causal relationships. We employed the Levin-Lin-Chu (LLC) test to test stationarity, with the results presented in Table 3.

Table 3. Results of LLC unit-root tests

	Lag 0		Lag 1	
	z-score	p-value	z-score	p-value
Labour productivity	-3.17678	0.0007	-4.83845	0.0000
General digital skills	-76297	0.0000	-6.26622	0.0000
Advanced digital skills	-10.2135	0.0000	-14.3188	0.0000
Digital technology	-5.21218	0.0000	-12.1504	0.0000
E-commerce	-8.56288	0.0000	-6.68193	0.0000

Source: Authors` processing based on Eurostat and DESI

The results of unit-root tests indicate that all the examined time series are stationary with lag 0, indicating that no transformation to the first difference is necessary. To enhance the accuracy, the test was also conducted for a lag of 1. The results are consistent with those obtained for a lag of 0. In the next step, the Granger causality tests were applied to the panel data, and the results are presented in Table 4.

Table 4. Results of panel Granger causality test

Variable	Ho:	Variable	Lag 1	Lag 2
Labour productivity	$\neq >$	General digital skills	2.2e-16	2.2e-16
General digital skills	$\neq >$	Labour productivity	2.2e-16	2.2e-16
Labour productivity	$\neq >$	Advanced digital skills	0.002835	2.2e-16
Advanced digital skills	$\neq >$	Labour productivity	2.836e-16	2.2e-16
Labour productivity	$\neq >$	Digital technology	0.001824	2.2e-16
Digital technology	$\neq >$	Labour productivity	2.2e-16	2.2e-16
Labour productivity	$\neq >$	E-commerce	0.282	2.2e-16
E-commerce	$\neq >$	Labour productivity	0.1326	2.2e-16

Source: Authors

The primary goal of the Granger causality test was to analyse the potential relationship between labour productivity per employee hours worked and other variables. Based on the low p-value, we can reject the null hypothesis H_0 at all common statistical levels of significance for most time series. This result confirms that digital skills affect both labour productivity (at both the user and specialist levels) and the use of digital technologies in enterprises. At the same time, labour is also linked to other

examined variables. Revealed bidirectional causality between labour productivity and digital skills highlights the importance of continuous training to improve the digital skills of employees. Moreover, the usage of digital technologies is also related to changes in labour productivity.

Regarding e-commerce variables, the number of lags plays a significant role. A one-year lag (lag 1), there is no statistically substantial Granger causality in either direction. However, when using a two-year lag, the relationship becomes significant in both directions. This result may suggest that changes in e-commerce have some impact on labour productivity, but this effect is noticeable with a longer time lag. The results of Granger causality further supported the creation of regression models.

The results of the Husman test help us to decide between the usage of fixed-effects and random-effects models. This test is commonly used to compare the fixed and random effects models for their consistency and efficiency. The result of the Hausman test is depicted in Table 5. The very low p-value suggests that the random effects model is not consistent. The test shows that the fixed effects model is a more suitable alternative, and the random effects model could lead to incorrect or inconsistent estimates.

Table 5. Results of Hausman test

Hausman test		
Chi-squared = 21.521	df = 4	p-value = 0.00025

Source: Own processing

The fixed-effects panel regression takes the following form:

$$LP_{it} = \beta_0 + \beta_1 * GDS_{it} + \beta_2 * ADS_{it} + \beta_3 * DBT_{it} + \beta_4 * EC_{it} + \beta_5 * RDexp_{it} + \mu_i + \lambda t + \varepsilon_{it} \quad (1)$$

Where:

LP_{it} – Labour Productivity per person per hour (Labour productivity) in country i and year t

IUS_{it} – General Digital Skills

ADS_{it} – Advanced Digital Skills

DBT_{it} – Digital Technology of Businesses

EC_{it} – E-commerce

RDexp_{it} – R&D expenditure - control variable, countries that invest more in innovation tend to have higher labour productivity

μ_i – Country fixed effects (economic differences between countries)

λt – Time effects (controls for the impact of specific events over time)

ε_{it} – Standard error.

R-studio and Stata software were used to calculate panel regression. The panel fixed-effects regressions have been further completed with GMM regression models. GMM models enable the elimination of potential endogeneity problems and allow for a comparison of the results. A robustness check has been performed by modifying regression specifications and by adding or removing some of the regressors. The results of the regression are summarized in Table 6. Some of the robustness checks are shown in the table.

Table 6. Results of panel regression analysis using fixed effects and GMM models

	Fixed-effects 1.	Fixed-effects 2.	Fixed-effects 3.	GMM 4.	GMM 5.
General digital skills	0.325*** (0.11)	0.375*** (0.110)	0.392*** (0.115)	0.172** (0.069)	0.098*** (0.017)
Advanced digital skills		-0.752 (0.497)	-0.661 (0.465)	-1.237 (0.983)	
Digital technology		-0.122 (0.079)	-0.119 (0.079)	-0.071 (0.169)	
E-commerce	-4.733 (3.11)	-0.121 (0.297)	-0.107 (0.292)	-0.072 (0.170)	-0.019 (0.059)
R&D exp.	-0.260 (0.277)		-3.245 (2.768)	-0.829 (3.761)	1.724 (2.97)
Labour productivity(-1) (lag= 1 year)				0.382*** (0.069)	0.284*** (0.035)
C (Fixed effects)	89.57*** (2.863)	89.82*** (3.42)	93.05*** (4.365)		
Observations	200	200	200	150	150
R2	0.988	0.988	0.989		
F-stat	525.9***	521.4***	50.93***		
J-statistic				11.935	13.26

Source: Authors

Lagged dependent variables were used in GMM models as required. Moreover, we also used independent variables lagged by one and two years to capture potential effects. However, the results were still very similar, and we lost a significant number of observations by this procedure. The results obtained by all models are identical, suggesting they are robust and interpretable. The general digital skills variables emerged as a positive and statistically significant factor in labour productivity. This result indicates that general digital skills enhance employee efficiency and overall productivity in digitised work environments. Advanced digital skills, closely linked to ICT specialists, do not have a statistically significant effect, which may indicate that advanced technical skills are not the primary factors influencing productivity. The results might indicate some adverse impacts of digital technologies in the short term, but this potential effect is again statistically non-significant. However, this may suggest that the introduction of digital technologies requires an adaptation period to have any positive impact on labour productivity or that not all enterprises use them effectively. R&D expenditure does not have a significant impact on labour productivity, which may indicate that the effect of R&D is more evident in the long run. It also implies that R&D requires additional factors, such as the availability of digital technology and digital skills, to be translated into significant productivity gains.

5. DISCUSSION

This section discusses the findings obtained within the context of the main aim and research questions. As reported in the literature review, all research questions have been created in line with the results of previous studies and to examine the critical research gap. Based on the literature review, we found that digitalisation is one of the essential factors determining economic growth and competitiveness. However, there is currently only a minimal number of studies focused on the relationship between digital technology, digital skills, and labour productivity. This study aims to clarify these relationships. The insights are provided by an empirical analysis based on Granger causality tests and panel regression analysis conducted using data from EU countries. We successfully addressed individual research questions.

Interconnectedness of digital factors (RQ1): We found a significant positive relationship between general and advanced digital skills and enterprise digitalisation. This finding aligns strongly with previous research, which indicates that skill availability is a crucial factor in technology adoption. [Bello et al. \(2021\)](#) and [Kamble et al. \(2018\)](#) argue that the skill gap is one of the main obstacles to the

digital transformation of businesses. [Hernandez-de-Mendez et al. \(2020\)](#) noted the need for trained professionals, and [Kinkel et al. \(2022\)](#) linked the level of employees' skills to the success of AI adoption. This evidence is also supported by our results, which suggest that countries with higher skills tend to have more digitised businesses. Bidirectional Granger causality between skills, technology, and productivity further expands the current knowledge of the problem and suggests the existence of more complex relationships. The finding that e-commerce exhibits a significant Granger causality link to productivity, albeit with a two-year lag, aligns with the results of [Kiani and Ahmed \(2013\)](#), who found that the relationship may be more complex. Only some e-commerce activities, such as e-selling, have a positive impact on productivity, while others do not have a similar effect.

Digital technology used in firms and labour productivity (RQ2): Our research also brings some interesting results regarding the impact of business digitalisation on labour productivity. While Granger causality suggested a potential link, the panel regressions did not find statistically significant short-term causal effects. This result partly contrasts with a study by [Varlamova & Larionova \(2020\)](#), who found a positive relationship between two similar indicators in Russia, as well as the general theoretical expectation that digitalisation enhances efficiency. However, the results align with those of [Chiemeke & Imafidor \(2020\)](#), who found an adverse short-term effect between digital technology and productivity, implying that the adoption of new technology does not immediately lead to productivity gains in the short run. The adaptation period of digital technology may depend on the availability of skills, as well as other complementary factors, such as effective management and processes.

General digital skills and labour productivity (RQ3): This part of the analysis provides some of the key findings. The results suggest statistically significant positive effects of general digital skills on labour productivity. These results are robust across all models. It supports the idea that general digital literacy, especially, has the potential to enhance labour efficiency in the economy. It also, to some extent, aligns with the previous studies despite their limited scope and depth. This fact further supports and enhances the arguments by [Daher & Ziade \(2024\)](#). They highlighted the importance of transferable skills for successful technology adoption in companies. It also complements the findings of [Magoutas et al. \(2024\)](#), who argue for the role of human capital in digital transformation and the use of ICT in business.

Advanced digital skills and labour productivity (RQ4): Our results are somewhat unexpected in this case. Interestingly, advanced digital skills, which are typically associated with ICT specialists, did not show a significant direct effect on labour productivity in the regression models. Despite some positive correlations and Granger causality results, we fail to find significant causal effects in the short term. This fact requires careful interpretation and discussion. Firstly, our findings do not necessarily contradict the importance of ICT specialists. However, this may not be notable in the short term, or the effect may not be detectable in isolation, but it is present through other factors.

Furthermore, while general digital skills are required across a broader range of activities, more specialised and advanced digital skills are usually needed in selected areas and professions. The impact could be more indirect, enabling the effective use of digital technologies and improving the general digital skills level in the population, with a certain time lag. The results of Granger causality also suggest this potential effect.

In general, our results strongly affirm the direct, positive impact of general digital skills on labour productivity. This fact emphasises the role of human capital and digitalisation. It especially highlights the crucial role of digital literacy despite the importance of advanced digital skills and up-to-date digital technology. Investments in emerging digital technology or training in advanced digital skills often fail to have an impact when a sufficient level of general digital skills is not available within the firm. The ability of employees to use technologies effectively is a crucial problem, as reported, for example, by [Miethlich et al. \(2020\)](#). General digital literacy across the workforce is a more immediate booster of labour productivity. Our results support the previous findings of [Skare et al. \(2020\)](#) and [Balashova \(2023\)](#) on the impact of digitalisation on the productivity and international competitiveness of countries. Hence, public support for digital training is crucial, especially given the signs of declining digital literacy among young people, as reported by [Stofova et al. \(2022\)](#).

Despite our efforts to utilise relevant data and methodology to achieve robust results, our approach still has some limitations. The research was conducted based on data from the Eurostat database and the DESI index. However, due to the differences in metrics, the results may exhibit certain inaccuracies. The analysis focused only on selected EU countries based on data availability, with France and Malta excluded from the study. Additionally, in the case of the regression model, Ireland was excluded. Despite these exclusions, the analysis includes 24 countries, which means the results may not be fully applicable to all EU Member States. The use of GMM models enables us to address the problem of endogeneity. However, we used only models capturing short-run causal relationships. To identify potential long-run causalities, it would be necessary to apply cointegration analysis and use panel cointegrated regressions, such as FMOLS or DOLS. Moreover, limited data availability did not allow us to include some variables that could have been significant in the models. The overall level of skills, management practices, capital allocation, infrastructure, and labour market policies are some of the main potential omitted variables.

In future research, it would be beneficial to consider other factors that influence labour productivity. Future research should also focus on a deeper analysis of firm data and regional comparisons. Firm data will allow us to obtain detailed information on firm-specific and sector-specific factors, which could further complement our results.

6. CONCLUSION

The main aim of this paper was to examine the potential relationship between the level of digital skills and labour productivity. Based on the results, we can observe significant geographical differences within the EU in all areas examined. The Netherlands achieved the highest level of digital skills, while Bulgaria was identified as the country with the most underdeveloped digital skills. Similarly, Bulgaria also faces an unfavourable situation in terms of labour productivity. Given the strong positive relationship between the mentioned, the lack of digital skills may be one of the key reasons for low labour productivity.

The results of the Granger causality confirm the significant impact of general digital skills on productivity. A similarly significant Granger-causal relationship exists between labour productivity and the integration of digital technologies in enterprises. On the other hand, the area of e-commerce affects productivity only in the long term. Regression analysis also confirmed the statistically significant impact of general digital skills on labour productivity. We fail to find any empirical evidence on the causal effects of advanced digital skills. Identified relationships highlight the need for additional investments in digital education to enhance labour productivity in EU countries.

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Appendix 1. Description of variables

Indicator	Description	Metric	Source
Internet use	Individuals accessing the internet at least once a week	% of individuals	Eurostat
At least basic digital skills	Individuals with at least basic digital skills	% of individuals	Eurostat
Above basic digital skills	Individuals who have above basic overall digital skills	% of individuals	Eurostat
At least basic digital content-creating skills	Individuals with basic or above basic digital content-creation skills	DESI weighted score (2016-2019) % of individuals (2020-2023)	Eurostat DESI
ICT specialists	ICT specialists as percentage of total employment	% of total employment	Eurostat
Female ICT specialists	Employed female ICT specialists	% of ICT specialists	Eurostat
ICT graduates	Graduates of tertiary education in the field of Information and Communication technology	% of graduates	Eurostat
Enterprises providing ICT training	Enterprises providing training to their personnel to develop their ICT skills in all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat
Electronic information sharing	Enterprises who have ERP software package to share information between different functional areas, including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat
Social media	Enterprises who use two or more social media including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat
Big Data / Data Analytics	Enterprises analysing big data from any data source including all manufacturing and service sectors except financial sectors (10 or more persons employed) Data analytics for the enterprises is performed by the enterprise's own employees or by an external provider including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat DESI
e-Invoices	Enterprises sending e-Invoices, suitable for automated processing, including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat
SMEs with at least basic digital intensity	Enterprises with at least basic level of digital intensity (DII Version 3) including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (from 10 to 249 persons employed)	% of enterprises	Eurostat
Cloud	Enterprises buying sophisticated or intermediate Cloud Computing services including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat
AI	Enterprises that use at least one of the AI technologies, including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (10 or more persons employed)	% of enterprises	Eurostat
SMEs selling online	Enterprises with E-commerce sales of at least 1 % turnover including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (from 10 to 249 persons employed)	% of enterprises	Eurostat
E-commerce turnover	Enterprises' total turnover from E-commerce sales including all sectors except agriculture, forestry and fishing, mining and quarrying and financial sector (from 10 to 249 persons employed)	% of turnover	Eurostat
Selling online cross-boarder	Enterprises that carried out electronic sales to other EU countries, including all manufacturing and service sectors except the financial sector	% of enterprises	DESI

PROBLEMS RELATED TO THE EU 28th LEGAL REGIME: THE BULGARIAN PERSPECTIVE

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ABSTRACT

Although the European Union has all the resources to be a leader in the modern global economy, in recent years it has lagged the United States and China in cutting-edge technologies and new, fast-growing industrial sectors. The main reason for this result is the growing lack of innovation in the European economy. Europe is failing to turn its ideas into new, marketable technologies and to integrate these technologies into its industrial base. The analysis of the existing problems shows that innovation must be at the heart of European revival, while removing other constraints that hinder growth. Addressing these problems and reforming the European economy means enabling innovative companies to operate under a single, harmonized set of rules within the European market, rather than having to deal with 27 different legal regimes. In this respect, the European Commission is expected to propose the creation, adoption and implementation of a 28th legal regime that will simplify the applicable rules and reduce the costs of failure, including in areas such as company law, insolvency, labor and tax law. The present scientific paper examines the characteristics of the new concept of the European regulatory regime for the economy and its most important aspects. Focus is given to the process of building the new legal framework, the integration of European capital markets and the optimization of tax legislation. In conclusion, recommendations are provided regarding the necessary legal, organizational and institutional measures for the successful preparation of the implementation of the 28th regulatory regime in Bulgaria..

Keywords: 28th EU legal regime, capital markets, tax system, investments

1. INTRODUCTION

The European Union has all the resources it needs to be a leader in the modern global economy. It has a large human potential and skilled workforce, a large private capital base, an internal market of continental dimensions, a stable and predictable legal environment, the rule of law and a unique social model. At the same time, however, the EU urgently needs to address long-standing obstacles and structural weaknesses that are holding back its economic and social development. For more than two decades, Europe has failed to keep up with other major economies due to a persistent productivity growth deficit. The European Union lags behind the United States in cutting-edge technologies, while China has demonstrated dynamic development in many sectors and even dominates some new industries. The main reason for this is the lack of innovation in the European economy. Europe has failed to translate its ideas into new, marketable technologies and to integrate these technologies into its industrial base.

Recent data shows that starting and growing companies in Europe are currently hampered by market fragmentation, limited access to venture capital and insufficient support for innovation. European start-ups find it difficult to scale up within the EU's Single Market due to persistent regulatory barriers. They also have less access to venture capital than their US counterparts: the share of global venture capital raised in the EU is just 5%, compared to 52% in the US and 40% in China. These two factors reinforce each other – the lower growth prospects of EU start-ups and the higher costs of failure reduce their attractiveness to investors. As a result, many companies are seeking funding in the US or relocating their operations there to take advantage of a larger market and customer base.

In this regard, it should be noted that a significant number of internal constraints prevent European companies from competing effectively. They are squeezed by high energy prices and the burden of regulations. In addition, at a global level, they are often placed in an unequal position, linked to the application of large-scale industrial subsidies in other countries and regions.

The analysis of the existing problems shows that innovation must be at the heart of European revival, while removing other constraints that hinder economic growth. The European industrial structure has become static, dominated by traditional sectors that allocate less money to research and innovation compared to technology-oriented sectors in the United States. Moreover, few start-ups reach critical mass with innovative technologies (European Commission, 2025a). With a shrinking population, Europe cannot rely on an increased workforce as a driver of future growth. Productivity must therefore be restored by investing in technological innovation and new skills, not by limiting wages.

To address these problems, a number of new proposals have been put forward in recent reports by Mario Draghi, former ECB President and Prime Minister of Italy (Draghi, 2024) and Enrico Letta (Draghi's predecessor as Prime Minister of Italy (2013–14) and President of the Jacques Delors Institute (Letta, 2024), as well as in a report by the McKinsey Global Institute (McKinsey Global Institute, 2025).

2. BUILDING A NEW REGULATORY FRAMEWORK FOR INNOVATION AND INVESTMENT IN THE EU

In recent years, a number of legal measures have been adopted at EU level with the aim of creating a more cohesive legal framework that promotes the free movement of goods, services, capital, and people, while ensuring a level playing field within the Single Market. Although these measures have improved the legal regimes of the EU and its Member States, they have also had unintended negative side effects, significantly increasing complexity and administrative burdens for citizens, businesses, and governments.

Despite the European Commission's efforts to simplify EU legislation and reduce administrative burdens since 2015 (when the "Better Regulation" agenda was published, updated in 2021), legislative proposals with a simplification focus have been limited. The publication of the Draghi Report in September 2024, combined with geopolitical shifts and the need for Europe to enhance its independence and self-sufficiency, served as a clear signal to the European Commission to act on this matter. The first concrete step taken by the European Commission towards implementing the renewed and comprehensive simplification policy was the announcement of the so-called "Omnibus Simplification Packages" (OSPs), which aim to revise, amend, harmonize, and supplement existing EU legal frameworks across different sectors. Among other things, these packages aim to reduce reporting burdens by 25% for all companies and by 35% for SMEs.

The European Union has indicated that it is ready to „remove barriers“ when it comes to economic investment to enable innovative companies to operate under a new single set of rules, defined as the 28th regime. This regime implies the inclusion of the topics of „corporate law, insolvency, labour law and taxation in a single and simple framework applicable within the European Union“ (Von der Leyen, 2025).

To secure its future as an economic powerhouse, an attractive location for investment and an industrial hub, the EU must react decisively and quickly. A special place in European economic policy should be occupied by the implementation of the future „EU Startup and Scaleup Strategy“(European Commission, 2025b), through the implementation of which the obstacles that hinder the emergence and development of new enterprises will be removed. It will improve the links between

universities and businesses and create better prospects for the commercialisation of patents. The strategy will remove barriers related to limited access to venture capital, fragmented markets, insufficient availability and mobility of talent and skilled workers, as well as insufficiently targeted support for innovation.

An important role in the implementation of the strategy will be played by the future „European Innovation Law“, which aims to promote the access of innovative companies to European research and technological infrastructures, intellectual assets created through publicly funded research and development activities. According to Zaharieva, E. (2024) „by simplifying the regulatory framework, barriers to entry for new businesses can be reduced, making it easier for them to innovate, grow and create jobs. By improving access to finance and investment opportunities, it can be ensured that start-ups and scale-ups have the resources they need to develop and commercialize ideas here in the EU” (Zaharieva, 2024). This could lead to an increase in patenting, as well as the implementation of regulatory solutions that allow innovators to develop and test new ideas.

Enabling innovative companies to benefit from a single, harmonised set of rules at EU level, wherever they invest and operate within the European market, instead of having to deal with 27 different legal regimes, would be a real game-changer for the EU’s economic and institutional landscape. Although the specific scope and main features of the 28th regime are not yet defined, it is expected to align with current EU policy recommendations and initiatives. Below we outline our vision of the likely direction of development.

3. GENERAL DIRECTION OF THE 28TH LEGAL REGIME

The EU legal framework, referred to as the “28th legal regime”, can be seen as part of the broader EU agenda for simplification and increasing competitiveness. The proposal for the 28th EU legal regime is based on the recommendations from the Letta and Draghi reports and forms part of Pillar I of the strategic actions within the “EU Competitiveness Compass” (i.e., closing the innovation gap).

The main aim of this new regime is to support innovative small and medium-sized enterprises (SMEs) to scale up and grow by enabling them to operate under a unified legal framework across the EU, rather than complying with 27 separate legal systems. Although the scope of the regime could in principle be broader, it is expected that its focus will be on “innovative companies” that meet certain criteria such as the qualifications of their workforce, R&D expenditure, and ownership of intellectual property rights.

The new EU “28th legal regime,” is expected to be proposed by the European Commission in late 2025 or early 2026. This new regime will allow innovative start-ups and scale-ups to operate across the EU under a single set of rules, thereby eliminating the need to comply with the different laws of individual Member States. The 28th legal regime aims to simplify applicable rules and reduce the cost of failure for companies, and it will cover aspects of corporate, insolvency, labour, and tax law. Although the proposal for the adoption of the “28th legal regime” is mentioned in the European Commission’s Work Programme, it is not included in the list of new legislative initiatives for 2025. Therefore, it is reasonable to assume that the proposal will be published in 2026. More information on the 28th legal regime is expected to be included in the upcoming EU Strategy for Start-ups and Scale-ups (Q2 2025) and in the European Innovation Act (Q4 2025 – Q1 2026). Consequently, it can be assumed that the regime will enter into force in 2026 or 2027.

The concept of a 28th regime, implies the creation of a special legal framework for the harmonisation of contract law in the European Union. This idea is not new and has been the subject of comments over the years. However, it is necessary to point out that “despite some successful proposals in certain areas (such as a unitary European patent), the implementation of the 28th regime is extremely difficult and represents a serious challenge for the European Union” (Gide, 2024).

In this case, the creation of a pan-European legal status is proposed. This status should allow companies to benefit from harmonised legislation in the areas of corporate law, insolvency, labour law and even taxation, which will facilitate their activities within the European Union, without having to register separately in each Member State.

European Commissioner Michael McGrath, responsible for democracy, justice, the rule of law and consumer protection, has already outlined a number of measures that will apply to start-ups under the 28th regime. These will include full online registration, the application of the Once-Only Principle when establishing subsidiaries and branches in another EU Member State, the abolition of the apostille requirement, the creation of a unique European identifier for companies that will guarantee a single identification and a multilingual digital company certificate in the EU.

4. PROBLEMS RELATED TO THE ADOPTION PROCESS OF THE 28TH REGULATORY REGIME

The process of implementing the 28th regime is not without challenges and uncertainties. One of the main concerns when adopting it is the hypothesis that member state governments will block the proposal, as has already happened in the past. Therefore, in order to implement the idea of a common regulatory regime, the European Commission must work closely with governments and the European Parliament to reach consensus and address any concerns that may arise during the legislative process.

Another challenge concerns the complexity of the regulatory framework itself. The adoption and implementation of the 28th regime will require significant changes to existing laws and regulations in individual countries, which can take a long time and can be associated with complex and lengthy procedures.

There is a risk that the new regulatory framework will have unintended consequences in its implementation and that loopholes may emerge that could be exploited by companies.

The European Commission will also need to ensure that the 28th regime is fair and applies equally to all companies operating in the EU. Achieving this requires designing and implementing measures to prevent larger companies from exploiting smaller ones or to address potential imbalances in the regulatory environment. The European Commission needs to carefully consider these issues and work closely with stakeholders to ensure that the 28th regime is effective and fair.

The implementation of the concept of the 28th regime offers a potential review and reform of European capital markets. By establishing a streamlined supervisory framework within the European Securities and Markets Authority (ESMA), the regime could improve market integration, reduce existing fragmentation and encourage cross-border investment. However, this process also carries risks, including the potential for deepening market divergences. For the new regime to succeed, it must balance national interests with the need for a cohesive and competitive European financial market to position Europe as a global leader.

European capital markets are currently in a difficult situation. Major challenges lie in the need for large-scale financing of the digital transformation of the European economy, which will require an amount of around €700-800 billion per year over the next decade (Draghi, 2025). This sum far exceeds the existing capacity of public budgets and traditional bank lending. Achieving such a level of investment will undoubtedly require the imperative commitment of private capital. However, Europe's financial sector remains structurally and regulatorily inefficient. Its state hinders the development of deep, integrated and efficient capital markets capable of addressing these challenges.

One of the key issues concerns the limited opportunities for retail investors to participate in capital markets. European savers are often limited to low-yield financial products due to consumer protection rules which, although well-intentioned, limit access to investment opportunities with higher returns. This dynamic discourages capital flows into innovative and growth-oriented sectors, limiting the potential for wealth creation and broader economic growth. Modernizing savings products and enabling more direct engagement with capital markets could be transformative for mobilizing private investment (Thomadakis, 2025).

The fragmentation of European capital markets further exacerbates these problems. National supervisory frameworks create inefficiencies as firms operating across borders have to navigate a patchwork of regulations that duplicate their efforts and significantly increase their costs. This lack of harmonisation hinders the development of pan-European financial products, which are essential for the creation of a truly integrated capital market. The current structure hinders the free flow of capital and restricts market participants from benefiting from the advantages of scale and competition.

To meet these challenges, a more systematic approach to determining the most effective oversight structure is needed. One future comprehensive solution to overcome these barriers is the establish-

ment of the concept of a ‘28th regime’ in the European capital markets sector. This concept could envisage a non-binding framework within the European Securities and Markets Authority that would allow firms to opt for centralised supervision while maintaining cooperation with national authorities. Such a regime could streamline the supervision of cross-border activities, reduce administrative burdens and encourage the creation of pan-European investment products. For example, a tool such as the „supervisory effectiveness test“ can be applied in cases where it reviews legislation by assessing whether supervision should:

- remain national;
- adopt mutual recognition; or
- move to a supranational level.

These solutions should take into account the complexity and integration of the market. By introducing the application of a single set of rules under the supervision of a single authority, the 28th regime could significantly improve the efficiency and attractiveness of the European capital market.

Beyond regulatory and structural reform, there is also a need for a cultural shift in the way Europe seeks to reform its capital markets. In the implemented regulatory and institutional policies, a balance should be sought between the striving for harmonization on the one hand and the need to promote innovation and growth on the other. Such an approach implies rethinking the role of regulation to ensure that it will primarily support and not stifle market development. For example, simplifying processes for asset managers’ cross-border activity and aligning rules to reduce regulatory compliance costs can increase competitiveness without compromising investor protection.

Corporate governance and shareholder rights issues present additional complexity. These areas occupy a significant place in national legal frameworks. Therefore, any attempt at harmonisation needs to be approached carefully to avoid disrupting established practices. A gradual approach to the transfer of regulatory and supervisory responsibilities can be useful here. This approach has been successfully applied in the construction of the European Banking Union and can help to mitigate resistance and build trust between stakeholders. Harmonisation efforts should focus on removing unnecessary national differences, especially in areas such as prospectus standards, to reduce duplication and complexity. Using key performance indicators to track market integration, using artificial intelligence and digital tools to overcome language barriers and increasing trust among retail investors are practical steps to increase efficiency. Mechanisms such as pan-European dispute resolution arbitration could simplify legal protection for retail investors by building confidence in cross-border products.

5. TAXATION OF DISTRIBUTED PROFITS AS A ROLE MODEL

The implementation of the “28th regime” has the potential to boost cross-border investment in Europe. However, increasing investment also depends on offering an attractive alternative to the current tax policies of Member States and avoiding the negative consequences of previous attempts at harmonisation.

First of all, it should be pointed out that the „28th Regime“ should, in its characteristics and manner of application, provide a genuine alternative to national rules, rather than adding yet another new level of regulation. Earlier initiatives for harmonised corporate tax rules, such as the “Business in Europe: Framework for Income Taxation” (BEFIT) proposal, failed because they required companies to implement their obligations at both national and EU level. (Bray, Mengden, 2023a).

Secondly, it should be borne in mind that harmonisation should not be pursued in the name of uniformity, but rather that it should imply the development of economically attractive policy rules. This aspect was neglected in earlier corporate tax harmonization proposals (European Commission, 2011), such as BEFIT and CCCTB (Common Consolidated Corporate Tax Base). These regulatory decisions left key indicators unspecified, while at the same time introducing cost recovery rules that negatively affected investment incentives in most member states compared to the existing status quo.

Thirdly, the “28th regime”, as a future well-structured corporate tax system, should follow the principles of a stable tax policy that is easy to administer and comply with by its addressees. Its implementation implies the collection of revenues with the least economic distortions. Its implementation

implies the collection of revenues with the least economic distortions. The success of the unified regime depends on these features, because the more organizations that can join the scheme and succeed economically, the better Europe will be positioned as a competitive center for investment and innovation (Mengden, 2025).

The degree of compliance of existing corporate tax policies in the countries of the European Union with the objectives of the 28th regime can be established through the existing European Tax Policy Scorecard (Bray, Mengden, 2023b). It assesses the tax systems in 32 major European countries, including all EU member states, in terms of their competitiveness and neutrality (see Table 1 below). This allows politicians to compare Member States' policies and to benchmark policy proposals against best practices in Europe.

Table 1. 2023 European Tax Policy Scorecard

Country	Overall Rank	Overall Score	Corporate Tax Rank	Individual Taxes Rank	Consumption Taxes Rank	Property Taxes Rank	Cross-Border Tax Rules Rank
Estonia	1	100	2	5	8	1	16
Bulgaria	2	92	3	2	6	10	10
Switzerland	3	89,4	9	14	1	31	1
Cyprus	4	88,8	4	8	3	3	21
Latvia	5	87,7	1	6	14	6	14
Malta	6	80,7	29	12	4	2	13
Czech Republic	7	80,3	11	7	12	7	9
Slovak Republic	8	75	20	3	15	5	28
Luxembourg	9	74,7	25	28	2	14	5
Lithuania	10	74	6	13	16	7	23
Hungary	11	73,2	8	4	32	19	4
Sweden	12	71,6	12	18	20	9	12
Turkey	13	71,2	17	23	5	22	6
Romania	14	70,9	7	1	27	27	20
Netherlands	15	69,6	26	21	10	14	3
Croatia	16	66,8	5	24	25	4	31
Slovenia	17	65,4	13	11	23	27	18
Finland	18	64,6	14	19	18	17	19
Germany	19	64,5	27	30	7	10	7
Norway	20	64,3	18	22	21	13	11
UK	21	62,4	28	20	26	19	2
Denmark	22	60,7	15	26	17	10	27
Austria	23	60,5	24	29	9	23	15
Belgium	24	60,5	19	15	13	25	26
Greece	25	60,1	21	9	31	21	24
Poland	26	56,9	23	10	29	24	29
Iceland	27	55	16	16	24	29	30
Ireland	28	52,9	10	27	28	17	32
Spain	29	52,6	31	25	11	30	17
Italy	30	48,6	22	17	30	32	22
Portugal	31	44,5	32	31	19	14	25
France	32	44,5	30	32	22	25	8

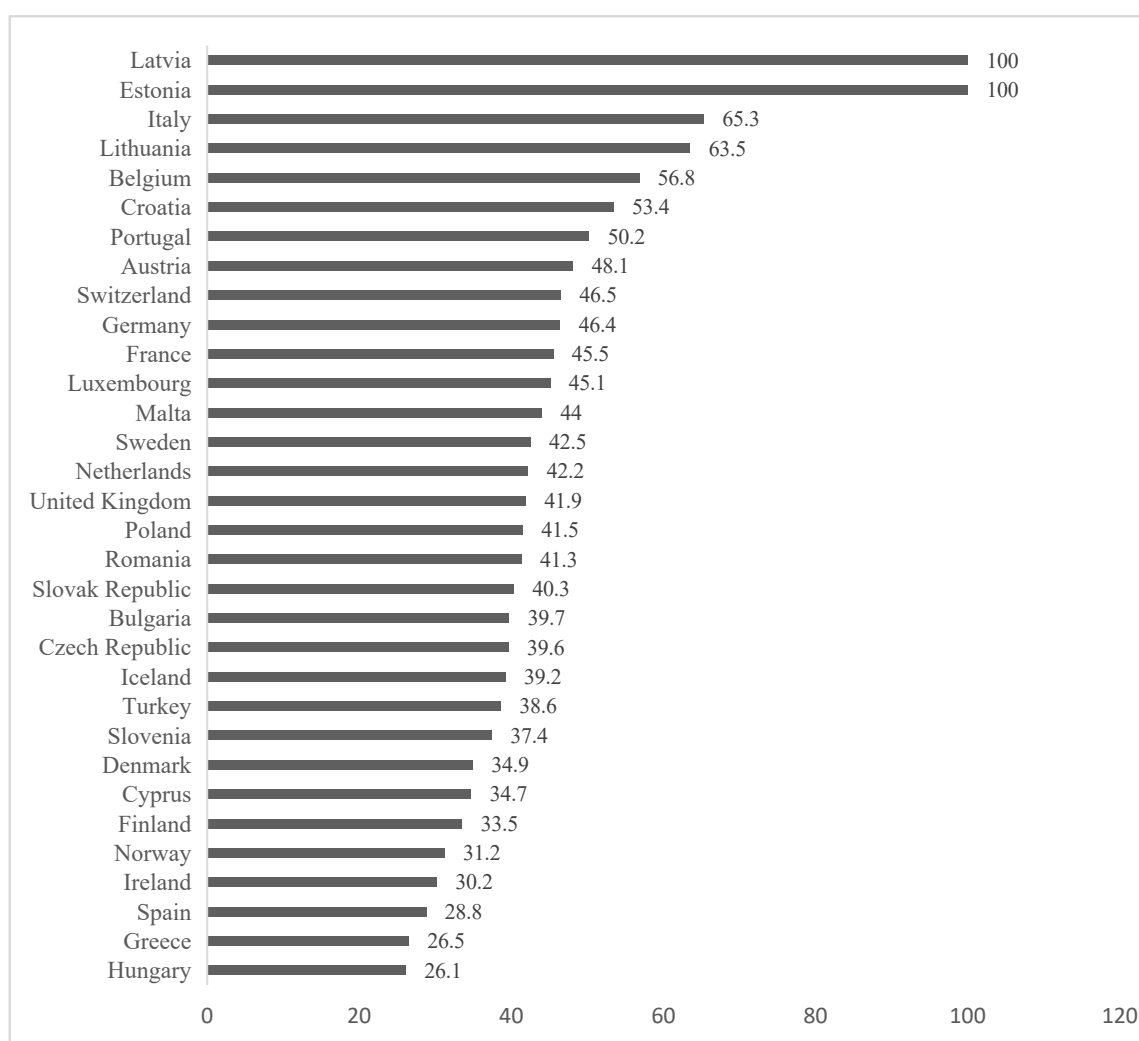
Source: Bray, S., Mengden, A. (2023b), 2023 European Tax Policy Scorecard

According to the 2023 ranking, Estonia has the highest-rated tax system. The top score is due to four positive features. First, it has a 20% corporate income tax rate that applies only to distributed profits. Second, it has a flat 20% personal income tax that does not apply to personal income from dividends. Thirdly, it has a property tax that applies only to the value of land, not to the value of real

estate or capital. Finally, it has a territorial tax system that exempts 100 % of foreign profits earned by domestic corporations from domestic taxation (with few restrictions). While Estonia's tax system is the most competitive, the tax systems of other leading countries also score highly due to high performance in one or more of the main tax categories. In second place is Bulgaria, which applies a flat personal income tax of 10%, a low corporate income tax of 10%, relatively good reimbursement of machinery costs, and a broad-based value-added tax (VAT) covering 96% of final consumption. Switzerland has a relatively low corporate tax rate of 19.7%, a broad-based consumption tax, and an individual income tax that partially exempts capital gains from taxation. According to the study, France has the least competitive tax system due to its multiple distortive property taxes on property, banking assets, financial transactions, and a wealth tax on real estate. The tax burden on labor reaches 47% for the average worker, one of the highest in Europe. On the other hand, the implementation of VAT in France covers less than 40%.

A particularly important place in corporate taxation policies in order to achieve the objectives of the 28th regime may be the introduction of the tax on distributed profits.

Graph 1. 2023 European Tax Policy Scorecard Cost Recovery Scores



Source: Bray, S., Mengden, A. (2023b), 2023 European Tax Policy Scorecard and Mangden, A. (2025)

In this regard, it can be pointed out that the European Union has specific national practices that can be adopted by other countries. Taxes on distributed profits in Estonia and Latvia can serve as an example for reciprocation by other EU countries in order to implement the 28th regime (see Graph 1). According to the tax systems of Latvia and Estonia, realized corporate profits are not taxed. Profits can be subject to taxation in the process of their distribution to shareholders. For this reason, the recovery of investment costs in these two countries can practically reach 100 %. Their positioning in the top two places (Bray, Mengden, 2023) in the assessment of national tax systems is not due

so much to their applicable corporate rates, which are approaching the level of 23.6%, but to their simple and effective tax structure.

The shift from a traditional corporate tax to a tax on distributed profits removes tax penalties on capital investments, as well as asymmetries in the treatment of profits versus losses and equity versus debt financing.

Providing favorable treatment to all investments, regardless of their type, removes obstacles to economic growth. It also simplifies the taxation of profits by eliminating differential treatment of assets and business models, as well as complex and distortive incentives such as tax credits for research and development.

Italy ranks third on this indicator with a 65.3% cost recovery. Bulgaria lags behind, ranking only 20th with a cost recovery rate of 39.7%.

6. THE BULGARIAN PERSPECTIVE OF 28TH LEGAL REGIME

Broader understanding the current technological trends leads to the conclusion that priority support to companies operating in Bulgaria that are creating cutting-edge products is urgently needed. In order such goal to be fulfilled Bulgaria should provide a more favorable environment for the realization of more high-tech investments with added value. This government policy should be proactive in its support for achieving a higher technological level for the country.

Achieving the desired investment attractiveness requires the Bulgarian state to develop and implement a number of important organizational, regulatory and institutional measures that *inter alia* relate to:

1. Bulgaria's accession to the Eurozone. Membership in the most developed monetary union in the world brings significant political and reputational benefits, although they cannot be quantified. By integrating more closely into the core of EU policy-making and thus moving closer to some of the most developed countries in Europe, Bulgaria will take a major step forward in separating itself from the EU's "periphery". Bulgaria's integration to the greatest extent into the core of the Economic and Monetary Union is important in view of the current geopolitical and economic situation. This will not only make the country better prepared for the current, but also for subsequent crises that it may face in the future, but will also increase our country's role in decision-making within the EU, which will further contribute to our national sovereignty. In addition to the economic benefits, the introduction of the euro is also expected to lead to institutional convergence with the developed EU countries, especially with regard to the quality of institutions in Bulgaria and the trust of citizens in them. Improving the quality of Bulgarian institutions will have both social and economic benefits.
2. Tax legislation should be reformed in order to move from a traditional corporate tax to a tax on distributed profits. This would provide favorable treatment to all investments, regardless of their type, and remove obstacles to economic growth. At the same time, the taxation of profits would be simplified by eliminating the differentiated treatment of assets and business models, as well as complex and distortive incentives such as tax credits for research and development. At the moment, Bulgaria lags behind in the application of this tax technique, ranking only in 20th place out of 39 countries surveyed, with a cost recovery rate of 39.7 %. Implementing such a tax reform would bring the country to the forefront of the Bulgarian tax system in the European Economic Area. Specific political balance needs to be achieved in the short term to accommodate incentives for high-tech companies and startups given the existing flat rate tax system of 10% corporate tax on company's profits and the 10% individual income tax, which are amongst the lowest in Europe.
3. In order to compensate for Bulgaria's significant lag in attracting foreign investment, an urgent change to the existing Investment Promotion Act is needed. The main objective of the future changes concerns the provision of state aid for productive investments, mainly in sectors with medium or high added value, and the simplification of the thresholds for the provision of state aid. According to some non-governmental organizations (Popov, 2023), the current law

is not adequate to the modern conditions, in which even industrial and strong countries, such as Germany and the USA, provide huge subsidies to attract strategic investors.

4. There are significant challenges in Bulgaria related to the protection of intellectual property. Many companies that invest in intellectual property prefer to register in jurisdictions with better property protection, while only carrying out their operational activities in Bulgaria. The main problem for them is that they cannot rely on a fair judicial system with guarantees of independence. The level of intellectual property protection is a critically important issue, especially for investments in information technology. To solve this problem, it is necessary to improve, first of all, law enforcement. Serious measures in such direction are already undertaken, however real-time implementation remains a challenge.

5. Another serious problem of the economic environment in Bulgaria is the level of education in Bulgaria. It is currently a significant challenge because only 5.5% of students specialize in STEM disciplines and 54% of them are functionally illiterate in mathematics according to the international PISA assessments. Insufficient investments in the education system, which are only 3.9% of GDP, in turn deepen regional inequalities and further limit economic prospects. To solve this problem, it will most likely be necessary not only to compensate for the existing shortcomings in the public education system, but also to create special technological schools. Their educational profile should be sufficiently broad, providing educational skills and specialization in various focus sectors – e.g. IT, energy, mechatronics, etc. Reform in primary, secondary and higher education requires significant and sustainable efforts combined with painful reforms, for which longer political horizon and stability are needed.

The above list of specific policy recommendations represents a summary of measures that could help Bulgaria to prepare better for the forthcoming implementation of the 28th legal regime and would stabilize Bulgaria as a leading hub of innovation and cutting-edge technologies in Southeast Europe. The main goals of the 28th legal regime regarding EU harmonization of corporate law, insolvency, labour law and taxation are no doubt part of the Bulgarian legislative agenda, however, not exactly in the current priority list due to the fragmentation of the focus of political elite represented in the government and of the Bulgarian parliament.

7. CONCLUSION

The implementation of the 28th legal regime by Bulgaria can be an important tool for accelerating the development of its economy and especially for attracting new and much needed foreign investments. Unfortunately, at the present moment, compared to other countries, Bulgaria is significantly lagging behind. The country's incompetitive investment conditions are associated with traditional problems such as cumbersome administration, outdated regulations, shortage of qualified labor, doubts about the rule of law, as well as the ongoing political crisis with too many consecutive elections which resulted in economic and political instability in recent years.

The current problems of adoption of the 28th legal regime in the European Union and Bulgaria will require a carefully planned road map for its implementation which should include the active involvement of state institutions, business organizations, academic and research institutions, as well as the non-governmental sector. Such a road map should be developed as soon as possible in order that the existing challenges to be addressed systematically and consistently, as to be accepted by society without undesirable stress.

In conclusion, it can be stated that Bulgaria should categorically introduce the harmonized regulatory framework designated as the „28th regime“. This will create opportunities for Bulgarian and European companies to expand their innovative and investment activities and to operate smoothly both in Bulgaria and within the 27 countries of the European Union. By establishing a single set of rules governing corporate law, insolvency, labor law and taxation, national barriers that have long hindered the future integration and growth of the European Union's single market will be removed.

In the implementation of these processes, Bulgaria has undeniable strengths and advantages, which it should purposefully and sustainably apply in its economic, technological and investment policy.

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BIBLIOMETRIC ANALYSIS AS A BASIS FOR RESEARCH ON SUSTAINABILITY IN TOURISM IN BOSNIA AND HERZEGOVINA

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ABSTRACT

This work is focused on easier understanding of the ambitions of sustainable tourism. The research was conducted through two contexts. The first is the analysis of scientific literature with the aim of establishing indicators that were used in the quantitative part of the research, which represents the second context of the work. A wide systematic review of the literature provided ideas for the construction of indicators from the three dimensions of sustainability, on the basis of which a composite index of sustainability was later established. This index is a useful tool that enables combining multiple indicators into a single, synthetic measure.

The goal of the overall research is to create a more innovative approach to the analysis of sustainable tourism, while respecting the importance of previous scientific works. The results of the regression analysis point to the controlled impacts of tourism, but in the short term, given that an increase in tourist arrivals would lead to an increase in the composite index. However, increasing the average length of stay would reduce sustainability. The purpose of the work is to contribute to future research in the field of sustainable tourism, the guidelines of which are set by the results of the analysis.

Keywords: sustainable tourism, bibliometric analysis, regression analysis, Bosnia and Herzegovina

1. INTRODUCTION

Sustainability as a term became popular in the late 1980s, yet it has still not been fully incorporated into all forms of tourism, nor into its strategies and policies. Although the concept has been defined, it is still not entirely applicable in practice. This is mainly due to the lack of consensus on the acceptance of the concept of sustainable tourism development, or more commonly, the lack of coordination among the large number of stakeholders involved in the tourism value chain. By emphasizing tourism growth, tourism management tends to neglect sustainability goals and traditionally pays more attention to environmental and economic aspects, while giving less consideration to social development and the impact on the local community. This threatens essential resources, leading to a situation where sustainable development is seriously compromised: economic prosperity declines, environmental conditions deteriorate, social injustice increases, and tourist satisfaction also diminishes (Briassoulis, 2002). Existing academic literature highlights various focuses and interpretations of sustainable tourism, most often suggesting reforms required by the concept and the degree of its applicability in practice. This paper aims to present a methodology for measuring and monitoring sustainable tourism through the construction of a Composite Index of Sustainable Tourism, as a synthesis of economic, environmental, and social indices. The introduction of a composite

index of sustainable tourism is a necessary step toward a comprehensive and objective monitoring of tourism's impact on the economic, social, and environmental dimensions of development. Since sustainability encompasses several interrelated factors, individual indicators often fail to provide a complete picture. A composite index allows for the integration of different indicators into a single metric, facilitating comparison among destinations, monitoring progress over time, and informing policy decisions important for the implementation of sustainable development.

2. REVIEW OF PREVIOUS RESEARCH

The term “*sustainable tourism*” emerged in the late 1980s and has since become firmly embedded in all initiatives, tourism policies, and tourism strategies. Therefore, tourism was one of the first sectors to establish definitions and principles for “sustainable tourism,” as well as strategies and action plans (Budeanu et al., 2016). Due to its potential to provide economic benefits without extensive extractive activities, tourism is often seen as a means of achieving sustainable development (Chakraborty, 2021).

Previous research has highlighted hedonistic experiences as synonymous with social sustainability, creating a short-term sense of happiness (Nawijn & Filep, 2016), while more recent studies increasingly focus on eudaimonic tourist experiences, which are associated with long-term psychological benefits (Dragija & Franić, 2024). Unforgettable tourist experiences are closely linked to the concept of sustainability, and any form of tourism based on them lays the foundation for sustainability. Some studies suggest that the use of metaversal tourism products represents a new approach to implementing sustainability goals (Go & Kang, 2023).

Sustainable tourism requires effective management, including appropriate institutions, decision-making rules, and practices for policy evaluation and monitoring, if it is to meet the economic, sociocultural, and environmental dimensions of sustainable development (Bramwell & Lane, 2011). The management of sustainable tourism development must maintain a high level of tourist satisfaction, ensure meaningful experiences for consumers, increase their awareness of sustainability issues, and promote sustainable tourism practices among them (Streimkiene et al., 2021). As an integral part of analyzing sustainable tourism, indicators emerge as reference points that show the degree of fulfillment of sustainable development. Most of these indicators are dedicated to the economic, environmental, and social dimensions, while the governance dimension is often overlooked, as is the case with SDG reports under the United Nations Agenda (Rasoolimanesh et al., 2023).

As a way to address such shortcomings, Hall et al. (2021) recommend managerial ecology, which entails the instrumental application of science and economically utilitarian approaches in the service of resource use and economic development. As noted by Mazziotta and Pareto (2013), it is necessary to find an adequate framework for monitoring sustainable tourism development, suggesting the use of a composite index.

In the context of tourism, the use of a composite sustainability index is particularly useful, as tourism activities impact multiple spheres — from economic gains and effects on the local community to pressure on natural resources. Choi and Sirakaya (2006) propose a set of indicators for measuring the sustainability of tourist communities, emphasizing the need to involve local residents in the process of defining and assessing sustainability. Tanguay et al. (2010) also demonstrate that combining local indicators into a composite index can support informed decision-making in destination management. Some authors shift their focus to issues of carrying capacity, tourism development control, and the relevance of the term in the context of mass or conventional tourism (Butler, 1999). Others, examining crises that affect the tourism sector, emphasize the importance of certain factors for strengthening resilience in the tourism industry: government response, technological innovation, local belonging, and the trust of consumers and employees (Sharma et al., 2021).

Therefore, new technologies or new products, as well as smarter ways of doing business and managing operations, are needed. In this way, not only is the financial prosperity of destinations supported, but it also paves the way toward sustainable and smart development (Vidak & Sindik, 2015). Moreover, some authors conclude that new policies should be developed—ones that can, in the short term, promote changes in consumer leisure habits in a more environmentally friendly direction, and

in the long term, alter the existing strong link between economic growth and leisure consumption (Aall et al., 2011).

3. RESEARCH METHODOLOGY

The fundamental steps in applying a scientific methodological approach to research include defining the problem and objectives, collecting relevant data, and processing that data. This study consists of two research components, each with multiple phases. The first part of the research involves a systematic literature review (SLR), accompanied by a bibliometric analysis using VOSviewer software. The first step was to select bibliometric sources, followed by defining the research period and key terms. After that, the creation of the co-authorship network was initiated—identifying key authors and collaborations. To expand the analysis, a “density map” was created to represent the concentration of key terms in the research. Visualizations from VOSviewer were used to identify the main themes, co-authorship networks, and most prominent works. Based on this, an interpretation of selected works by key authors was made to extract indicators relevant for further processing. In the second part of the research, a quantitative analysis of the indicators was conducted using the example of Bosnia and Herzegovina. Analyzing previous research that points to the unbalanced development of tourism in Bosnia and Herzegovina and competitiveness defined primarily through two categories of natural and cultural resources, and less through created resources (Mrkaić Ateljević et al., 2024), revealed the need to interpret certain indicators more precisely and use them as input data for further analysis (salaries, number of employees, environmental index and others).

The primary hypotheses of this part of the research are:

H_0 : An increase in tourist arrivals negatively affects the composite sustainability index.

H_1 : Longer stays may negatively affect the composite sustainability index.

The first part of the quantitative analysis involved establishing a composite sustainability index based on social, economic, and environmental indicators. The main research instrument for the quantitative analysis was regression correlation analysis. The components of the regression analysis included the “composite sustainability index” as the dependent variable and “tourist arrivals” and “average length of stay” as the independent variables. In this part, the standardization of the indicators used to create the dependent variable was first performed. The independent variables were not standardized, as their interpretations in natural units (number of tourist arrivals and average length of stay) are relevant to the research objectives. This allows for the direct application of the results in real-world tourism conditions. The regression analyses resulted in equations and scatter diagrams for predicting the movement of the dependent variable.

In addition to the aforementioned methods, historical methods, analysis, and synthesis were also used.

4. BIBLIOMETRIC NETWORK ANALYSIS

4.1. PHASE I OF BIBLIOMETRIC RESEARCH

VOSviewer is a software tool used for constructing and visualizing bibliometric networks in research. Its purpose is to establish a network of researchers, journals, or publications based on specific criteria related to a given topic in order to identify which authors most frequently cite particular terms and how interconnected the authors are. Based on this, a co-authorship map can be created, and author clusters can be formed. Members of a single cluster are interconnected authors who either cite each other or are co-authors of scientific papers. Additionally, this type of analysis provides insight into the most prominent authors in the researched field.

Google Scholar was selected as the primary database for this research, and the chosen keywords were sustainable tourism, development, and sustainability. However, since Google Scholar does not support direct data export to VOSviewer, the initial step of this research involved the use of software that provides insight into the citation impact and productivity of academic publications—appropriately named “Publish or Perish.”

The time frame for the publications included in the analysis was set between 2020 and 2025. A total of 201 highly cited papers were selected from the database, with a combined citation count of 21,678. The results of this preliminary research are presented in Table 1.

Table 1. Citation Metrics for the Selected Research

Publication years	2020-2025
Citation years	5
Papers (total number of papers)	200
Citations (total number of citations)	21678
Cites/year (average number of citations per year)	4335.60
Cites/paper (total citations/total papers)	108.39
Cites/author (citations for each publication divided by the number of authors)	10448.57
Papers/author (average number of papers per author)	83.95
Authors/paper (average number of authors per publication for a certain author)	3.10
h-index	82
g-index	141

Source: Author's analysis using Harzing's Publish or Perish, with explanation available at <https://libguides.ru.nl/publishorperish/authormetrics>, accessed on 01/04/2025

The **h-index**, as a substitute for the impact factor, reflects the *scientific performance of a researcher* by simultaneously taking into account both the researcher's *scientific productivity*, measured by the number of published papers, and *impact*, measured by the number of citations those papers have received in other works (https://kobson.nb.rs/vrednovanje/vrednovanje/h_-_index.120.html). The value of **h** is equal to the number of papers (N) on the list that have N or more citations. This metric is useful because it reduces the disproportionate influence of highly cited papers or papers that have not yet been cited (https://support.clarivate.com/ScientificandAcademicResearch/s/article/Web-of-Science-h-index-information?language=en_US). For the selected set of papers, the h-index is 82. Since many researchers believe that the h-index ignores the number of citations of highly cited papers, the g-index is often used alongside it, as it gives more weight to highly cited works. The g-index is always at least equal to the h-index and is usually higher—as is the case in the selected sample, where it reaches 141.

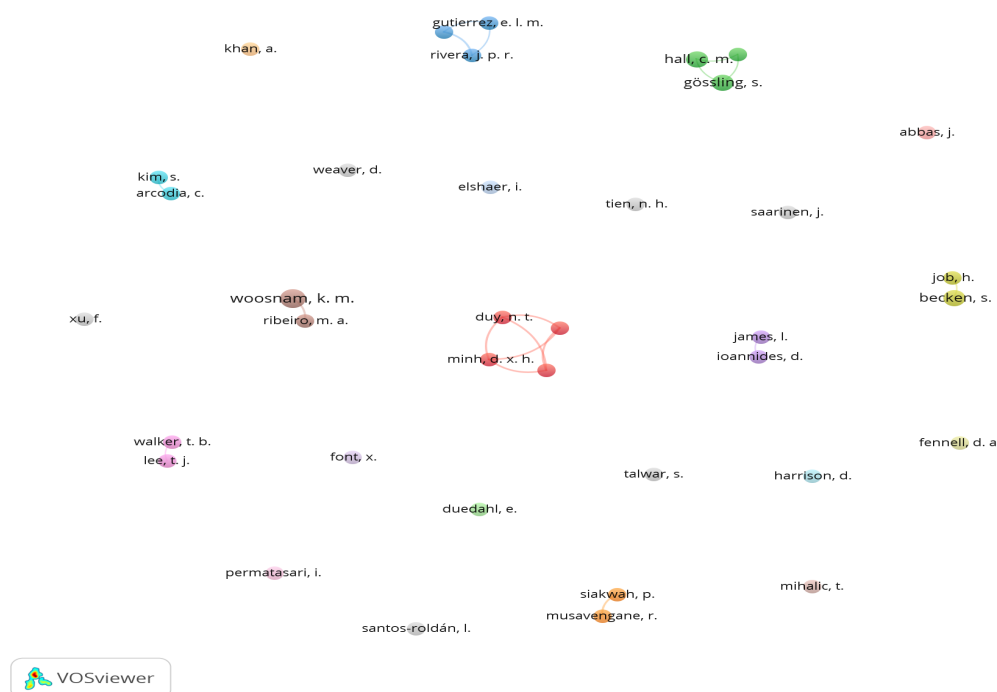
4.2. PHASE II OF BIBLIOMETRIC RESEARCH

After completing the citation metrics, data was exported and formatted into a format compatible with VOSviewer. Using the ZoteroBib software, the data was transferred from CSV format to structured bibliographic data (RIS format). After importing the structured data into VOSviewer, a map was created based on the selected bibliographic units. For a more detailed analysis, the authors chose co-authorship, that is, the author network. This analysis shows the connections between authors based on co-authoring papers. Authors who frequently collaborate on papers are connected with stronger lines and closer nodes. An author with more collaborations with other authors appears as a larger node. For the purpose of creating the map and identifying co-authorship connections, the software automatically selects authors with the strongest overall link strength. Optionally, documents with a higher number of authors were excluded.

In the selected group, which consists of 201 papers, VOSviewer recognizes a total of 462 authors. As the minimum number of documents, respecting the research keywords, two papers per author were selected, indicating that the researcher has seriously engaged with the topic derived from the keywords. As a result, 37 authors were identified met this criterion. This means that the strength of co-authorship links with other authors was observed for these 37 authors. In addition, bibliometric clusters were formulated to group papers with similarities. Clusters in this program are represented by nodes, with each node representing one cluster. A minimum cluster size of two documents was set, with the research condition that any clusters below the minimum size should be merged into larger clusters. After this analysis, 24 clusters were obtained.

The visualization of the obtained data is presented with two types of maps. The first is network visualization, which shows the connections between authors and can include a temporal dimension that explains how the collaboration between authors has evolved over time. The second map is density visualization, which visualizes the density of the researched area, i.e., the frequency of certain authors' appearances in the sample.

Figure 1. Network Visualization

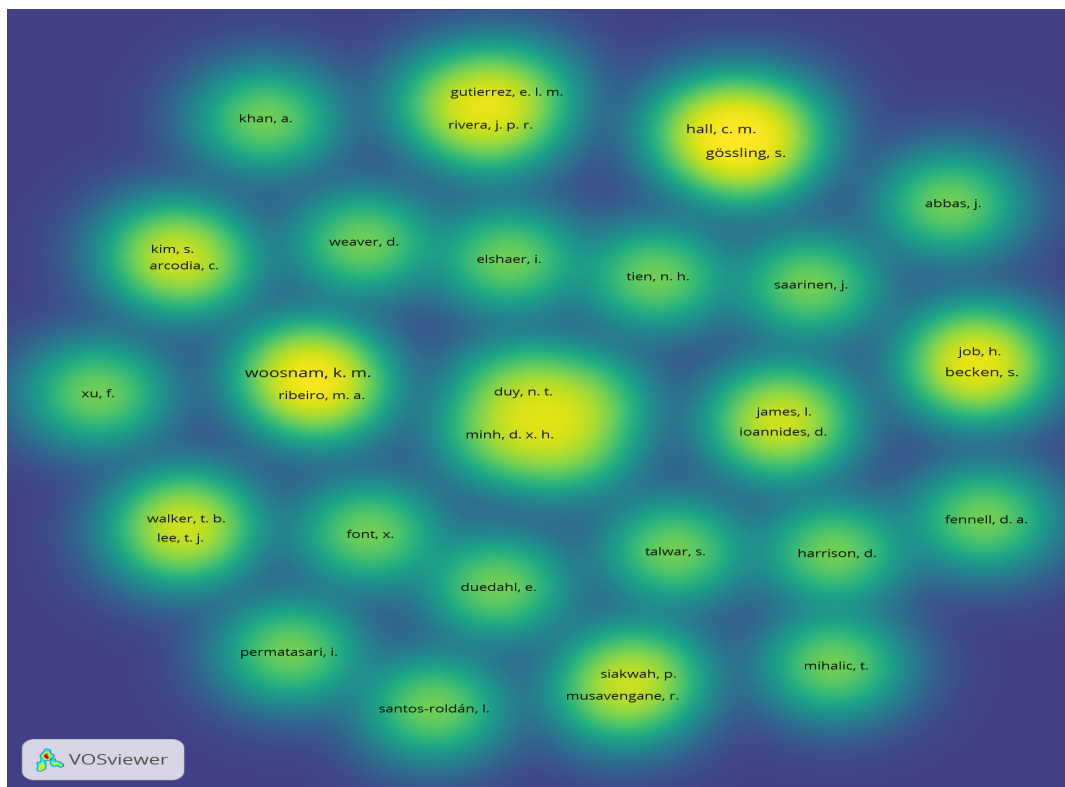


Source: Author's own processing in VOSviewer

This is the co-authorship network from VOSviewer, showing authors who have conducted research in the field of sustainable tourism and their interconnections. Observing the structure of the network, it is evident that most authors are not directly connected, indicating the presence of multiple independent research groups. A larger node on the map indicates more frequent occurrences of the previously defined keywords, which in this case applies to the author Hall, meaning he is one of the most influential authors in the dataset. The thicker lines connecting the nodes also indicate stronger connections. Smaller and more distant nodes (e.g., Abbas, J. or Weaver, D.) represent authors with lower connectivity in the analysis.

A total of 24 research groups, or clusters, were identified. The red cluster consists of authors Duy, T. T. and Minh, X. H., who are strongly connected, indicating frequent co-authorship in publications. The green cluster includes Hall, C. M. and Gössling, S.—both well-known for their research on sustainable tourism and ecotourism. The blue cluster comprises Gutierrez, E. L. M. and Rivera, P. R. The yellow cluster includes authors whose research focuses on the economic sustainability of tourism, such as Job, H. and Becken, S. The purple cluster includes James, L. and Ioannides, D., where further research on tourism policy and management is possible. Authors with the largest nodes are the most influential, meaning they have published the highest number of papers in the sample with strong scientific impact—specifically, the authors from the green cluster: Hall, C. M. and Gössling.

Figure 2. Density visualization



Source: Author's own processing in VOSviewer

Higher density is represented by light yellow and indicates the most frequently cited and connected authors, with Hall and Gössling standing out in particular. Lower density is shown in blue and may point to potential research areas or authors who are not central but still relevant.

4.3. PHASE III OF BIBLIOMETRIC RESEARCH

After identifying the connections between authors and the frequency of their appearance—visualized through the maps—the most influential authors were selected based on the mentioned criteria. According to this analysis, the key researchers with a high level of collaboration across a significant number of papers are:

- Hall, C. M. – One of the most cited researchers in sustainable tourism. He focuses on sustainable development policies, destination management, and ecological aspects of tourism.
- Gössling, S. – Focused on sustainable transport, climate change, and the environmental aspects of tourism.
- Becken, S. – Researches destination sustainability, energy policies, and climate change in tourism.
- Ioannides, D. – Focused on tourism policy, economic impacts, and sustainable destination development.

As the selected bibliometric sample contains a larger number of works by the mentioned authors, the most relevant ones were selected based on the highest number of citations, in which they are either the main authors or co-authors. The aim of this part of the research is to:

- Conduct a systematic review of the selected literature sources,
- Identify the trade-offs between sustainable tourism and overall sustainability,
- Identify the key indicators to be subjected to further analysis,
- Provide guidelines for future research based on the interpretation of the results.

Tourism fully reflects the past, present, and future economic, environmental, and social impacts (UNWTO-UNDP, 2017), making the metaphor of human impact the central focus of sustainable tourism as a concept (Hall, 2019). Some studies on sustainable tourism are grounded in the SDG (Sustainable Development Goals) ideology. “The SDGs are a global call to action to achieve a better, more sustainable future for all” (Al Abbadi et al., 2025). For example, Hall (2019), referencing

Bavington & Slocombe (2002), argues that managerial ecology is particularly important—expressed through the management of the environment and resources—which includes the instrumental application of science and utilitarian economic approaches in the service of resource use and economic development. However, in the same work, Hall also offers criticism, suggesting that “initiatives such as the SDGs fail because they do not challenge the way neoliberal rationalities are embedded in many tourism policy practices” (2019). Hall (2019) argues that the managerial approach promoted by the UNWTO is rooted in the context of capitalist exploitation of available resources, where tourism growth often results in failure—for example, in the form of uneven development or various environmental pressures. In more recent studies, Hall, as a co-author, continues to address the issues surrounding the SDG ideology, emphasizing the importance of specific goals—particularly: Goal 8 – Inclusive and sustainable economic growth, Goal 12 – Sustainable consumption and production, and Goal 14 – Sustainable use of oceans and marine resources (Rasoolimanesh, Ramakrishna et al., 2023). Due to its emphasis on generating employment and tourism-related jobs, a modified form of SDG 8 will be used in this study as the most relevant goal.

Table 2. Sustainable Development Goals

GOAL 1: No Poverty	GOAL 2: Zero Hunger
GOAL 3: Good Health and Well-being	GOAL 4: Quality Education
GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation
GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth
GOAL 9: Industry, Innovation, and Infrastructure	GOAL 10: Reduced Inequality
GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption
GOAL 13: Climate Action	GOAL 14: Life below Water
GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions
GOAL 17: Partnerships to Achieve the Goals	

Source: <https://tourism4sdgs.org/>, accessed 03/04/2025

In his works, the second most influential author typically addresses climate change, the transition of management towards green practices, energy, or issues of carbonization. His most cited work in the bibliometric sample is “Pandemics, tourism and global change: A rapid assessment of COVID-19”, which highlights the negative impact of the pandemic on the sustainability of tourism. The authors emphasize that “the COVID-19 pandemic should lead to a critical reconsideration of the global volume growth model of tourism,” which increasingly resembles overtourism and poses a threat in the context of climate change (Gössling, Scott, & Hall, 2020). Therefore, respecting the integrity of the aforementioned work, this research also includes the period of the pandemic in order to account for the consequences of that crisis. Considering the research focus of the mentioned author, this paper also provides an overview of the EPI – Environmental Performance Index – in order to summarize the impact of numerous environmental sustainability indicators, which represent one of the dimensions of sustainability in tourism. Gössling, in his earlier works (2002, 2015), also emphasized the need to implement more sustainable forms of tourism that would reduce the consumption of water, energy, or land. Therefore, presenting the Environmental Performance Index of Bosnia and Herzegovina is fully justified.

Moreover, Becken (2017), in her earlier research, devoted special attention to new approaches to managing natural ecosystems, which are often disrupted under the influence of tourism. Tourism in protected areas is seen as a way to move toward sustainable development. In her more recent research (Becken, 2020), her area of interest remains the ecological dimension of sustainability in tourism, with a focus on climate change, particularly emphasizing strategies and policies that document and underscore the importance of climate change.

Table 3. Environmental Performance Index, Bosnia and Herzegovina 2024

Index 2024	Rank	Score
Environmental Performance Index - total	87	46.0
Ecosystem Vitality	76	52.1
Environmental Health	118	36.1
Climate Change	67	45.9

Source: <https://epi.yale.edu/country/2024/BIH>, <https://epi.yale.edu/measure/2024/PAE>, accessed 02/04/2025

Table 3 shows the position of Bosnia and Herzegovina on a list of 180 countries, along with weighted scores for specific index categories expressed as a percentage of the total score. Based on this, it is possible to determine where the country lags in environmental performance compared to others. Within the Ecosystem Vitality component, there is an indicator for protected areas, which measures the percentage of the country's terrestrial protected areas where the area of arable land and buildings increases by more than 0.5% annually. According to this indicator, Bosnia and Herzegovina was ranked 47th for the year 2024 (www.epi.yale.edu). The importance of human capital as the main driver in tourism is explored by Ioannides in several of his works. Acknowledging the “precarious and marginal status of tourism labor,” he raises the question: “What should sustainable work in tourism look like?” (Ioannides, 2021).

The same author, referencing Winchenbach (2021), notes that in the pursuit of profit maximization, the tourism workforce is often exploited, receiving minimal wages and being overworked. Given that the situation in Bosnia and Herzegovina is similar, employment and average wages in tourism have been taken into consideration for this research in order to examine the social dimension of sustainability.

5. QUANTITATIVE PART OF THE RESEARCH – CONSTRUCTION OF A COMPOSITE SUSTAINABILITY INDEX AND REGRESSION ANALYSIS

In contemporary sustainable development literature, there is an increasing need to quantify the complex and interrelated dimensions of sustainability. In this context, composite sustainability indices integrate economic, environmental, and social indicators, thus providing a holistic approach to assessing sustainable development. The application of a composite sustainability index in this research enables the quantification of the overall sustainability status of the destination over time, as well as the examination of the relationship between sustainability and tourism activity, contributing to a better understanding of tourism development dynamics.

The quantitative part of the research was conducted in phases. In the first phase, a composite sustainability index was created. It represents the sum of the average standardized values of the social, economic, and environmental indices. The indicators selected for the construction of these indices are derived from the bibliometric foundation presented in the previous section of the paper. The years selected for analysis were 2020, 2022, and 2024, as data were available for these years (e.g., the EPI index for 2023 was not available). The input indicators, along with the corresponding data, are presented in Table 4.

Table 4. Input Data for Constructing the Composite Sustainability Index

Type of Indicator	Year		
Indicators for Social Index	2020	2022	2024
% of employees in tourism	4.73%	4.78%	4.93%
Wages in tourism (BAM)	596	749	927
Indicators for Economic Index	2020	2022	2024
Number of registered tourism businesses	930	1209	1297
Gross value added of tourism (% of total)	1.70%	2.26%	2.40%
Indicators for Environmental Index	2020	2022	2024
EPI index	78	102	87
Tourist arrivals – Independent Variables	500916	1477371	1935745
Length of stay – Independent Variables	2.5	2.2	2.1

Source: <https://bhas.gov.ba>, <https://www.rzs.rs.ba>, <https://www.rzs.rs.ba>, <https://epi.yale.edu>, accessed on 22/04/2025

Since the data is expressed in different units (convertible marks, %, number, etc.), the first step is to standardize the data using the Z-score. This removes the influence of different units and makes

comparison and interpretation easier. The Z-score calculation is achieved using the following formula (Gravetter, 2017, p. 136):

$$Z = \frac{X - \mu}{\sigma} \quad 1)$$

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):

$$\mu = \frac{1}{n} \sum_{i=1}^n x_i \quad 2)$$

x_i = individual value (observation)

n = number of observations

The sample standard deviation (in Excel: stdevs or simply stdev.s) is calculated using the following formula (Gravetter, 2017, p. 113):

$$S = \sqrt{\frac{SS}{n-1}}, \quad SS = \sum_{i=1}^n (x_i - \mu)^2 \quad 3)$$

Based on Formula 1, new standardized values were obtained in Excel for each of the three years individually: Z_emp (percentage of employees in tourism), Z_salaries (salaries in tourism), Z_nrc (number of registered tourism enterprises), Z_gsv (gross social value in tourism), Z_epi (EPI index). Based on these, the arithmetic means of the indicators were calculated to obtain the Z_Social Index, Z_Economic Index, and Z_Environmental Index. The arithmetic mean of these three standardized indices actually represents the Composite Sustainability Index for each year individually.

Table 5. Standardized Values of Individual Indices (Variables)

Indicators for the Social Index	2020	2022	2024	Mean	stdevS
Z_emp	-0.80064077	-0.320256308	1.120897077	4.81%	0.001041
Z_salaries	-0.97389826	-0.050304662	1.024202921	757.3333333	165.6573
Z_Social Index	-0.88726951	-0.185280485	1.072549999		
Indicators for the Economic Index	2020	2022	2024	Mean	stdevS
Z_nrc*	-1.12384203	0.332281467	0.791560562	1145.333333	191.6046
Z_gsv	-1.13389342	0.377964473	0.755928946	2.12%	0.003704
Z_Economic Index	-1.12886772	0.35512297	0.773744754		
Indicators for the Environmental Index	2020	2022	2024	Mean	stdevS
Z_epi (Z_environmental Index)	-0.90726471	1.072221928	-0.16495722	89	12.12436
Z_Composite Index	-0.97446732	0.414021471	0.560445844		

*Data from 2023, as later data is not available

Source: Author's own calculation in Excel

During 2024, an increase in the index is noticeable, likely due to the post-pandemic recovery, which resulted in a higher number of employees and greater economic output for the population in terms of generated gross value added. The Environmental Index was understandably highest during the pandemic, given that tourist movements and environmental pressures were significantly reduced.

To examine the impact of the observed phenomena, regression analysis was used, with an equation indicating the functional relationship between the dependent and independent variables. The Composite Sustainability Index in Bosnia and Herzegovina was selected as the dependent variable, as it is influenced by the independent variables. The independent variables chosen were tourist arrivals during the research years and the average length of tourist stays, each used separately in simple regression to avoid the problem of multicollinearity, as the predictors have similar effects. The functional and stochastic relationship is represented by the least squares mathematical expression (Lovrić et al., 2017).

$$Y = a + bx + \varepsilon \quad 4)$$

Y – dependent variable,

a – regression constant (intercept on the y-axis),

b – regression coefficient (slope of the simple linear regression),

x – independent variable,

ε – random disturbance, error.

5.1. DISCUSSION OF REGRESSION ANALYSIS RESULTS

The results of the regression analysis between the composite index and the number of tourist arrivals, along with the ANOVA variance interpretation, indicate that the correlation coefficient of 0.97 shows a strong correlation between the variables. The positive sign of the coefficient suggests a direct, positive correlation, meaning that the observed phenomena exhibit similar variations, and that an increase in tourist arrivals leads to an increase in the composite sustainability index.

Figure 3. Results of the Correlation and Regression Analysis of the Relationship Between the Composite Index and the Number of Tourist Arrivals

Regression Statistics								
Multiple R	0.973314397							
R Square	0.947340915							
Adjusted R Square	0.894681831							
Standard Error	0.274901883							
Observations	3							
ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	1.359528826	1.359529	17.99008	0.147402271			
Residual	1	0.075571045	0.075571					
Total	2	1.435099872						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-1.46782611	0.380725062	-3.85534	0.161566	-6.3053967	3.369744477	-6.3053967	3.36974448
tourist arrivals	1.13E-06	2.6525E-07	4.241471	0.147402	-2.2453E-06	4.49537E-06	-2.2453E-06	4.4954E-06

Source: Author's own calculation based on the data from Table 5

The coefficient of determination of 0.94 indicates that 94% of the variability is explained by the model, while the remaining variability is influenced by other factors. Since the significance F is greater than the reliability level of $\alpha = 0.05$, this suggests a high level of caution in applying the model and variables.

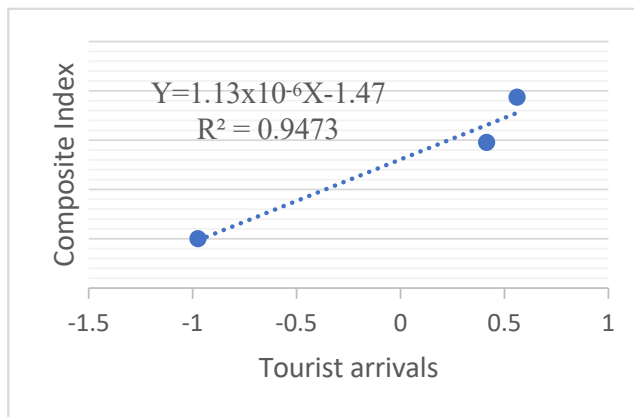
Figure 4. Results of the Correlation and Regression Analysis of the Relationship Between the Composite Index and the Average Length of Stay

Regression Statistics								
Multiple R	0.987852408							
R Square	0.975852381							
Adjusted R Square	0.951704761							
Standard Error	0.186156508							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	1.400445626	1.400446	40.4119497	0.099330091			
Residual	1	0.034654245	0.034654					
Total	2	1.435099872						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	9.111601913	1.437333007	6.339242	0.09960444	-9.15144555	27.37464938	-9.1514456	27.37464938
Average Length of St	-4.019824374	0.632342216	-6.35704	0.09933009	-12.05449404	4.014845293	-12.054494	4.014845293

Source: Author's own calculation based on the data from Table 5.

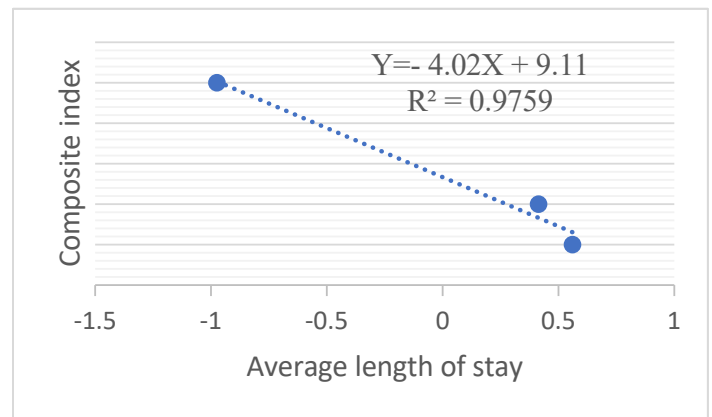
In the second regression analysis, the correlation coefficient is 0.98, indicating a strong correlation between the variables with variations moving in the same direction. Since this is a simple regression, the coefficient of determination (R Square) is observed, and it shows the percentage of the dependent variable explained by this analysis. It can be concluded that approximately 97% of the changes in the dependent variable – the Composite Sustainability Index – are explained by variations in the independent variable – the average length of stay.

Chart 1. Composite Index vs Tourist Arrivals



Source: Author's own calculation in Excel

Chart 2. Composite Index vs Average Length of Stay



Source: Author's own calculation in Excel

The first regression equation suggests that each additional tourist arrival leads to an increase in the composite sustainability index, given that the regression coefficient has a positive sign, assuming all other factors remain unchanged. The coefficient of 1.13×10^{-6} indicates that an increase of one tourist arrival leads to a rise in the composite sustainability index by 0.00000113. Practically, this means that if the number of arrivals increases by 100,000 tourists, the composite index would rise by approximately 0.113. This result suggests that the impacts of tourism on all three dimensions of sustainability—social, economic, and environmental—are still under control.

The second regression equation shows that an increase in the average length of stay by one day would lead to a decrease in the composite index, implying that longer stays reduce sustainability.

Based on all the above, it is concluded that the first hypothesis – regarding the negative impact of the increase in tourist arrivals on the composite index – cannot be accepted. However, the second hypothesis is accepted and indicates that tourist overnight stays and the average length of stay are

more significant indicators than arrivals. Longer stays clearly have a detrimental effect on the composite sustainability index.

6. CONCLUSION

This research provides a valuable contribution to understanding the relationship between sustainable tourism and its impact on the overall sustainability of a destination, with a focus on Bosnia and Herzegovina. By applying bibliometric tools such as Publish or Perish and VOSviewer, a relevant scientific foundation was identified, including a total of 201 scientific papers and 462 authors. Among these, 37 authors have published at least two scientific papers in the fields of sustainable tourism, development, or sustainability.

To ensure the sample was as representative as possible, a smaller group of authors was selected using the commands within the aforementioned VOSviewer software. These authors were selected based on significant citation metrics and publications in journals such as *Taylor & Francis*, *Elsevier*, and *Emerald*. Their studies served as the conceptual basis for defining indicators relevant to Bosnia and Herzegovina. Three indicators were created encompassing the ecological, economic, and social dimensions of sustainability. Based on the available statistical data, a composite sustainability index was developed as the arithmetic mean of the three standardized sustainability indices. This index was used as the dependent variable in regression analyses.

The results of the first regression analysis indicate a positive and relatively strong relationship between the number of tourist arrivals and the composite sustainability index. The obtained coefficient suggests that each additional tourist arrival contributes to an increase in the sustainability index, implying that the growth of tourism traffic—when conducted in accordance with the principles of sustainable development—can have a positive impact on the overall level of destination sustainability.

An increase in the sustainability index points to an improvement in the overall balance between tourism development and the long-term well-being of the local community and the environment. This means that a rise in the value of the composite sustainability index does not necessarily pose an obstacle to advancement across different dimensions of sustainable development—including economic stability, social inclusivity, and environmental conservation.

On the other hand, the negative correlation between the average length of stay and the sustainability index suggests that longer stays, in the absence of sustainable practices, may negatively affect certain aspects of destination sustainability. Given the small number of years observed, these findings should be interpreted with caution. It is necessary to further expand the sample in order to ensure greater statistical reliability and enable a more robust validation of the results. Despite this, the significance of this study lies in:

- Interdisciplinary Approach: By combining bibliometric analysis and econometric modeling, the study integrates theoretical and empirical insights from the fields of tourism, sustainability, and development.
- Use of Modern Software Tools: The application of VOSviewer and Publish or Perish enabled the objective identification of the most relevant authors and publications, thereby enhancing the scientific validity of the selected indicators.
- Development of a Composite Sustainability Index: Using available data for Bosnia and Herzegovina, a concrete quantitative indicator was created to serve as a basis for policymaking in the field of sustainable tourism.
- Practical Applicability of Results: The findings can be valuable for decision-makers in the tourism sector, offering insight into how tourism flows affect sustainability and what measures should be taken to achieve a balance between development and resource conservation.

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MODEL FOR BUILDING A CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES ALONG BULGARIA'S REPUBLICAN HIGHWAY NETWORK

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ABSTRACT

The electrification of mobility has been identified as a precondition for successfully reducing dependence on fossil fuels, it also contributes to the reduction of air and noise pollution (Lan, 2023). The reduction of harmful emissions on a global scale requires the mobility industry to simultaneously invest in and study low-carbon energy technology and infrastructure (Shahzad, 2024). When it comes to determining the locality of the charging infrastructure, one of the challenges is the capacity of the vehicles' batteries and the charging stations. The approach for determining the charging points will be approbated for long-distance travel along the republican highway network. Solutions and possible scenarios for upgrading the transport sector and the associated guarantee of energy resources will be provided through a multidisciplinary analysis which includes current and future necessities for accessible charging infrastructure. This will be based on the calculation of the average distance from the starting point to the necessary station depending on the battery capacity, the amount of energy which can be charged in a 30-40-minute range, as well as the condition that the battery is in.

Keywords: *charging infrastructure, electric vehicles, charging stations, transport networks, decarbonisation*

1. INTRODUCTION

In the conditions of the Green Deal, the spread of electromobility is a key element in the efforts to reduce harmful emissions which are set in the Paris Agreement and the objectives of the EU (EEA, 2024). The goal of the "Green Pact" is to reduce the amount of harmful emissions of greenhouse gases to 55-60% by 2030 and to 95% by 2050, i.e. to achieve a carbon neutral economy in Europe in terms of climate (CT, 2021). The reduction of harmful emissions on a global scale requires the mobility industry to simultaneously invest in and study low-carbon energy technology and infrastructure (Shahzad, 2024). One way to significantly reduce carbon emissions is to switch to alternative fuels in motor transport (NP Group, 2023). The allocation of energy resources, energy efficiency and the changing demand models are a challenge for electric vehicle manufacturers. The goal in the strategy for intelligent, sustainable and inclusive growth is to increase competitiveness and energy security by reducing the dependency on fossil fuels, thus achieving more effective use of resources and energy, which also involves a sustainable strategy for powering vehicles, as well as their appropriate infrastructure, through alternative sources. Electric energy, hydrogen, biofuels, natural gas and liquefied petroleum gas can be viewed as such sources, as they presently have the potential for long-term and sustainable use, as a complementary (two-fuel) system at first. Presently, electric energy is viewed as the most promising technology for limiting greenhouse emissions in the transport sector (ME, 2024). Its nature is deduced from the use of electric engines for vehicle pro-

pulsion. Additional advantages of electromobility include: increased energy efficiency, reduction of harmful emissions in the atmosphere, and reduced noise pollution (Idris & Rahman Razak, 2025). Innovative decisions in the incorporation of new technology related to electromobility are key in the development of the electric vehicle market and the charging infrastructure. In addition to playing a fundamental role in the competition with conventional cars and the existing infrastructure, they, along with battery capacity, will also be the key to the future choices of consumers. It is precisely the readjustment of consumers to the new type of mobility that will be one of the many unknown factors in the emergence of electric vehicles. Other such factors involve the development of technology for energy charging of vehicles, the costs for new production, the various propulsion technologies, and especially the final costs of consumers for vehicle acquisition and maintenance. Nowadays the two biggest and most fundamental problems that influence the selection of the type of propulsion energy are the run (the battery capacity) and the availability of an appropriate charging infrastructure along the primary republican highway network. Taking into account the ever-growing number of electric vehicles which are being registered in Bulgaria, especially over the last 5 years, this raises the question of how dense the charging infrastructure needs to be. When it comes to determining the locality of the charging infrastructure, one of the challenges is the capacity of the vehicles' batteries and the charging stations. The approach for determining the charging points will be approbated for long-distance travel along the republican highway network. The model excludes everyday travel in an urban environment where 90% of the charging happens in home conditions or at workplaces.

2. LITERATURE REVIEW

The strategy for developing the charging infrastructure in Bulgaria cannot be based on the number of registered electric vehicles but rather by preliminarily providing the backbone of the necessary accessible infrastructure which will respond to the growing emergence of electric mobility. When determining the minimum mandatory national goals of EU countries for expanding the alternative fuel infrastructure in accordance with "Fit for 55", one of the requirements is the availability of charging stations at every 60 km for cars and every 120 km for trucks (EP, 2023). Additionally, ultrafast charging stations with at least 150 kW of power will have to be installed, as this will guarantee that 1,3 kW of output power will be provided for each registered electric car by a publicly accessible charging infrastructure (EC, 2023). These charging stations need to have a capacity of 400 kW along the routes of the primary TEN-T network. In accordance with the "Transport Connectivity" program, 10 million BGN are envisioned for charging hubs for electric vehicles along the primary and comprehensive Trans-European Transport Network (MT, 2024). The reason for the relatively small share of electric vehicles in Bulgaria has less to do with their high prices and the lack of subsidies, but more so with the lack of a sufficiently well-developed charging infrastructure (Rachev, 2019). By 2030 the number of necessary public charging stations in the EU will exceed 2 million, whereas the expected number in Bulgaria for the same period is 10 000 (CEER, 2023). According to Dimo Kolchev, CEO of Eldrive, about 25-30% of electric cars in Bulgaria are charged in the public network, the rest are charged at home or in the office (Kolchev, 2025). As of 2025, there are nearly 3,000 charging points in Bulgaria, but only a little over 500 are fast-charging, and more than half of them have a power of 22 to 50kW, which requires a longer charging time (Boceva, 2025). Fair access to a charging infrastructure will help form target strategies for its expansion as well as accelerated emergence of electromobility (Burra, 2024). Electric vehicles add large and dynamic loads to the network, requiring adaptation to the capacity and integration of intelligent systems for consumption management. The impact of EVs on the overall energy system will depend on when and how EV users charge their vehicles (Kareta, 2022).

3. METHODOLOGY

The approach for making decisions about the future development of electromobility in Bulgaria involves a step-by-step examination of the current state of the charging infrastructure and its potential intelligent construction in the context of the energy transformation of motor transport. Solutions and possible scenarios for upgrading the transport sector and the associated guarantee of energy resources will be provided through a multidisciplinary analysis which includes current and future

necessities for accessible charging infrastructure. This will be based on the calculation of the average distance from the starting point to the necessary station depending on the battery capacity, the amount of energy which can be charged in a 20-30-minute range, as well as the condition that the battery is in. To that end, scientific publications in the field, regulations and future planned applications of new technology will be reviewed. The economic capabilities will be analyzed by identifying the benefits and disadvantages of creating the charging infrastructure for the purposes of developing a universal approach.

4.STATE AND DEVELOPMENT OF CHARGING INFRASTRUCTURE IN BULGARIA

The creation of a charging infrastructure is the primary challenge that Bulgaria faces in regards to switching to electric mobility and by extension to a motor park with absolutely zero emissions by 2050 (ECA, 2021/5). However, there are several factors which are unfavorable to future users of electric vehicles, such as limited accessibility, insufficient charging speed, and the quality of the utilized equipment (Zhang, 2020). In that regard, it is imperative that the charging of electric vehicles be as accessible and easy as the fueling of conventional cars. The goal is to make traveling by electric vehicles problem-free not just along the republican highway network, but within the EU as a whole. In order to achieve the set goal, the following two-fold problem needs to be solved – accelerating the emergence of electric vehicles requires an established charging infrastructure along the primary TEN-T network; on the other hand, however, investments in such an infrastructure requires more security in regards to the degree of emergence of this type of vehicles (Nurgaliuly & Smagulova, 2025). This is also one of the fundamental challenges that the larger-scale (wider) emergence of electromobility in the EU faces. Without an established and accessible infrastructure where electric vehicles can be easily recharged at a reasonable price and, most importantly, at a reasonable time, it will be difficult to achieve commercial success in the realization of this type of vehicle. While the risk of the vehicle ending up blocked without energy while traversing is minimum, conventional cars have not faced such a problem during their life cycle.

Charging stations play a key role in the switch to electric mobility by providing a convenient and effective way of charging. The advancements in technology make charging stations more effective, which in turn contributes to increasing their number on the basis of faster charging, intelligent management and remote control and monitoring.

5.DATA AND ANALYSIS

In the past 10 years Bulgaria has made wide-range developments in its alternating current (AC) and direct current (DC) charging infrastructure. Currently, there are approximately 2000 public charging stations in the entire country, approximately 15% of which are located within the capital (VT, 2025). Public charging stations provide non-discriminatory access to all consumers in accordance with Directive 2014/94/ES (EU, 2014). According to Traffic Police data, the number of registered electric vehicles in Bulgaria as of March 31 2025 is 19 630 (Traffic Police, 2025). The average storage capacity of a lithium-ion battery is 60 kW, which is equal to approximately 1200 MW of the total amount of energy necessary for charging. This in turn is equal to 1/4 of the total amount of electricity consumed in Bulgaria, which represents a significant percentage of the self-capacitance for production of electric energy in the country. This significant share needs to be corrected by taking into account the simultaneity coefficient which varies between 4 and 11%, with the charging period reaching its peak during the night.

The study only takes into account the charging of vehicles which traverse distances of over 150 km, i.e. traveling between various populated areas. Everyday travel within an urban environment has been excluded from the analysis due to the fact that more than 80% of electric vehicle owners charge their vehicles with home-based charging stations during the night, meaning that they practically do not use public ones. A distance of 150 km (Sofia – Plovdiv) is viewed as the minimum traversed distance, whereas a distance 460 km (Sofia – Varna) is viewed as the maximum one. That way, it is accepted that the average distance that an electric vehicle will traverse is 300 km. This will serve as a basis for analysis of the demand for charging along Bulgaria's republic highway network. The num-

ber of cars in Bulgaria (in total and solely electric ones) for the April 1 2021 – April 1 2025 period (data.egov.bg, 2025) is presented in Table 1.

Table 1. Ratio of Electric Vehicles to the Total Number of Cars

years	total number of cars	EV's	% of electric to total	percentage growth
1.4.2021	2 765 397	2 348	0,0008	
1.4.2022	2 815 628	3 835	0,001	39%
1.4.2023	2 899 264	7 427	0,002	48%
1.4.2024	3 014 969	13 052	0,004	43%
1.4.2025	3 141 954	19 630	0,006	33%

Source: data.egov.bg

The data from the table shows that, despite an 88% rise in the number of electric vehicles for the entire period, a trend of decline in the number of registered electric vehicles in comparison to each previous year has been observed in the last three years. Additionally, it is quite striking that the number of registered electric vehicles in regards to the total number of cars is negligibly small.

A new test for examining and measuring fuel economy, electric vehicle run and emissions was introduced in 2017. The new WLTP (Worldwide Harmonized Light Vehicle Test Procedure) has replaced the old NEDC (New European Driving Cycle) standard. The introduction of this new method of testing cars has led to more accurate and realistic data about energy expenditure and emissions. The elements which are taken during the test include: Rolling resistance; Air resistance; Different engine and gearbox combinations; and Optional equipment ([VCA, 2021](#)). Different car brands have different models of electric vehicles with different capacity and range. The WLTP characteristics of some models, in accordance with the average mileage calculated above, are shown in Table 2.

Table 2. WLTP Characteristics of Car Models

models	range (km)	charging time from 20% to 80% (minutes)	average consumption (kW)	battery capacity (kW)
Dacia Spring	225	45	14,6	50
Renault Zoe	325	50	16	52
BMW i3	235	35	16,1	38
Opel Ampera E	345	40	16,8	58
Peugeot E 2008	250	30	18	45
Hyundai Kona	400	45	16	64
Volkswagen ID.3	350	30	16,6	58
Tesla 3	386	30	16	62
Skoda ENYAQ	330	50	17,6	58

Sources: EVpoint ([EV, 2025](#)) Dacia Spring ([Dacia, 2025](#))

The following inferences can be made on the basis of the data in the table for the purposes of the study:

- the average run of an electric vehicle is approximately 320 km;
- the average charging time is 40 minutes;
- the average consumption of electricity for a run of 100 km is 16,5 kW per 100 km;
- the average battery capacity is 54 kW.

The average range of electric vehicles is reduced by 20% because when the remainder of the battery capacity is 20%, all manufacturers recommend charging, plus another 10% for additional battery consumers in cold and hot weather which affects the battery capacity. Upon completing the calculations, it is estimated that the average range of one car is 220 km. During the first charging, only 60% of the capacity (80 – 20) can be added at an average charging time of 40 minutes, which is equal to a hypothetical additional run of 130 km. If a second charging is required, it will be after approximately 100 km (130 – 20%) – the quantified power between the first and second charging is only 60% of the battery capacity.

The traffic along the main roads in Bulgaria, which have a total length of approximately 4000 km (first-class – 2900, and highways – 840) is unevenly distributed in the network (NSI, 2025). There are time variations in the demand – the intensity during workdays and weekends/holidays, during morning, noon and evening hours is different, which creates additional pressure in the country's transport network. Said time variations create an imbalance in the demand for a charging infrastructure, meaning that the number of necessary charging points along the main roads needs to be determined on the basis of the maximum intensity during peak days and hours. This in turn will guarantee the high quality of the provided services, which is at the basis of charging services for consumers of electrical mobility. These variations in the demand for a charging infrastructure and various routes from the perspective of distances which can be traversed with one charging and a reduced second one as a capacity can be presented through queuing models (Soylu, 2016). These models evaluate the use of charging points for service depending on the allocation of time during charging. Of significant importance for the larger-scale emergence of electric vehicles in Bulgaria are several factors:

- the amount of time necessary to charge the battery;
- the amount of waiting time at the charging station (if there are other cars);
- the availability of an ultrafast charging station;
- the high and sometimes unknown prices per kW of energy.

An author's study among users of electric vehicles shows that the low charging costs are at the basis of the criteria for purchasing cars with electric traction. The other criteria involve convenient locations (in terms of shopping or workplaces) and the availability of ultrafast charging stations (DC).

This approach allows us to calculate the locality of the charging infrastructure along the republican highway network and the necessary number of charging points on the basis of traffic and arrival frequency. The deployment distance of charging stations, their power and the number of necessary charging connectors will be determined by the number of cars which will arrive during peak days and hours and require simultaneous charging. The goal is to minimize waiting time and charging time – the use of charging stations should be between 80 and 100%, and the total waiting time should not exceed 30-40 minutes.

6.RESULTS

Applying the queueing model, based on the frequency of arrival of electric vehicles at charging points during peak loads (holidays and weekends) and the corresponding levels of use (arrival time and battery capacity and condition) will allow us to calculate the required number of points (not the number of charging stations) for charging. With an average number of vehicle arrivals per hour – 5, an average number of charging per hour per point – 2 and an average waiting time of 8 to 10 minutes. In a scenario of 35 000 electric vehicles in 2026 calculated on the basis of the data in Table 1, as well as an average number of people traveling in them during peak days and hours plus transiting foreign vehicles 10500 (30%), at a minimum waiting time of 9 minutes and average charging time of 35 minutes, 460 ultrafast charging stations (DC) with a capacity of over 350 kW are required, each with 2 connectors.

The recommended distance is between 70 and 90 km along the primary network – first-class roads and highway network. As of April 2025, ultrafast charging stations in Bulgaria are a little over 500 in total and only 20% of them have a capacity of over 200 kW (VT, 2025). Another peculiarity is that more than half of them are located in the city of Sofia and its surrounding areas. The relation between the number of charging points, the waiting time and their spatial arrangement along the republican highway network is crucial in analyzing customer preferences, especially in the context of the growing number of home charging stations. Transparent pricing, the unification of various charging connectors and the integration of electric vehicles in the country's common electrical grid in the context of ecological goals is another important topic. To have a sustainable development of electromobility, it is necessary to build publicly accessible charging stations, located on the main republican roads, no more than 70-90 km apart in both directions of travel. Each of these stations must have a capacity of at least 350kW and the presence of two charging points, each with 150kW.

In summary, the study shows that the charging infrastructure in Bulgaria is not only insufficient but also distributed unevenly along the republican highway network. The creation of new charging stations should include a geographical dimension, i.e. average distance between charging points, incorporation of ultrafast charging points, various methods of payment and provision of accurate and appropriate information for consumers.

7. CONCLUSION

The development of the charging infrastructure needs to be in synergy with technological development – life cycle of various drive systems, analysis of building costs (their physical building and energy costs during exploitation) and interface (hardware and software) for charging with direct current (DC). The development of a charging infrastructure should not be to the detriment of the existing one, as society and enterprises need to continue having access to conventional fuels for the existing motor fleet.

The article examines an approach for the development of the charging infrastructure which is based on the demand regarding long-distance travel (over 150 km) on the main roads of the TEN-T network. The methodology is based on the assumption that a comparatively slow rise is observed in the demand for electric vehicles capable of long-distance travel and that more than 70% of consumers use home or office charging. While the development of the charging infrastructure is included in the prerogatives of every country, the approaches in regards to its creation, as well as the support for its expansion vary. There is a lack of a harmonized pan-European infrastructure due to high initial costs and the lack of critical mass on behalf of consumers, which causes private investors to act with restraint. The fact that the standards regarding the switch-in technology (interface) of charging stations are not uniform poses another problem. Securing an infrastructure which is interoperable, reliable and convenient for customers is the key to the sustainable creation of charging stations. A fundamental argument against the larger-scale integration of electromobility in Bulgaria is consumers' reluctance to purchase electric vehicles with an average run of 300-320 km and the uncertainty in the pricing of public stations and the low density of their location along the main transport network. An essential element of this future development of electromobility involves manufacturers who will need to design cars with an autonomous run of at least 500 km, and state institutions need to create conditions for building a charging infrastructure which will make travel secure and reliable.

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THE CIRCULAR ECONOMY AS AN INNOVATIVE APPROACH TO FIGHTING CLIMATE CHANGE: A STATISTICAL STUDY OF ITS IMPACT ON THE SUSTAINABLE DEVELOPMENT

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ABSTRACT

The circular economy, based on principles of resource preservation, recycling, and reuse, presents an innovative solution to the challenges of climate change and sustainable development. This economic model aims to minimize waste, reduce greenhouse gas emissions, and improve the efficiency of resource use, offering significant environmental and economic benefits. It represents a shift towards a more sustainable industrial model that enhances economic efficiency while reducing environmental impact. This study analyzes the impact of circular economy practices on sustainable development in Ukraine through statistical examination of key indicators such as GDP, CO₂ emissions, waste generation and treatment, and investments in environmental protection. Special attention is given to waste management metrics, including recovery, incineration, and landfill disposal. A comparative analysis between Ukraine and EU countries explores the correlation between waste generation and economic growth, providing insights into the future development of circular practices. The authors assess the correlation between implemented circular practices and changes in economic, environmental, and social indicators to evaluate overall effectiveness in addressing climate change. Additionally, analysis of environmental expenditures highlights the practical and economic advantages of circular strategies, particularly in air and water protection. The research offers a theoretical and practical framework for understanding the circular economy's potential to reduce environmental pollution and enhance natural resource use. The findings support the circular economy's role in achieving the UN Sustainable Development Goals, particularly in mitigating climate change and preserving biodiversity. The study underscores the urgency of Ukraine's transition to a circular economy, especially amid the challenges of military aggression.

Keywords: circular economy, climate change, sustainable development, GDP, CO₂ emissions, waste generation, waste recovery, current expenditures, capital investments, environmental domain, statistical study

1. INTRODUCTION

The circular economy, as a model of production and consumption that minimizes waste, is a key part of the philosophy of sustainable development and the green economy in general. The benefits of the circular economy include stimulating economic growth and job creation and reducing negative environmental impact and emissions. Many countries have included circular economy commitments in their national development plans and climate programs. The circular economy is a way to reduce environmental pollution and save production costs. This economy is a prerequisite for a new industrial revolution, as it helps maximize economic efficiency in industry and reduce the negative

environmental impact. Its implementation involves a set of measures aimed ultimately at the sustainable development of enterprises and society.

The concept of circular economy is becoming increasingly relevant in the context of sustainable development and environmental protection. The linear model of “extraction-production-consumption-disposal” leads to resource depletion, pollution, and waste accumulation. On the other hand, the circular economy is based on the principles of a closed cycle, where waste from one production becomes a resource for another, thus minimizing losses and negative environmental impact. For Ukraine, as a country with a resource-dependent economy, implementing the principles of circularity and zero waste production is a highly relevant and important task. Creating closed cycles of material flows, reintegrating waste into production systems and maximizing the resource value of products at all stages of their life cycle is the basis for the transition to a sustainable and eco-efficient economy in Ukraine.

In the context of Ukraine’s European integration course, it is important to develop innovations and transition from a traditional linear economy to a modern circular economy model. This transition should be carried out comprehensively, per current requirements and European trends. In order to ensure competitive advantages and create favourable conditions for the development of the circular economy in Ukraine, it is necessary to conduct thorough scientific research and study the experience of developed countries in implementing this model, which will help to increase our country’s competitiveness.

The purpose of this study is to assess the impact of implementing the circular economy model on achieving sustainable development in Ukraine by analyzing economic, environmental and social indicators, as well as to study the relationship between waste generation and recycling, greenhouse gas emissions, gross domestic product and investments in environmental activities. It will also substantiate the prospects and direction of further development of the circular economy in Ukraine, considering international experience and current challenges, particularly under martial law.

2. LITERATURE REVIEW

2.1 CIRCULAR ECONOMY: EVOLUTION OF THE CONCEPT AND ESSENCE OF THE ECONOMIC CATEGORY

The modern economic system requires new innovative approaches and has lost the ability to ensure sustainable development of society in the future. The category “circularity” means the efficient reuse and recycling of resources, materials and products in closed cycles.

Reike D., Vermeulen W.J.V. and Witjes S. (2018) identify three key stages in the development of the circular economy concept:

The first stage (1970-1990) focused on waste management, emphasizing waste reduction, reuse and recycling. It was during this period that the 3R concept – Reduce, Reuse, Recycle – began to take shape: 1. Reduce – to reduce the use of natural resources and increase production efficiency; 2. Reuse – to reuse products for their original purpose; 3. Recycle – to recycle materials to create new products of the same or lower quality.

The second stage (1990-2010) saw the implementation of an environmental efficiency strategy based on the idea of environmental payments. During this period, environmental problems acquired an economic dimension. In addition, the issues of ozone depletion and global warming acquire the status of global challenges, and waste-free technologies are introduced mainly in industry.

In the third stage, which lasts from the end of 2010 to the present day, the concept of the circular economy is finally taking shape. The World Economic Forum proposed and expanded the principles of the circular economy in 2018 and is currently applying the 10R model: Refuse – refusal to produce a product using an “environmentally hazardous” technology, offering another product; Rethink – rethinking the use of a product, its exchange or sharing; Repair – repair and maintenance of a defective product with its further use; Refurbish – restoration of an old product for its further consumption; Remanufacture – re-processing and use of a part of an old product in a new product; Repurpose – reorientation of a part of an old product in a new product for another purpose; Recover – burning materials to recover the energy lost in their production (World Economic Forum). Thus,

the 10-R model is less resource-intensive than the 3-R model, but much more complex and requires a clear selection and selection of raw materials at the design stage and in the design process.

During this period, along with the already recognized global problems of the second stage, new threats to the survival of humanity were also identified:

- Global population growth: according to the UN, in 2010 the population amounted to 6.96 billion people, in 2023 - 8.01 billion, and the forecast for 2050 - 8.92 billion people ([World Population Prospects](#)).
- Increased waste: according to the World Bank, waste will increase from 2.24 billion tons in 2020 to almost 3.88 billion tons by 2050 ([Silpa K., Siddarth S., Sarur Ch., 2021](#)).
- Depletion or disappearance of most natural resources: global resource extraction is projected to reach 190 billion tons by 2060, up from 143 billion tons in 2019 ([United Nations Environment Programme, 2019](#)).

Today, more than 500 global companies are implementing the concept of a circular economy.

[Geissdoerfer M. et al. \(2017\)](#) theoretically proves that the circular economy is a regenerative system in which resource consumption, emissions and energy losses are minimized by closing and reducing material and energy cycles.

[Haas W., Krausmann F., Wiedenhofer D., Heinz M. \(2015\)](#) consider the circular economy as a strategy to reduce the consumption of raw materials and waste production by closing the economic and environmental loop of resource flows. [Kirchherr J., Reike D., Hekkert M. \(2017\)](#) define the concept of "circular economy" as an economic system based on business models that provide for alternative reuse. It is aimed at achieving sustainable development, environmental protection, economic growth and social justice in the interests of both present and future generations. The circular economy as an economic model is described by [Murray A. Skene K. and Haynes K. \(2015\)](#). They believe that in this model, both the results and processes of resource supply and production are planned and organized to maximize human well-being and the efficiency of ecosystems.

The circular economy model is an innovative platform that ensures sustainable development through the transition from a linear model based on consumption and disposal to a model in which the life of products is maximized, natural resources are reused, and materials and waste are minimized as much as possible. Currently, there are three distinctive circularity cycles that are gradually becoming more widespread: the closing of resource cycles, which is defined by the traditional economic system; the slowing of resource cycles and material flows through the extension and intensification of product use to maintain their value and cost over time; and the narrowing of resource cycles through the more efficient use of materials, resources and products in a linear system.

A systemic and comprehensive approach to the implementation of the circular economy can be implemented holistically, but at the same time, each regional or urban system is based on the features of the circular economy ([Yatsenko, O., Shvydanenko, O., & Shvydanenko, H., 2022](#)). We agree that the circular economy is focused on resource recovery, which determines its essence and structure.

2.2 THE INNOVATIVE ROLE OF THE CIRCULAR ECONOMY IN THE FIGHT AGAINST CLIMATE CHANGE AND IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Reducing greenhouse gas emissions, addressing resource depletion and environmental pollution, and optimizing waste management have become hot topics at the global level ([Dantas et al. 2021; Sadhukhan et al. 2020; Zhang et al., 2019; Mahdhi & Belgaroui, 2025](#)). Countries around the world have defined climate change mitigation efforts as a commitment to reduce emissions or implement advanced technologies to limit them ([Peña et al. 2021; Serrano et al. 2021](#)). In addition, the growth of population and living standards has led to the automation of production, which in turn has contributed to mass production and consumption, as well as to the increase in solid waste. The growing amount and complexity of waste seriously threaten the environment and human health ([Chioatto and Sospiro, 2023; Kurniawan et al., 2022](#)).

Implementing circular economy strategies is an effective tool for increasing the sustainability of the global system. It is increasingly clear that achieving structural optimization within the sustainable

development framework is impossible without using circular economy strategies (Alhawari et al., 2021). National governments are striving to decouple economic growth from the consumption of natural resources and environmental pollution while trying to preserve economic resources as long as possible (Almagtome et al., 2020; Atabaki et al., 2020). The application of circular economy principles is primarily aimed at preventing resource waste and optimizing energy and material cycles at different levels: the micro level includes businesses and consumers, the meso level includes economic agents that interact symbiotically, and the macro level includes cities, regions, and governments (Rincón-Moreno et al., 2020).

Due to the significant differences between research areas and schools of thought, Nikolaou et al. (2021) found that definitions of the circular economy emphasize both material conservation and economic growth. As a new economic development model, the circular economy requires the restructuring and modernization of the economic system by the laws governing the circulation of materials and energy flows in the natural ecological system (Shen et al., 2020). The circular economy is not limited to improving the waste management system to increase resource efficiency, reduce raw material consumption, and increase economic benefits. It is increasingly recognized as an effective strategy for policy development and for reducing environmental pollution and greenhouse gas emissions (De Pascale et al., 2021; Durán-Romero et al., 2020).

Countries worldwide have agreed to work together to mitigate the effects of climate change (Fawzy et al., 2021). One of the main goals is to reduce global warming to below 1.5 °C compared to pre-industrial levels. It also envisages a 45% reduction in carbon emissions by 2030 and achieving carbon neutrality by 2050 by the Paris Agreement, which was signed by 196 parties at the 21st Conference of the Parties (United Nations Framework Convention on Climate Change 2021). To achieve these goals, countries are implementing economic and social reforms. Additional measures include raising social awareness, implementing policies that promote climate stability, implementing sustainable urban planning, transitioning to a circular economy, supporting sustainable agriculture, developing clean transport, and conducting climate research (Moore et al., 2021).

The innovative role of the circular economy in combating climate change and in the context of sustainable development is most clearly manifested in the following areas:

1. With the growth of industrialization, the issue of climate change caused by industry is becoming increasingly urgent. Circular economy strategies help reduce carbon emissions and create profitable business models for the industry, improving quality, efficiency, and working conditions by monitoring the carbon footprint throughout the product life cycle (Khan et al., 2021). Blockchain technology in supply chains can provide accurate, real-time data on closed-economy processes such as circular design, production efficiency, and recycling, significantly reducing the carbon footprint of supply chain operations. The conversion of carbon dioxide, which contributes to global warming, into high-value-added products has become an important area of research. The authors estimate that 5–10% of carbon dioxide emissions can be converted into fuels and chemicals within the framework of a circular economy (Cucciniello and Cespi, 2018). Wang et al. (2019) found that resource recovery measures can reduce the overall carbon emissions of industrial parks by replacing carbon-intensive energy sources through a quantitative analysis of the impact of the circular economy. Therefore, it can be argued that using industrial by-products in the circular economy reduces carbon emissions and increases the value of industrial processes. Overall, the circular economy strategy can effectively reduce carbon emissions from industrial processes and help combat climate change.
2. Population growth leads to an increase in waste, the disposal of which is becoming increasingly complex and contributes to climate change. At the same time, a circular economy based on waste recycling can effectively combat climate change (Osman et al., 2022). The European Union is implementing strategies to achieve a circular economy, in particular, it plans to increase the recycling rate of municipal waste to 65% and ensure that all plastic packaging is recycled by 2030 (Aceleanu et al., 2019). Recycling and transforming waste into valuable raw materials to produce value-added goods contributes to a more efficient use of resources and a reduced carbon footprint compared to traditional disposal methods such as landfilling and

incineration. Therefore, conducting more research in large-scale recycling and implementing technologies to achieve a circular economy and combat climate change is important.

3. Global energy consumption is increasing due to improved quality of life. However, increasing energy consumption is accompanied by increased greenhouse gas emissions, which raises concerns about climate change (Nurgaliuly & Smagulova, 2025). Implementing circular economy strategies and digital technologies, including artificial intelligence, can improve energy efficiency and facilitate carbon trading, which can help countries achieve their climate change mitigation goals (Jose et al., 2020). Using a standard greenhouse gas quantification model and scenario analysis, Islam et al. (2021) found that combining circular economy principles with renewable energy can reduce greenhouse gas emissions in the livestock sector in Bangladesh by 37.5%. A circular economy strategy is well-aligned with climate change goals and serves as an effective tool to address climate change challenges. It can reduce carbon emissions in industry, waste management, energy consumption, construction and transport, which helps mitigate global climate change. In addition, circular economy strategies impact air and water quality, energy consumption, natural resource use, solid toxic waste and land use. Therefore, circular economy strategies can contribute to mitigating global climate change by increasing the use of renewable energy and transforming the energy mix into a more sustainable one.
4. The circular economy will create numerous opportunities for industrial growth and provide opportunities for optimizing the food system. A proposed circular economy path can provide a theoretical basis for the future sustainability of industry, agriculture and trade. Concentrating on the recycling, treatment, production, packaging, and marketing of waste in individual enterprise parks and developing an eco-industrial park based on a closed-loop economy can bring several benefits. For waste generated from bulk products such as construction waste, the quality and productivity of the waste are assessed, and the waste data is uploaded to the cloud, thus facilitating the trade of bulk waste. At the same time, implementing waste separation at the processing site will undoubtedly lead to long-term benefits in sustainable development.

There are opportunities to recycle construction waste and use it in new construction sites, which allows for resource conservation and carbon reduction, thus contributing to the fight against climate change. Instead of throwing away waste that hurts the climate, the focus should be reusing construction waste. The transition to a circular economy based on reuse and recycling is key to resource efficiency and climate change mitigation. Circular economy strategies are essential for combating climate change in all sectors, as they ensure the rational use of resources and reduce carbon emissions (Podlevska O., & Podlevskyi, A., 2023). It is important to focus on the entire life cycle, especially the end-of-life phase, which is critical for reuse, recovery and recycling.

The circular economy is an innovative waste management approach implemented through three main pathways: waste elimination, material recycling, and natural regeneration through ecosystems. Circular economy strategies can contribute to the creation of sustainable waste management systems that maximize economic efficiency, reduce resource consumption, and prevent environmental pollution, thus reducing the pressures faced by individual countries (Yang et al., 2023). The closed-loop economy is an important strategy for preventing waste generation through sustainable product design, using recycled materials, and reducing packaging. Implementing circular design principles, such as extending product life, encouraging reuse and repair, and increasing consumer awareness of sustainable practices, can significantly reduce waste (Nelles et al., 2016). Recycling is a key element of the circular economy, as it provides secondary raw materials for new products and highlights the importance of reducing the amount of waste going to landfills to avoid soil and groundwater pollution (Gheewala, 2014). Improving waste collection infrastructure, setting strict recycling standards, and introducing incentives for using recycled materials are necessary to increase recycling rates (Hua et al., 2024). Together, these measures contribute to sustainable development.

5. The circular economy is key to combating climate change and achieving the Sustainable Development Goals (SDGs) by significantly reducing greenhouse gas emissions (Leal Filho et al., 2024). By using practices such as reusing, repairing, recycling and remanufacturing materials, the circular economy reduces the need for new raw materials, reducing emissions associated with extraction, processing and transportation. Furthermore, by promoting the use of renewable energy sources and

increasing energy efficiency, the circular economy contributes to reducing emissions associated with energy production (Janik et al., 2020). By reducing waste and minimizing incineration and landfill, the circular economy also helps reduce emissions of methane and other greenhouse gases, which has a positive impact on air quality and, consequently, reduces the risks of respiratory and heart diseases, improving both the environment and human health (Kalebaila et al., 2024).

3. METHODOLOGY

The documents were selected for this work using the following electronic resources: MDPI, IEEE, Sciendo, Scopus and Science Direct. These sources were chosen due to their leading role in technological knowledge and the availability of numerous studies.

The study covered the entire territory of Ukraine, as well as individual enterprises that are the largest polluters in the country in the period from 2010 to 2023. For a more detailed analysis, statistical information was obtained from administrative data of the Ministry of Environmental Protection and Natural Resources of Ukraine and the State Statistics Service of Ukraine. Data based on the results of state statistical observations for 2010–2023 are given without taking into account the temporarily occupied territories of the Autonomous Republic of Crimea and the city of Sevastopol, as well as for 2014–2023 without taking into account part of the temporarily occupied territories in Donetsk and Luhansk regions. Information for 2022–2023 also does not include temporarily occupied territories captured by Russia. (State Statistics Service of Ukraine).

The methodological basis of this study is the concept of a closed-loop green economy and the circular economy's role in ensuring the state's sustainable development. This concept considers socio-economic development as a process of social changes occurring within the limits determined by the ability of ecosystems to restore, absorb pollution and support the vital activity of current and future generations. The concept is formulated using the dominant point of view in the European Union, according to which the circular economy covers the entire life cycle of a product and is aimed at preserving its value for as long as possible. This is achieved by using multiple resources and materials in the production cycle and minimizing waste. Among the main advantages of the circular economy are innovative production processes, resource-saving, prevention of inefficient waste management, creation of new business opportunities and environmental friendliness. The study used analysis, synthesis, generalization, analogy and comparison methods. To investigate the statistical relationship between Ukraine's gross domestic product (GDP) and total air emissions over the period 2010–2023, a correlation analysis was employed. Specifically, the Pearson correlation coefficient was calculated to assess the strength and direction of the linear association between these two variables.

4. RESULTS

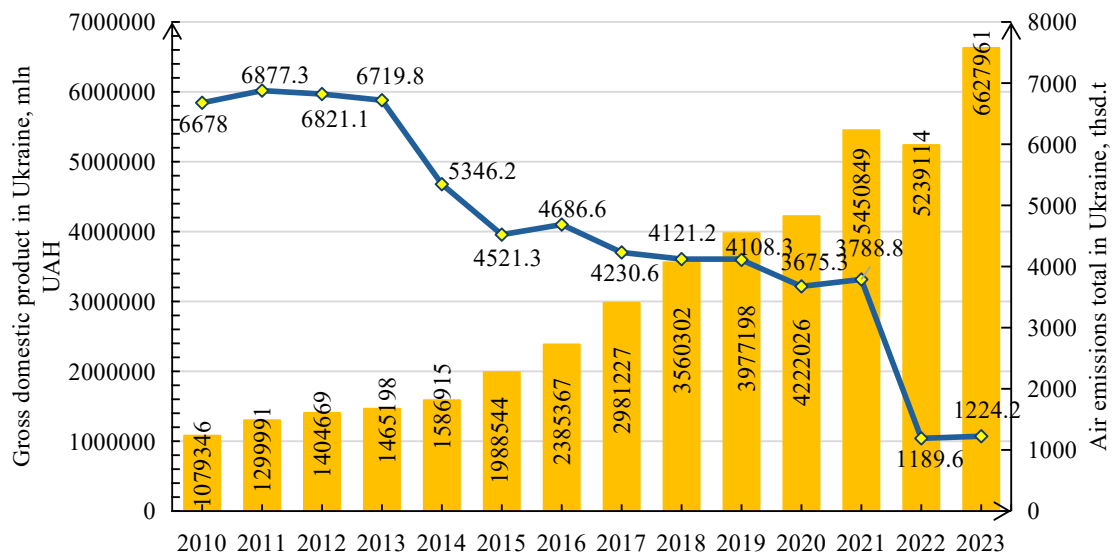
4.1. STATISTICAL STUDY OF THE IMPLEMENTATION OF THE CIRCULAR ECONOMY AS AN INNOVATIVE MECHANISM FOR PROTECTING ATMOSPHERIC AIR AND COMBATING CLIMATE CHANGE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT OF UKRAINE

As a result of the full-scale war and terrorist actions of the Russian troops, Ukraine has experienced a significant burden on the environment and economy. Implementing the principles of the circular economy will contribute to creating conditions for the sustainable development of the regions of Ukraine and strengthening their socio-economic security.

GDP remains an important indicator in studies of the principles of implementing the circular economy (Kobylynska et al., 2023). To assess the effectiveness of the circular economy, we will compare GDP with other indicators, such as greenhouse gas emissions, the level of waste generation, etc.

Studies of the relationship between gross domestic product (GDP) and air emissions showed that from 2010 to 2023, air emissions total decreased by almost 5.5 times, from 6,678 thousand tons to 1,224 thousand tons (Fig. 1) (State Statistics Service of Ukraine).

Figure 1. Comparison of gross domestic product and air emissions total in Ukraine, 2010-2023, mln UAH / thsd.t



Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

The most significant reduction in air emissions was observed after 2014, which is associated with the beginning of the war in Donbas and the decline of industry. In 2022–2023, a sharp drop in pollutant emissions is observed due to a full-scale war, the shutdown of enterprises and the relocation of production.

Analyzing the top 10 enterprises – the most significant air pollutants, it is worth noting that this anti-rating differs significantly in the period before and during the war (Table 1).

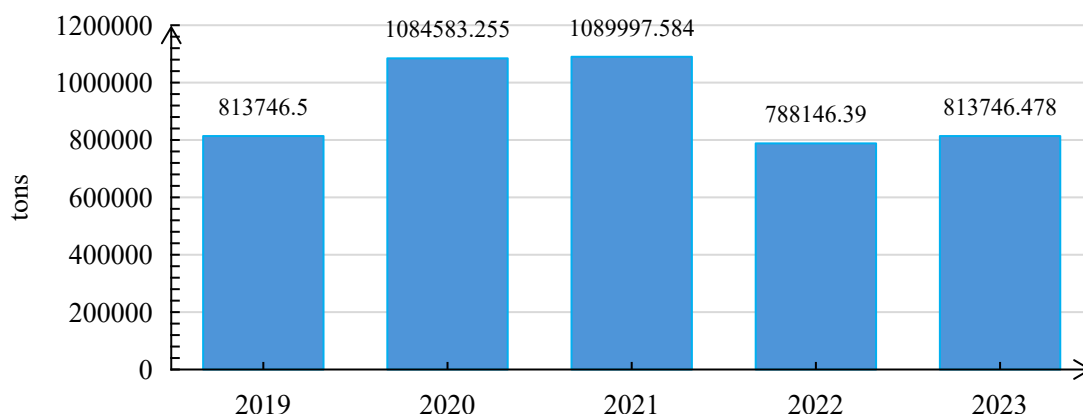
Table 1. Top 10 largest air pollutant enterprises in Ukraine in 2019-2023

rank	2023		2022		2021		2020		2019	
	enterprise	tons	enterprise	tons	enterprise	tons	enterprise	tons	enterprise	tons
1	DTEK Westenergy JSC	198859,7	DTEK Westenergy JSC	209678,4	PJSC Ilyich Iron And Steel Works Of Mariupol	258689,8	PJSC Ilyich Iron And Steel Works Of Mariupol	254099,1	PJSC Ilyich Iron And Steel Works Of Mariupol	247322,1
2	DTEK Pavlohradcoal PRJSC	134849,2	DTEK Pavlohradcoal PRJSC	117543,1	PJSC ArcelorMittal Kryvyi Rih. Metallurgical production prom №2	145796,4	PJSC ArcelorMittal Kryvyi Rih. Metallurgical production prom №2	139344,2	SS Burshtynska Thermal Power Plant. DTEK Westenergy JSC	169887,9
3	PJSC CG Pokrovs'ke	76139,3	PJSC CG Pokrovs'ke	100377,0	SS Burshtynska Thermal Power Plant. DTEK Westenergy JSC	145630,3	DTEK Kurahivs'ka TPP LLC	113336,2	PJSC ArcelorMittal Kryvyi Rih. Metallurgical production prom №2	150899,6
4	PJSC Kamet-Steel	75658,0	DTEK Skhidenerho TPP LLC	76220,8	DTEK Kurahivs'ka TPP LLC	109315,4	SS Bursh-tynska Thermal Power Plant. DTEK Westenergy JSC	109990,4	DTEK Kurahivs'ka TPP LLC	131391,8
5	DTEK Dniproenergy JSC	70154,6	PJSC Kamet-Steel	67997,2	PJSC CG Pokrovs'ke	96512,9	PJSC Dneprovsky Iron & Steel Integrated Works	91608,5	SS Zaporizhzhia thermal power station. DTEK Dniproenergy JSC	98650,9
6	PJSC ArcelorMittal Kryvyi Rih	63552,1	DTEK Dniproenergy JSC	56468,7	SS Zaporizhzhia thermal power station. DTEK Dniproenergy JSC	76472,4	SS Zaporizhzhia thermal power station. DTEK Dniproenergy JSC	86277,0	PJSC Azovstal Iron And Steel Works	81404,8
7	PJSC Centrenergo	60463,0	PJSC ArcelorMittal Kryvyi Rih	55634,8	PJSC Azovstal Iron And Steel Works	74058,1	PJSC Azovstal Iron And Steel Works	84323,5	PJSC Dneprovsky Iron & Steel Integrated Works	78090,5
8	DTEK Kurahivs'ka TPP LLC	59278,8	PJSC Centrenergo	41315,8	Vuhlehirska power station PJSC Centrenergo	70528,6	PJSC CG Pokrovs'ke	74983,8	Vuhlehirska power station PJSC Centrenergo	77590,2
9	PJSC Zaporizhstal	45803,0	PJSC Zaporizhstal	35856,4	PJSC ArcelorMittal Kryvyi Rih. Metallurgical Prod.	58319,7	Vuhlehirska power station PJSC Centrenergo	67289,5	PJSC ArcelorMittal Kryvyi Rih. Metallurgical Production	73375,1
10	PJSC Cherkasky Chemical Fiber	28988,8	SE L'vivvughiliya	27054,3	Ladyzhynska thermal power station DTEK Westenergy JSC	54674,1	PJSC ArcelorMittal Kryvyi Rih. Metallurgical Production	63331,1	Ladyzhynska thermal power station DTEK Westenergy JSC	70844,3

Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

Unfortunately, the most significant number of enterprises among Ukraine's top 10 largest air polluters in 2019-2021 left it not because of the implementation of circular economy practices but because they were entirely or partially destroyed due to a full-scale war. However, if we examine the total emissions of the 10 largest air polluters in Ukraine in the period 2019-2023, not from the perspective of changing the rating of the enterprises themselves but from the perspective of the dynamics of their emissions (Fig. 2), it is worth noting in the context of the implementation of a circular economy, it is worth noting that the growth in emissions in 2020-2021 is a sign of a linear economy.

Figure 2. Emissions of the top 10 largest air polluters in Ukraine in 2019-2023, tons



Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

The increase in emissions in these years indicates the predominance of the traditional, linear production model: “take → use → throw away”. This is when insufficient attention was paid to resource efficiency, technological modernization, and the implementation of closed cycles, which are key aspects of the circular model.

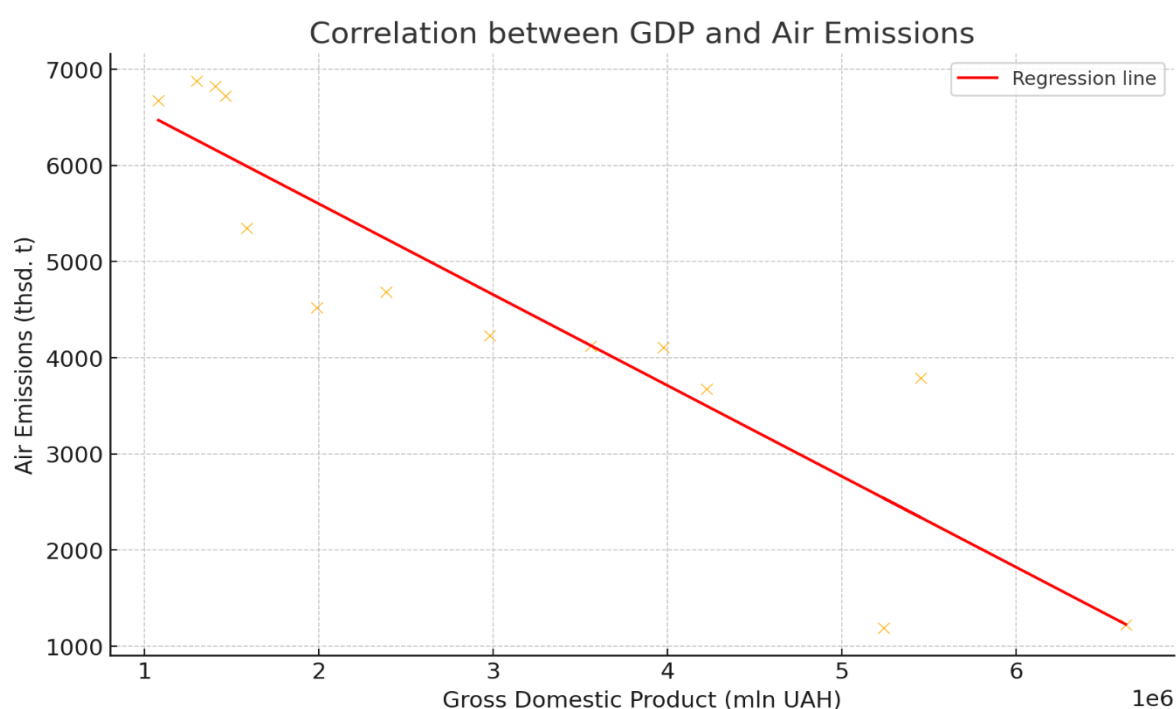
As noted earlier, the drop in emissions in 2022 was a forced consequence of the war, not the result of sustainable innovation or the transition to a circular economy. This is more of a forced “air cleaning” than the achievement of a decarbonization policy or a real transition to “green” production.

In 2023, a return to the level of 2019 is observed. Restoring indicators to pre-war levels is a crucial moment to launch circular approaches. This is a good time for the mass implementation of environmentally friendly technologies, expansion of renewable energy, and modernization of enterprises with an orientation towards reducing emissions and reusing resources.

As Figure 1 shows, GDP in Ukraine increased 6 times (nominally). This indicates a relative “decoupling” between economic growth and the level of air emissions. It is worth noting that the relative reduction in pollution against the background of GDP growth is a positive signal for sustainable development. The correlation analysis was conducted to examine the statistical relationship between Ukraine's gross domestic product (GDP) and total air emissions over the period 2010–2023 (Fig. 3). The Pearson correlation coefficient was calculated to quantify the strength and direction of the linear relationship between these two variables.

The analysis yielded a Pearson correlation coefficient of -0.91 with a p-value of 0.000005, indicating a strong and statistically significant negative correlation. This suggests that, as GDP increased over time, the level of air emissions tended to decline. The negative sign reflects an inverse relationship, implying that economic growth in Ukraine has been accompanied by a notable reduction in atmospheric pollutants.

Figure 3. Correlation between GDP and Air Emissions



Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

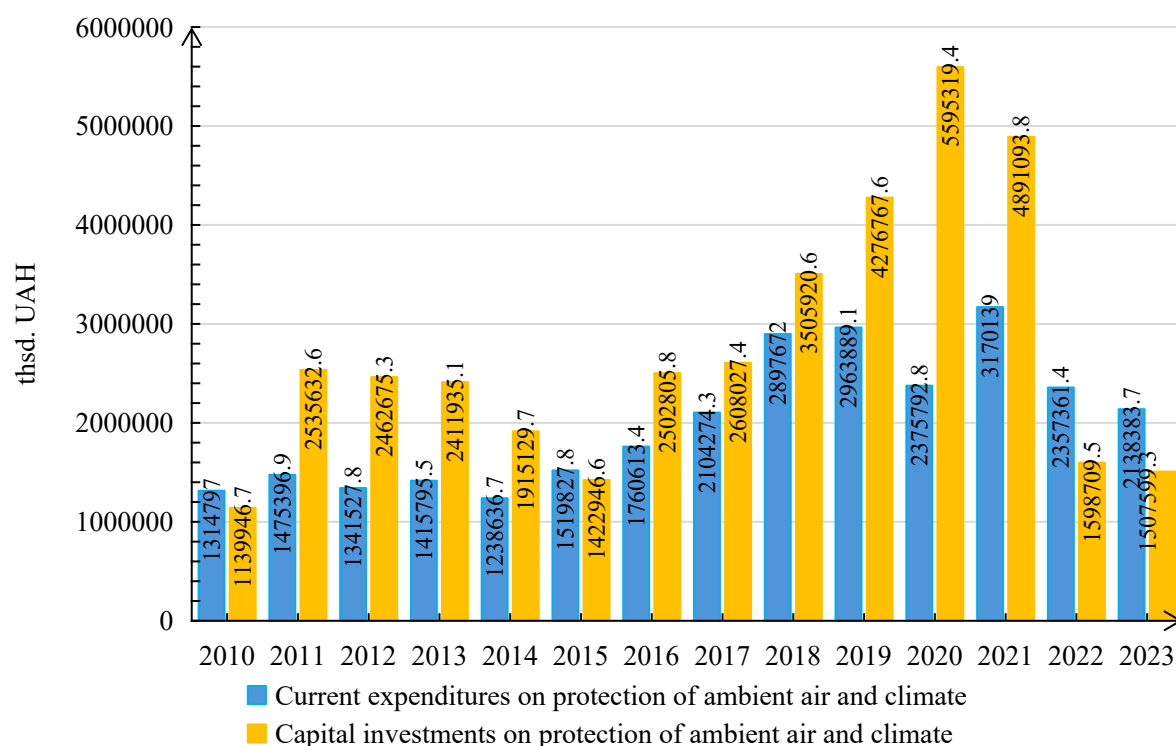
This finding indicative of multiple structural changes within the economy, including improvements in energy efficiency, shifts toward less carbon-intensive sectors, technological modernization, or the impact of environmental regulations and policies aligned with EU standards. The observed decoupling between economic growth and environmental degradation is a key indicator of sustainable development and supports the hypothesis that economic progress in Ukraine does not increased environmental burdens. Such results underscore the importance of integrating environmental considerations into economic planning and reinforce the relevance of green growth strategies in post-industrial and post-crisis recovery contexts.

Important indicators of the effectiveness of environmental protection policy are current expenditures and capital investments on protection of ambient air and climate change problems (Fig. 4) ([State Statistics Service of Ukraine](#)).

Thus, current expenditures on air protection and climate change issues in Ukraine had a general upward trend from 2010 (1.3 billion UAH) to a peak in 2021 (3.17 billion UAH). After 2021, a decline began: 2.35 billion in 2022 and 2.13 billion in 2023. A significant increase in this indicator occurred in 2016–2021. Capital investments in air protection and climate change issues in Ukraine, which in 2010 amounted to 1.14 billion UAH, showed significant growth in 2011, amounting to 2.5 billion UAH (more than 2 times). The peak of capital investments in air protection and climate change issues is reached in 2020 — 5.6 billion UAH, after which a sharp drop is observed: 1.6 billion in 2022 and 1.5 billion in 2023 ([State Statistics Service of Ukraine](#)).

It is worth noting that in 2020, despite the COVID-19 pandemic, capital investments were the highest. This may result from the implementation of previously planned projects or international support. 2022–2023 is an anti-crisis period when environmental investments are significantly reduced. Capital investments lay the foundation for circular transformation. Current costs support this transformation, ensuring its sustainability. The synchronous growth of these costs from 2015 to 2021 indicates an active environmental policy and the desire for circularity. This is logical – large eco-projects require: capital investments in infrastructure (purification systems, filters), ongoing costs for maintenance, modernization and monitoring.

Figure 4. Current expenditures and capital investments on protection of ambient air and climate change problems in Ukraine in 2010–2023, thousand UAH



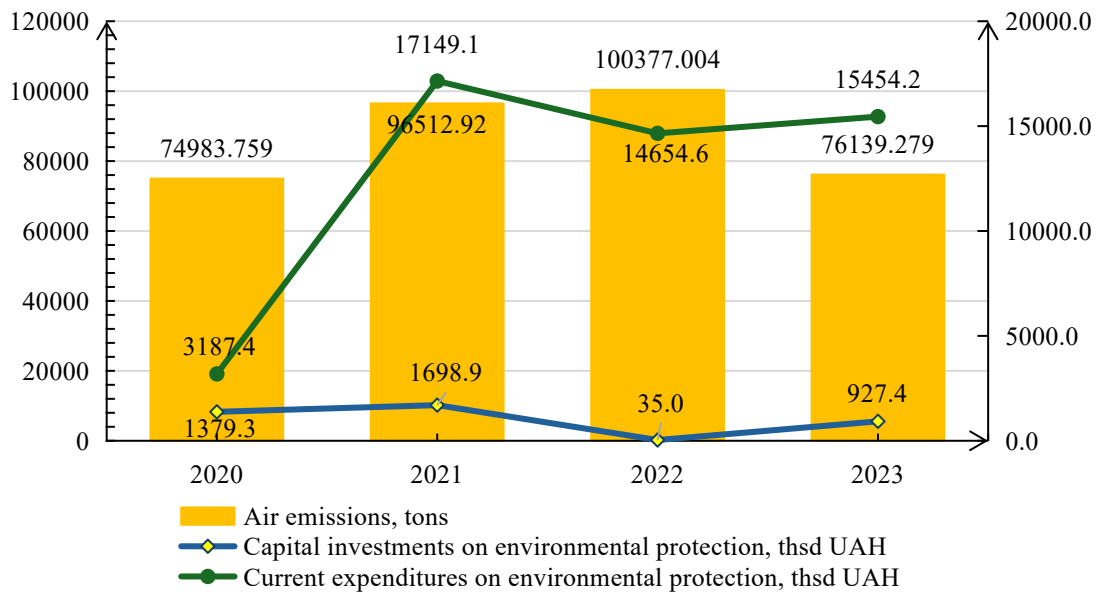
Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

As for capital investments in atmospheric air protection and the problem of climate change as a driver of circularity, their peak in 2018–2021 (3.5–5.6 billion UAH) is justified by the launch of innovative solutions (replacement of equipment with low-carbon ones), the introduction of cyclical processes, such as heat recovery, reuse of CO₂ emissions. These infrastructural changes lay the foundation for long-term “green” practices. A sharp drop after 2021 indicates the risk of stopping or regressing circular processes. This is due to the war, the prioritization of security and defence spending, and the general economic downturn ([State Statistics Service of Ukraine](#)).

To study the Comparison between the volume of emissions of particulate pollutants into the air and the volume of capital investments and current environmental protection costs in the context of a circular economy at the micro level, PJSC CG Pokrovs'ke was selected, which for the last 4 years has been among the top 10 largest air polluters in Ukraine (Table 1, Fig 5).

Emissions of particulate pollutants into the air at PJSC CG Pokrovs'ke increased from 2020 to 2022 (+34%), and in 2023 fell almost to the level of 2020. Capital investments fell sharply in 2022 – only 35 thousand UAH, but partially recovered in 2023. Current expenses increased sharply in 2021 (by 5+ times) and have been maintained at a high level. The enterprise actively fought emissions in 2021, investing in the current system support. 2022 became the most critical year: no investments, but current expenses were still maintained. In 2023, there is a restoration of the course towards environmental efficiency. The enterprise may have a high potential for circularity if it maintains the investment level and continues reducing emissions.

Figure 5. Relationship between the volume of emissions of particulate pollutants into the air and the volume of capital investments and current environmental protection costs of PJSC CG Pokrovs'ke in 2019-2023



Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

Therefore, both at the macro and micro levels, to restore the course towards circular economy, it is necessary to stabilize the situation, obtain external support and integrate the green economy into the recovery plan of Ukraine. In modern economic conditions, the management of Ukrainian enterprises often faces numerous problems related to the effective allocation of resources, raw materials and materials. This is necessary to ensure positive performance indicator dynamics and reduce harmful environmental emissions. The low level of competitiveness of the Ukrainian industry today is due to the lack of innovative technologies and insufficient material, technical and resource support. Additional difficulties arise due to the latest challenges of the world system, such as the transformation of the resource-based model of development, globalization, the fourth industrial revolution and, in recent years, war.

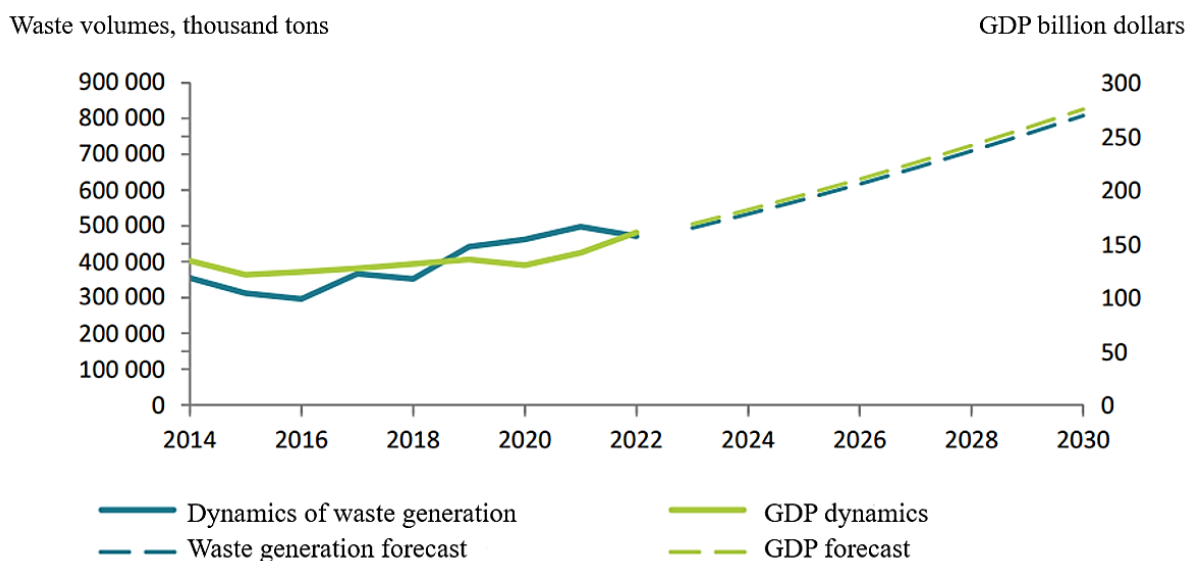
4.2. STATISTICAL STUDY OF THE IMPLEMENTATION OF THE CIRCULAR ECONOMY AS AN INNOVATIVE TOOL FOR COMBATING CLIMATE CHANGE THROUGH EFFECTIVE WASTE MANAGEMENT IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT OF UKRAINE

For Ukraine, the transition to a closed-loop economy is significant and relevant since, before the war, the annual volume of household waste was about 11 million tons. According to the State Statistics Service, over 25 billion tons of waste have been accumulated in Ukraine, of which more than 4 billion tons are toxic, and 23 thousand tons are prohibited and unsuitable for use with pesticides and toxic chemicals. As a rule, Waste disposal in Ukraine includes incineration and removal to specially designated places and facilities. The circular economy can become an effective tool for solving the problem of excessive accumulation of waste that arose both before the war and during hostilities.

High level of waste generation (11.1 tons per person per year) is twice as high as that of EU countries, which is 4.8 tons. Low recycling and recovery rates have resulted in significant amounts of waste accumulating in Ukraine yearly. Under the Association Agreement between Ukraine and the EU, Ukraine has committed to align its national legislation with EU legislation on environmental protection, waste management, climate change, ozone layer protection, industrial pollution and air quality. Ukraine has adopted a waste reduction plan by 2030.

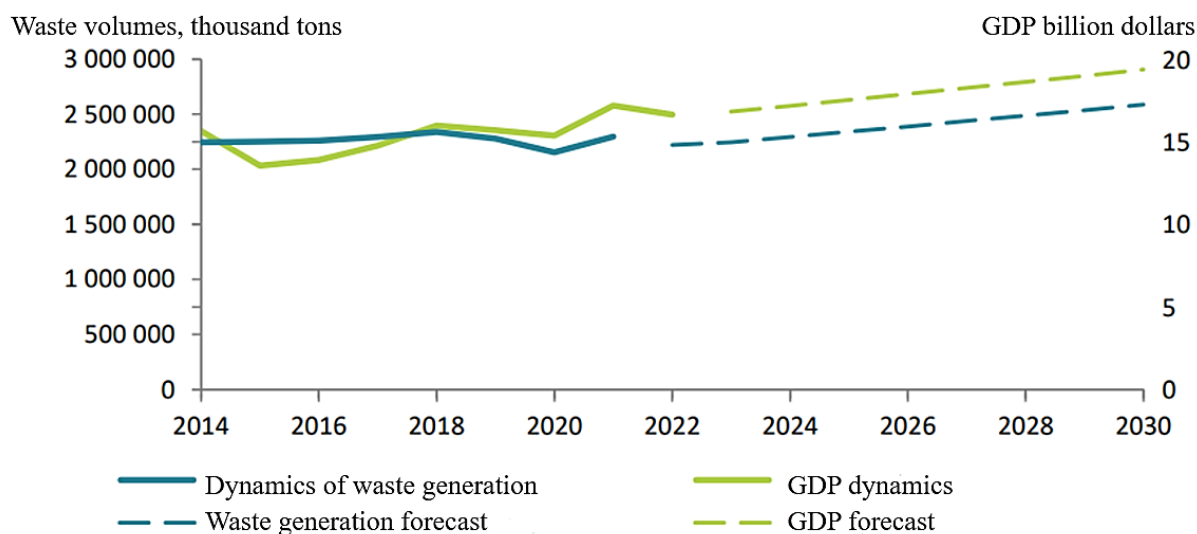
In the structure of household waste management in the EU in 2021, 49.6% of waste was sent for recycling. Compared to Ukraine, where only up to 8% of household waste was recycled, this indicates a gap in waste treatment methods. Stable GDP growth leads to increased production and, accordingly, an increase in waste. The task of the circular economy is to bridge the gap between economic growth and increased waste generation (Fig. 6-7) ([Circular economy strategy - Green Mind, 2024](#)).

Figure 6. Relationship between waste generation and GDP growth in Ukraine, thousand tons / billion dollars



Source: [Circular economy strategy - Green Mind, 2024](#).

Figure 7. Relationship between waste generation and GDP growth in EU countries, thousand tons / billion dollars



Source: [Circular economy strategy - Green Mind, 2024](#).

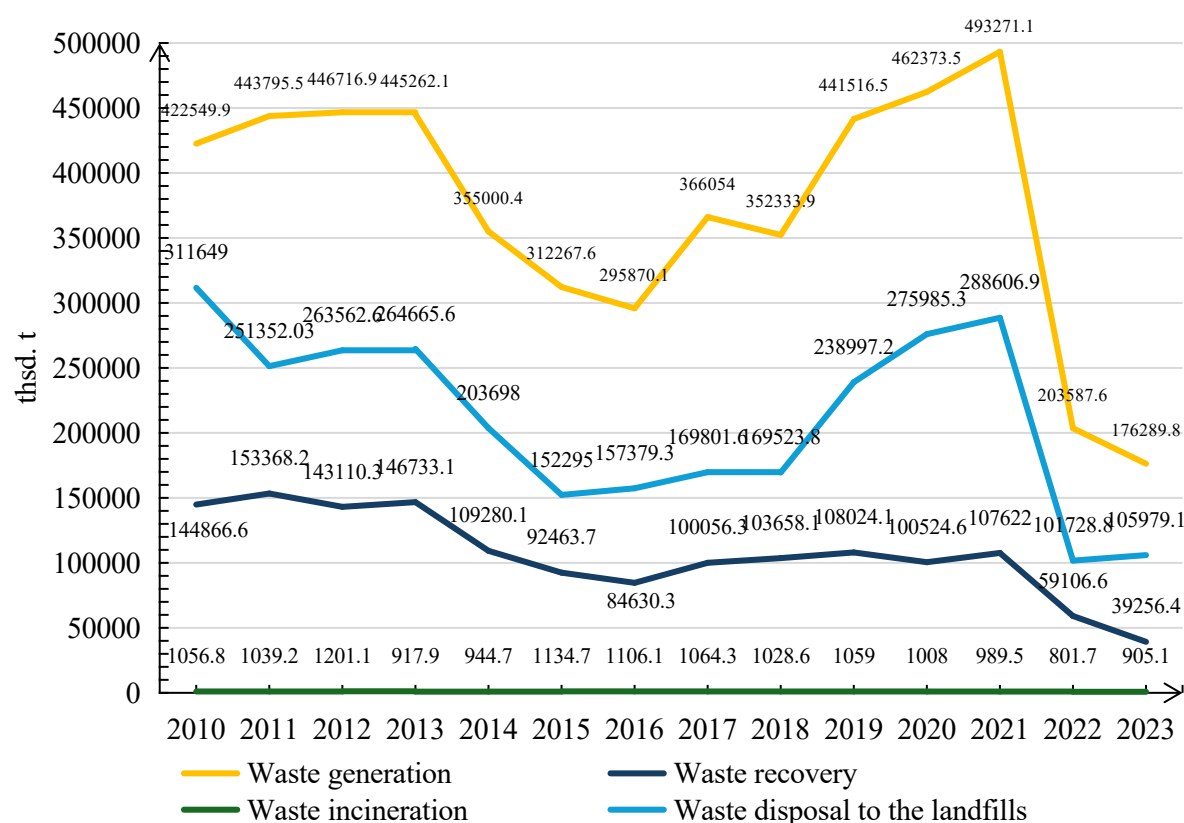
Key problems with waste in the direction of resources for recovery:

1. Lack of waste accounting mechanisms, in particular: precise mechanisms for accounting for waste volumes and their structure have not been introduced; a system for informing about the volumes of waste processing in the extractive industry has not been introduced; a separate legal framework for managing waste in the extractive industry has not been established.
2. Lack of regulation of disposal: the problem of disposal of waste generated at specially designated sites has not been resolved; the problem of the lack of a sufficient number of disposal enterprises in Ukraine for the reuse of slags, production tailings, and wastewater has not been resolved.
3. The problem of waste transportation: much waste is located in the eastern part of Ukraine and has no possibility for transportation; the processing complex should be located in a transport hub where it will be easy to transport waste for further processing; alternatively, the creation of a joint processing complex requires cooperation between different manufacturers.

According to official data from the [State Statistics Service of Ukraine](#), in recent years, the organization of economic activities of enterprises based on a closed-loop economy for waste of hazard classes I–III has achieved only minor successes. At the same time, waste of hazard classes I–IV, including that generated in households, makes up 4 to 7% of the total volume of landfills in Ukraine. Analyzing waste management indicators in the structure of their generation (hazard classes I–IV), without taking into account the total volume of accumulated waste in specially designated places (waste disposal sites), we can conclude that only a third of the total amount of waste generated is utilized, while more than half is thrown away in designated places.

The study shows that waste generation is decreasing in Ukraine from 422 million tons in 2010 to 176 million tons in 2023, i.e., this indicator has more than doubled. (Fig. 8)

Figure 8. Waste generation and treatment of the I-IV hazard classes in Ukraine, 2010–2023, thousand tons



Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

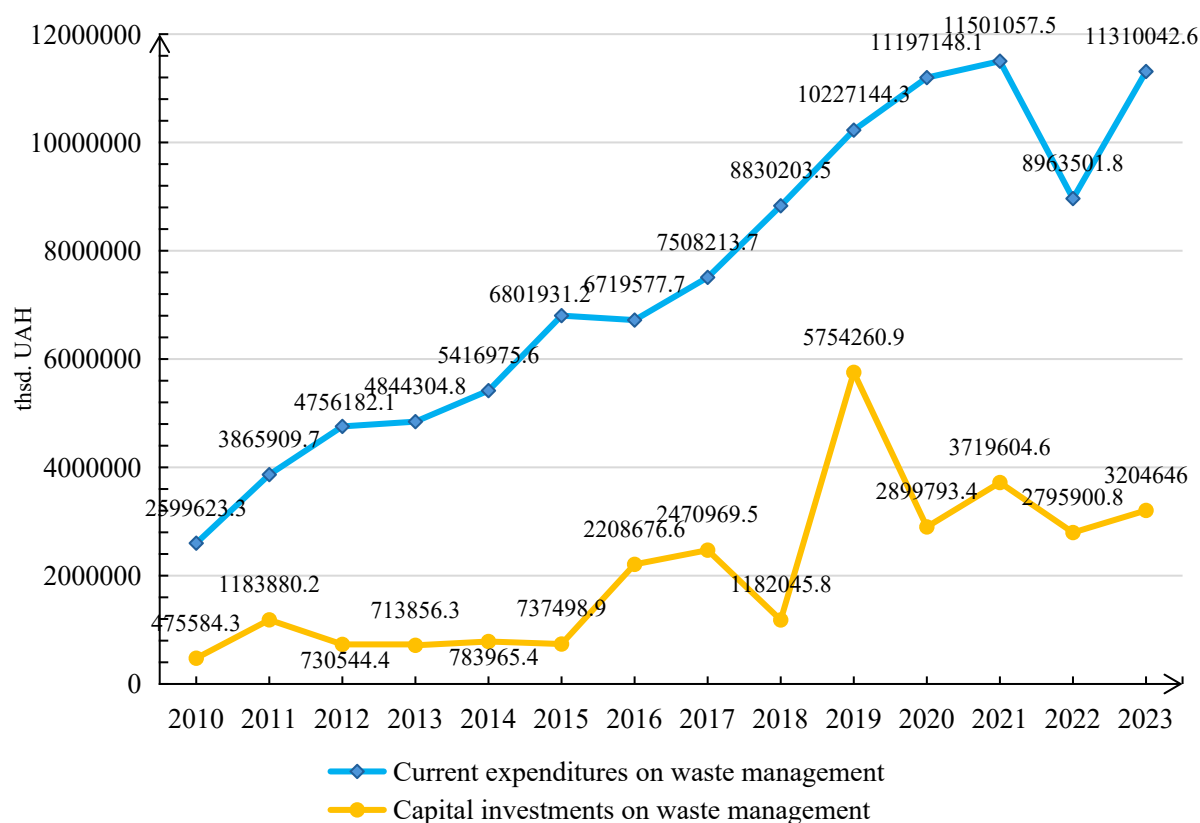
The sharp decrease in waste generation in 2022–2023 results from a full-scale war (less production, logistics, and construction). At the same time, waste recovery is also decreasing, from 144.9 million tons in 2010 to 39.3 million tons in 2023. Despite the drop in the total volume, the share of recovered waste is insignificant (~22% in 2023). The volumes of incinerated waste are consistently meagre – within 800–1100 thousand tons per year. This is less than 1% of the total volume, i.e., it can be said confidently that incineration as a disposal method is practically not used. The primary method of waste management in Ukraine today is landfilling. Constantly, over 50% of waste goes to landfills. In 2023, over 60% of the waste will be disposed of by landfilling, which indicates a low level of circularity.

Thus, the problems of applying the circular economy as an innovative development model in combating climate change and sustainable development are our country's high dependence on landfills, insufficient recovery and reuse of waste, and low level of thermal treatment (energy waste is not used). At the same time, all this opens up great potential for developing sorting, recycling, and composting infrastructure and reducing the volume of waste generated through the design of easily repaired/recycled products.

However, one of the main barriers to the innovative development of Ukrainian enterprises is the lack of state financial support for scientific and research institutions and a sufficiently strong base of institutions that control the rational use of innovative capital of enterprises.

Important indicators of the effectiveness of waste management policy are current expenses and capital investments in waste management (Fig. 9)

Figure 9. Current expenses and capital investments on waste management in Ukraine in 2010–2023, thousand UAH



Source: developed by the author based on the data of the [State Statistics Service of Ukraine](#)

Figure 9 shows a vast gap between current expenditure and capital investment in waste management. According to various estimates, the average capital investment required to develop a circular economy was approximately 3% of GDP per year, while in Ukraine, this figure is significantly less than 1% ([European Investment Bank](#)).

A large amount of waste from the destruction of facilities causes damage to the country's territory, pollutes water, soil, and air, and produces greenhouse gas emissions, leading to climate change ([Kolesnichenko, O. 2023](#)). According to the calculations of the [Ministry of Environmental Protection and Natural Resources of Ukraine](#), the amount of damage caused to the country's environment was approximately 2 trillion UAH.

As a result of the war in Ukraine, about 11-12 million tons of destruction waste were generated (excluding destroyed equipment). The Government has approved the Procedure for Handling Waste Generated in Connection with Damage (Destruction) of Buildings and Structures as a Result of Hostilities ([Resolution No. 1073 of the Cabinet of Ministers of Ukraine dated September 27, 2022](#)). Communities are taking out destroyed waste and putting it in temporary storage sites.

According to local government bodies, as of the beginning of 2024, about 600 thousand tons of destruction waste have accumulated in temporary storage sites and landfills in the territory controlled by Ukraine.

According to the [World Bank's](#) Third Rapid Damage and Needs Assessment (RDNA), the total cost of processing demolition waste will be almost \$11 billion (RDNA3, December 2023), ~\$5 billion

(RDNA2, January 2023), and \$3.1 billion (RDNA1, August 2022). Thus, in one and a half years (August 2022 - December 2023), the total cost of waste processing has increased more than threefold.

The key problems of demolition waste management in Ukraine are:

1. Lack of targets: no targets have been set for preparing waste for reuse, recycling, other material recovery, including backfilling; the procedure for their implementation has been approved.
2. Lack of incentives: no practice of selective demolition of buildings and incentives for reuse and recycling of construction and demolition waste has been implemented; low tax on waste disposal, no ban on placing construction waste in landfills; no taxes on primary resources and materials to encourage the use of secondary ones.
3. Low level of regulation: no defined ownership of construction waste (building owner, dismantling contractor, sorting or recycling operator); no pre-demolition audits required; no requirement to develop a waste management plan for dismantling works.
4. Lack of infrastructure: infrastructure for preparation for reuse and recycling of waste is not developed; market for building materials from secondary raw materials is not developed.

Having analyzed pollution indicators and the results of implementing a circular-oriented economic model, it can be stated that the pollution and waste volumes are quite significant. Accordingly, introducing the main mechanisms of a circular-oriented model at the national level is necessary for further economic development.

All this emphasizes the need to implement a new alternative resource and waste management model to balance economic interests, the ecological system and the rational use of nature.

Ukraine is beginning to actively apply modern innovations to increase its productivity and reduce the negative impact on the environment. Some sectors of the economy and enterprises have been implementing the principles of the circular economy in their activities long before the progressiveness, environmental friendliness, economic feasibility, and relevance of this concept were recognized. Given the current circumstances, increasing efforts and drawing attention to these innovative enterprises are important to implement the circular economy principles.

An important component is the need to organize production so that the waste of one becomes a resource for another, minimizing the need for raw materials.

Researching the circular economy model and directions for improving waste management in Ukraine is one of the directions that can solve the problems of secondary use and recycling of waste, and the gradual transition to a circular production model.

In addition, studies show that thoughtful green spending can counteract the environmental crises caused by climate change and pollution while providing social benefits. Green innovation's primary focus is minimizing the negative impact of production and consumption activities on the environment.

This can be achieved through the use of renewable energy sources. In addition, reusing and recycling materials and product elements reduces the need for additional resources and production processes. Implementing the circular economy model also saves material resources due to a longer product life cycle. Thus, fewer additional resources will be required to ensure the national economy.

The implementation of circular economy methods in Ukraine is accompanied by several features and obstacles that complicate the transition to a renewable type of production. One of the main reasons is the opacity of the secondary raw materials market, where more than 50% of the volumes are in the shadows. In addition, the market for recycling and waste-free technologies, particularly innovative ones, is at the initial stage of development. Another negative factor is the lack of tariffs for recycling secondary resources. There are 6.5 thousand authorized landfills in Ukraine, of which 25% do not meet environmental standards, and 35 thousand natural landfills.

For the effective development of the circular economy, it is necessary to adopt relevant regulatory legal acts at the state's top leadership level. The beginning has already been made - the Cabinet of Ministers of Ukraine adopted the Resolution of 25.04.2018 No. 313 "On the establishment of the Co-

ordination Council on the implementation of the National Waste Management Strategy in Ukraine until 2030” and approved the [National Waste Management Strategy in Ukraine until 2030](#).

The insufficient development of the circular economy in Ukraine is due to the ongoing unprovoked and unjustified aggressive war of Russia against Ukraine, the imperfection of the institutional environment, and insufficient business motivation. The implementation of the principles of the circular economy in Ukraine requires a systemic and comprehensive restructuring based on the legislative framework, the introduction of innovative technologies, the digitalization of production and trade processes, the financing of environmental initiatives, the stimulation of innovative eco-friendly business models, the formation of environmental awareness in society and the formation of the habit of broader use of sustainable products and the creation of new ways of interaction between producers and consumers, the stimulation of the emergence and development of innovative professions. Ukraine’s faster adaptation to the requirements of the CEAP can be realized by joining the Global Alliance for the Circular Economy (GAERCE) in matters of bringing the functioning of the national economy closer to the principles of circularity; supporting the transition of businesses to circular models of work, through cooperation and interaction with international initiatives similar to SWITCH to Green; closer cooperation with the EU on circular economy issues; harmonization of several directives and strategies and waste reduction.

4.3. SWOT ANALYSIS OF THE IMPLEMENTATION OF CIRCULARIZATION OF PRODUCTION PROCESSES IN UKRAINE

With systematic state measures for deregulation, stimulation of eco-innovation and harmonization of domestic legislation with European standards, implementing the circular economy principles can significantly optimize resource flows, minimize the negative impact on the environment and strengthen the competitiveness of Ukrainian industry.

The SWOT analysis shows that despite several problems and threats, Ukraine has a relatively favourable basis for developing and gradually implementing the circular economy model, provided that the existing strengths and opportunities are carefully considered (Fig. 10).

Analysis of potential benefits from Ukraine’s transition to a circular production model in different time horizons allows us to identify several important environmental and economic effects:

- saving money on waste disposal by involving it in production cycles as secondary raw materials;
- creating new jobs in the recycling, repair, and remanufacturing sectors;
- reducing greenhouse gas emissions from waste processing compared to landfilling;
- improving the environmental image of domestic companies in foreign markets;
- saving money on the import of primary raw materials due to the use of secondary resources, etc. ([Hakhovych at all, 2020](#); [Hurochkina & Budzyska, 2020](#)).

In addition to direct economic benefits, the transition to circular production models will have important positive externalities for the environment and society. This includes protecting and restoring ecosystems, preserving biodiversity, minimizing pollution, and improving the population’s quality of life.

Realizing the circular economy potential will allow Ukraine to make significant progress towards sustainable development, strengthen economic and resource security, gain competitive advantages in external markets, and ensure the harmonious coexistence of society and nature.

The importance of circular economy principles for achieving sustainable development goals cannot be overstated. As Ukraine seeks to rebuild and develop its economy in the post-war period, implementing a circular economy can be important in promoting sustainability, resource efficiency, and environmental protection. By adhering to the principles and goals of a circular economy, Ukraine can adapt its economic strategies to promote long-term sustainability and address pressing issues such as waste management and resource scarcity. This transition to a circular economy can lay the foundation for Ukraine’s more resilient, resource-efficient, and sustainable economic future.

Addressing resource scarcity is critical to economic development, especially in the post-war period when recovery efforts require effective resource management. The circular economy represents a strategic approach to mitigating resource scarcity by promoting reuse, recycling, and repurposing of materials. In Ukraine, implementing circular economy principles can help mitigate resource constraints by maximizing the value derived from existing resources and reducing waste generation. By adopting a circular economy system, Ukraine can increase resource efficiency, minimize dependence on external resources, and build a more resilient economy capable of sustainable growth.

Figur 10. SWOT analysis of the implementation of circularization of production processes in Ukraine

Strengths - High potential for resource conservation and circular business models in resource-intensive industries (metallurgy, chemical industry, agro-industrial complex). - Availability of significant volumes of industrial and agricultural waste that can be used as secondary raw materials. - Possibility of attracting foreign investment and transfer of advanced circular technologies in the event of systemic reforms. - Potential for developing the processing and recycling industry and creating new "green" jobs. - Growing environmental awareness of society and interest in the principles of sustainable development.	Weaknesses - Imperfect regulatory framework, lack of clear incentives for implementing circular practices. - Lack of investment resources and state funding for "green" initiatives. - Outdated waste management infrastructure, dominance of landfill. - Low level of corporate social responsibility of business and "green" thinking. - Lack of qualified personnel and educational programs on the circular economy.
Opportunities - Harmonization of legislation with European standards and directives in the field of circular economy. - Development of public-private partnerships for the implementation of circular projects. - Using the opportunities of industrial and agrosymbiosis to create regional closed cycles. - Export of circular products and services to Western markets in case of sufficient quality and competitiveness. - International technical assistance, grants and soft loans for circular initiatives. - Strengthening the country's energy and resource independence.	Threats - Delays in waste management reform and lack of political will. - Possible resistance from linear business models due to a lack of understanding of a circular approach's benefits. - Lack of skilled labour and "brain drain" in case of insufficient support for circular initiatives. - Economic and political instability, risk of devaluation of investments in circular projects. - Unpreparedness of society for a radical change in consumption habits and worldview. - Lobbying for the status quo by some industrial and financial players.

Source: developed by the author

One of the key benefits of implementing a circular economy model in post-war Ukraine is to stimulate innovation and entrepreneurship.

5. CONCLUSIONS

This study highlights the strategic relevance of transitioning to a circular economy (CE) in Ukraine as a key pathway toward sustainable development, climate resilience, and post-war recovery. The analysis reveals a statistically significant decoupling between GDP growth and air emissions over the period 2010–2023, indicating that economic advancement is not inherently linked to environmental degradation. However, the reduction in emissions during recent years was largely driven by wartime industrial decline rather than systemic implementation of circular practices.

The research further identifies critical weaknesses in Ukraine's waste management system, including overreliance on landfilling, low recycling rates, and insufficient capital investment in circular infrastructure. Case studies at both macro and micro levels demonstrate the potential for circular transformation but also expose gaps in policy, funding, regulation, and institutional capacity.

Despite the current challenges, Ukraine possesses notable sectoral potential - particularly in metallurgy, construction, chemical processing, and the agro-industrial complex - to adopt circular economy principles. Strengthening regulatory frameworks, scaling up innovation ecosystems, enhancing environmental governance, and fostering public-private partnerships will be essential to accelerate this transition.

The findings underscore the urgency of integrating circular economy models into Ukraine's national recovery strategy. Doing so will not only support environmental restoration and economic revitalization but also align Ukraine more closely with EU standards and global sustainability objectives. Continued research, policy reform, and coordinated stakeholder action are needed to unlock the full potential of circularity in shaping Ukraine's resilient, low-carbon, and resource-efficient future.

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IMPLEMENTATION OF SMART IOT TECHNOLOGIES ON THE BULGARIAN MARKET - AN INNOVATIVE APPROACH FOR ECONOMIC SUSTAINABILITY AND ENVIRONMENTAL BENEFITS

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ABSTRACT

The article presents opportunities for implementing an innovative entrepreneurial model, based on IoT technologies in the context of the Bulgarian urban environment. The focus is on “smart poles” that use existing urban infrastructure (street lighting), additionally equipped with smart modules and sensors. The presented approach considers economic sustainability and environmental benefits such as reducing energy costs, optimizing urban processes and creating new opportunities for entrepreneurial activity, without significant initial investments in new infrastructure.

The article examines in detail the theoretical context of IoT technologies and the specifics of the Bulgarian market, and highlights the potential economic benefits, improved efficiency in infrastructure management and opportunities for new business models. Environmental benefits include a significant reduction in carbon footprint, optimization of energy and resource consumption.

Key potential customer segments have been identified, including city administrations, public and private organizations responsible for infrastructure and utility management, smart building companies, utility providers, and private technology entrepreneurs. The proposed model is distinguished by its flexibility, making it suitable for both large urban municipalities and smaller settlements striving for sustainable development.

An empirical study is proposed, including a quantitative method, which aims to assess market needs, readiness for technology adoption, and expected benefits.

The scientific novelty of the study lies in the development of an entrepreneurial IoT business model adapted for Bulgaria, which provides concrete solutions for sustainable urban development and economic improvement, while at the same time addressing current global environmental challenges.

Keywords: *Internet of Things (IoT) Business Model, Smart city infrastructure, Sustainable urban development*

1. INTRODUCTION

Urbanization is a global phenomenon that also affects Bulgaria, with nearly 77% of the country's population living in urban areas. This process leads to population concentration, which poses serious environmental and economic challenges. Among the most significant of these are air pollution, high energy costs, difficulties in mobility and insufficient efficiency in managing urban resources and infrastructure. These problems have a negative impact on the quality of life of the residents and the sustainable development of cities.

The aim of this article is to present an innovative entrepreneurial model based on the Internet of Things (IoT), with a focus on the implementation of the so-called “smart poles”. These intelligent

solutions use the existing urban infrastructure by equipping it with modules and sensors to improve energy efficiency, optimize traffic flows and monitor air quality. The working hypothesis of the study is that the integration of the IoT technologies into urban infrastructure not only improves the economic sustainability by reducing operational costs, but also contributes significantly reducing the ecological footprint, providing long-term benefits for society and the business. The article will examine theoretical propositions and empirical evidence supporting this hypothesis.

1.1. THEORETICAL FRAMEWORK AND LITERATURE REVIEW OF IOT TECHNOLOGY, SMART CITIES AND BUSINESS MODELS IN THE CONTEXT OF IOT

1.1.1. ESSENCE AND APPLICATION OF IOT TECHNOLOGIES

The Internet of Things (IoT) refers to a complex ecosystem where physical devices embedded with sensors, communication modules, and intelligent software interact via internet, creating a data-driven environment capable of autonomous decision-making and optimization (Gubbi et al., 2013). The foundational elements of IoT include hardware sensors, wireless networks, data processors, and automation platforms.

Within urban areas, the implementation of IoT can transform public services and infrastructure by enabling solutions such as adaptive traffic management, real-time environmental monitoring, smart lighting, and automated public safety systems (Zanella et al., 2014). For instance, “smart poles” – streetlight structures equipped with sensors and communication devices – offer functionalities such as pollution monitoring, emergency communication, and surveillance integration. These systems often rely on existing urban infrastructure, reducing capital investment requirements and accelerating deployment.

In Bulgaria, one of the most promising IoT technologies is the concept of “smart poles”, representing modernized street lighting poles equipped with intelligent modules and sensors. They provide opportunities for energy-efficient lighting, monitoring of air quality, traffic and weather conditions, as well as integration of safety systems such as video surveillance and SOS buttons for emergencies (Kakizhanova et al., 2025). The advantage of this technology is that it is based on existing infrastructure, which significantly reduces the need for initial investments in new urban infrastructure.

Urban areas globally consume nearly 60% of the world’s energy and produce over 70% of greenhouse gas emissions, making them prime candidates for IoT-enabled sustainability strategies (Cocchia, 2014). By leveraging sensor data, municipalities can optimize traffic flow, monitor environmental changes, and automate public utilities for greater efficiency and reduced ecological footprint.

The benefits of implementing IoT technologies are multifaceted: reduced operating costs for electricity and maintenance, increased efficiency of urban services and infrastructure management, creation of new entrepreneurial opportunities and business models, as well as a significant improvement in environmental sustainability and the quality of life of the urban population. Thus, the implementation of IoT solutions can provide significant added value for both the public and private sectors, becoming an important driver for the development of modern smart cities in Bulgaria.

1.1.2. IOT AND SMART CITIES

Smart cities rely heavily on digital transformation strategies where IoT technologies are deployed to optimize resource management, increase citizen engagement, and support environmental sustainability. Core elements include data-driven governance, real-time service delivery, and automated infrastructure control (Bibri, 2021).

Smart poles serve as a key example of this transformation (Priambodo et al., 2025). Modernized or newly constructed lighting poles with integrated technology can support urban monitoring systems, traffic management, wireless coverage, and environmental sensing - all while using pre-existing urban installations (Zanella et al., 2014).

Notably, global cities such as Barcelona and Amsterdam have successfully integrated IoT solutions to enhance urban mobility and energy management. In Barcelona, intelligent lighting and traffic control have led to measurable efficiency gains, while Amsterdam’s smart transport infrastructure has significantly improved air quality and congestion management (Cocchia, 2014).

In the Bulgarian context, the introduction of IoT solutions such as “smart poles” has the potential to achieve similar results, solving the specific environmental and economic challenges associated with the urbanization. The proposed technology allows for effective data collection and analysis, which in turn helps to make informed management decisions in the field of urban mobility, environmental management and public safety. This provides real opportunities for Bulgarian cities to significantly improve their economic, social and environmental indicators, becoming more attractive, both for living and for business and investment.

1.1.3. ENTREPRENEURSHIP AND BUSINESS MODELS IN THE CONTEXT OF IOT

IoT fosters innovation in entrepreneurial ecosystems through multiple business models — product-centric, service-based, platform-oriented, and data-driven approaches (Westerlund & Rajala, 2014). For example, product innovation in IoT includes developing devices such as air quality sensors and smart surveillance units. Cities can modernize existing streetlight infrastructure with these technologies, transforming them into multifunctional “smart poles” with minimal additional investment.

Smart poles benefit from proximity to roads, existing power sources, and wide urban distribution. By embedding IoT components into these structures, municipalities gain access to real-time data on traffic, weather, noise, and pollution - useful for both immediate urban operations and long-term planning.

Such platforms may include 5G or Wi-Fi hotspots, CCTV systems, emergency alert buttons, EV charging points, and digital displays. Their modular design allows for scaling and adaptability based on specific urban needs.

In terms of monetization, municipalities or businesses can adopt one-time purchase models, subscription services for infrastructure management, or data commercialization strategies (Westerlund & Rajala, 2014). In Bulgaria, such monetization strategies can be tailored to local governance and market dynamics to foster sustainable entrepreneurship.

In the Bulgarian context, applicable monetization mechanisms include:

- Platform model, in which municipalities or organizations purchase hardware and software for “smart poles” once and manage the platform with their own resources.
- Subscription service model, in which the provider offers comprehensive infrastructure support, with the client paying a regular fee for operation, monitoring and maintenance.
- Monetization through the sale of anonymous data collected by the IoT devices, which can be used for urban planning, marketing analyses or scientific research.

In the case of “smart poles”, the possibility of generating revenue from both the sale of the IoT devices and infrastructure themselves and the provision of cloud services for management and maintenance of the infrastructure, with monthly or annual subscription models, is being considered.

This spectrum of innovation opportunities and monetization models provides significant potential for entrepreneurship development and economic growth, especially when these models are adapted to the specific needs and conditions of the Bulgarian market.

2. RESEARCH METHODOLOGY

2.1. RESEARCH APPROACH AND DESIGN

This research utilized a quantitative approach, employing structured surveys directed at municipal administrations and potential business partners. Results were analysed using statistical methods to interpret numerical data and uncover patterns, relationships, or trends with data visualization charts. The survey was conducted online, through the “Google Forms” platform to collect direct responses and opinions from participants working in state/municipal institutions and a few people, engaged in private sector serving large facilities that could be interested from the “smart pole” platform. For this purpose, a questionnaire including 39 questions was developed, 134 respondents took part in filling out the survey. The core objective was to explore awareness, expectations, and the level of preparedness regarding the adoption of IoT technologies and “smart pole” platforms in Bulgaria’s urban environment. The questionnaire included various segments: understanding of IoT and smart

poles; anticipated societal and economic benefits such as cost savings and pollution reduction; infrastructure readiness, workforce capacity, and data governance (Westerlund and Rajala 2014).

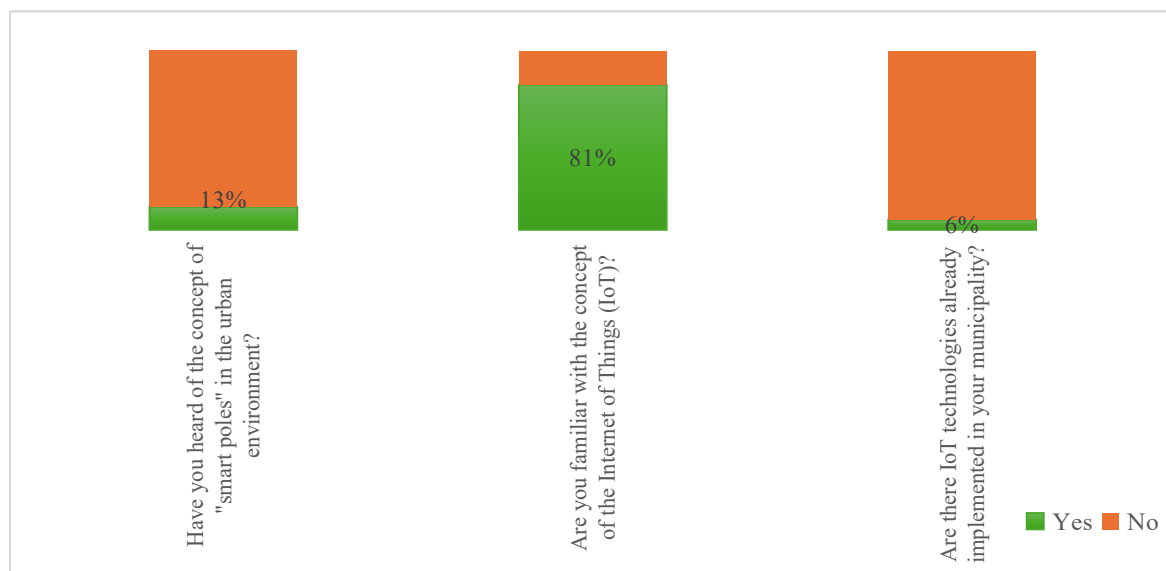
Respondents were prompted to evaluate economic and environmental implications, identify driving motivations for implementation, and suggest potential public-private collaboration strategies. The survey also integrated demographic profiling to contextualize the insights and trends observed across different stakeholder groups. Some of the more interesting results of the study are presented below.

2.2. ANALYSIS AND INTERPRETATION OF DATA

The survey responses reflected region-specific characteristics and revealed limited awareness of the smart pole concept, despite the general familiarity with IoT. This represents both a challenge and an opportunity - awareness campaigns could facilitate broader adoption. As seen in the responses, participants recognized the advantages of the proposed system in reducing energy consumption, enhancing urban planning, and supporting local economies (Zanella et al. 2014).

In “General Questions and Awareness” answers we can see that majority of the participants are familiar with the IoT technology but not with the “smart pole” concept. This can be a challenge and will need additional effort to build awareness, but at the same time adoption of IoT technology is very low and this can be considered as and good opportunity to grow the demand.

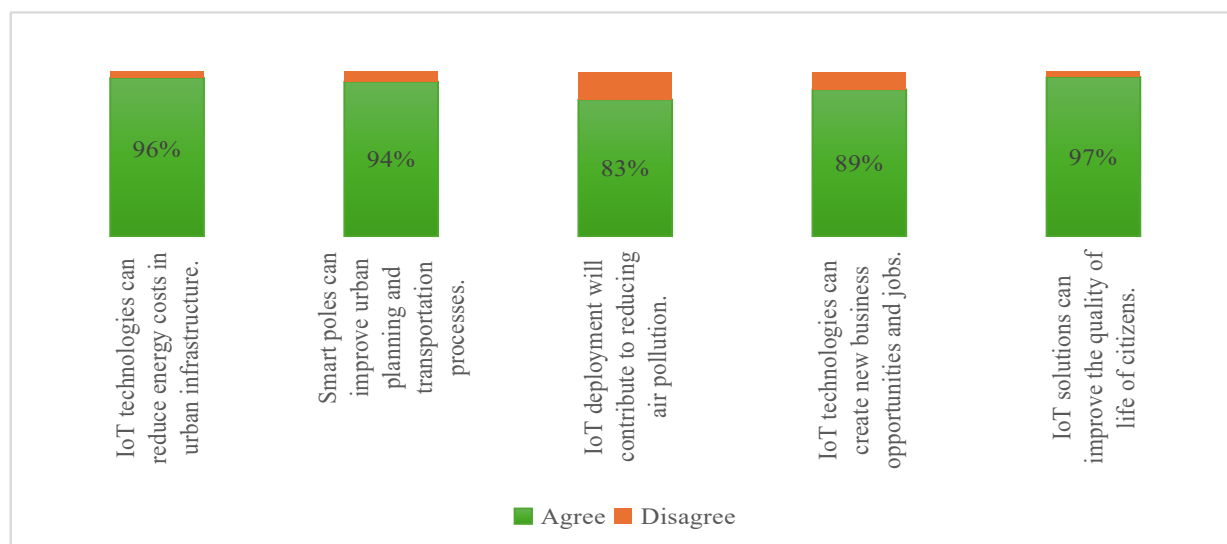
Figure 1. General Questions and Awareness



Source: Created by the author

“Potential benefits” answers (figure 2) clearly shows that the IoT and “smart poles” platform can bring significant advantages to the entire urban ecosystem like reducing energy costs, improving planning and traffic flows, reducing air pollution, and at the same time create new jobs and business opportunities. All these combined will improve the quality of life.

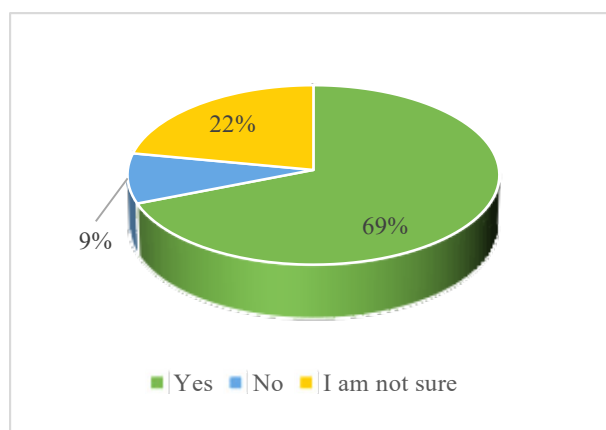
Figure 2. General Questions and Awareness



Source: Created by the author

In the “Assessment of needs and market interest” and “Are you interested in implementing smart poles in your municipality/organization?” questions we received positive answer from 2/3 from the participants. There is also not a small group of people that cannot decide.

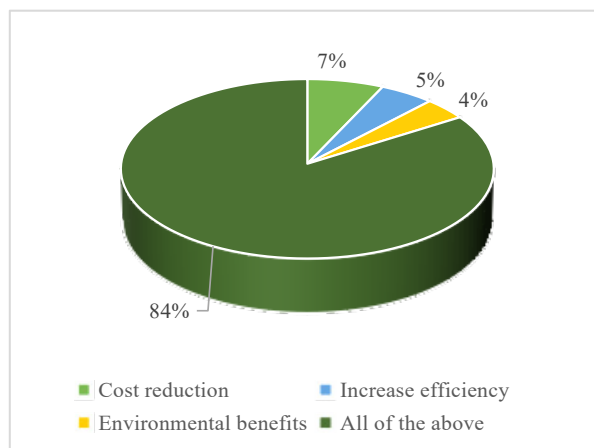
Figure 3. Are you interested in implementing smart poles in your municipality/organization?



Source: Created by the author

On the “What is the main factor that would motivate you to implement IoT?” question, most of the participants expressed opinion that implementing and using IoT technologies will be driven by multiple factors related to cost reduction, increase efficiency and environmental benefits.

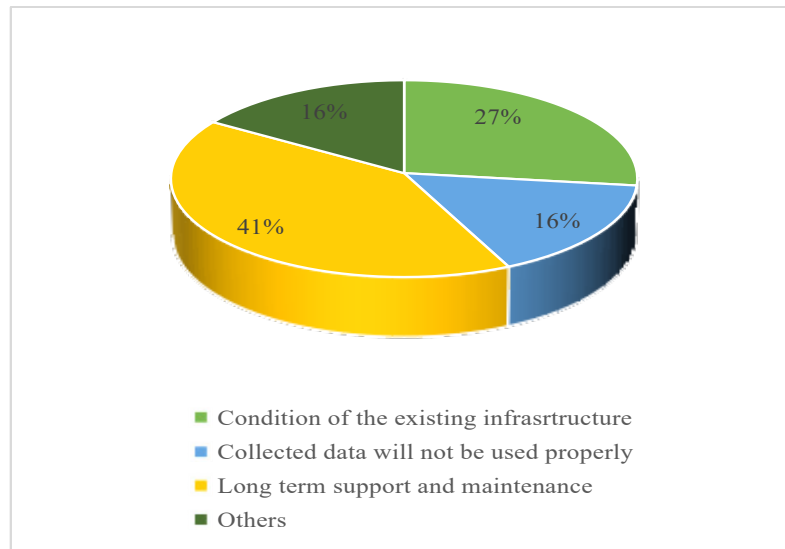
Figure 4. What is the main factor that would motivate you to implement IoT?



Source: Created by the author

In the “Technological aspects and challenges” and “What are the main technological barriers you see to the implementation of smart poles?” questions worth to mention the top 3 answers. Participants identified as the main hurdle the long term support and maintenance, and this is a valid concern. Very often in Bulgaria there are great initiatives completed and after some time left unattended without proper maintenance. Will need to put special attention on this topic in the “smart pole” service with at least 5 years operational time where maintenance will be incorporated. The other two challenges are also important and should not be neglected – how the collected data will be used (whether will be used at all) and the condition of the existing infrastructure that in most of the cases is old and not serviced regularly.

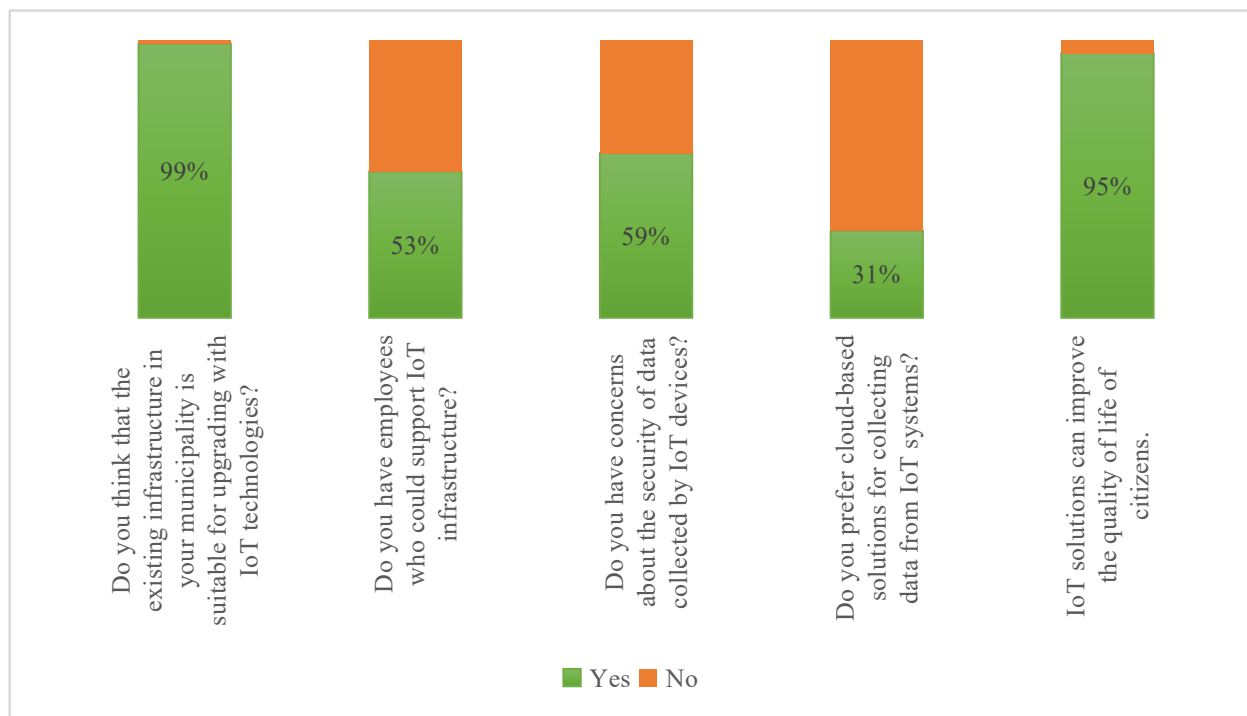
Figure 5. What are the main technological barriers you see to the implementation of “smart poles”?



Source: Created by the author

In the other questions from the “Technological aspects and challenges” section we received the following answers, stating challenges with the availability of trained people to support IoT infrastructure, data security and using the public clouds to host the service. While the struggle with the prepared people can be relatively easily resolved, with additional specialized trainings or outsourcing to 3th party vendors, the security of the data will need special attention. Security in the IoT infrastructure is always a challenge due to the need of a distributed sensor architecture. Security is also not cheap so we need to find the right balance. “smart pole” platform relies on security industry standards/protocols and best practices that are followed to guarantee acceptable security level. Also regular updates are considered to prevent vulnerabilities. Related to concerns with the usage of public clouds we can always use on-prem infrastructure but this will be more expensive to be setup and maintained.

Figure 6. Technological aspects and challenges



Source: Created by the author

Approximately two-thirds of respondents expressed interest in implementing smart poles, though a notable portion remained undecided. Cost efficiency, service automation, and environmental sustainability were highlighted as key motivators. However, long-term maintenance, underdeveloped infrastructure, and data utilization remain significant concerns.

The study also exposed challenges related to the availability of trained personnel and the reliability of public cloud infrastructures. While workforce limitations could be mitigated via specialized training or outsourcing, ensuring robust data protection requires adherence to recognized security standards and continuous system updates (Bibri 2021).

Based on the data collected from the survey, we can draw the following conclusions and recommendations regarding the market readiness for adoption of the IoT technologies and “smart” pole platform:

- Bulgarian market has good potential for adopting new IoT technologies and “smart pole” platform.
- Building more awareness on the “smart” pole concept – platform and service will be needed. Having the first reference customer implementation will be a key milestone.
- Addressing technological challenges is essential for the success of the platform adoption with focus on security, data processing and work force readiness.
- Initially need to focus more on marketing and platform potential benefits with priority on service and long-term relationship – working as partners with customers.
- Utilizing EU funding

Overall, the results emphasize the Bulgarian market’s receptiveness to IoT adoption, contingent upon enhanced awareness, structured support for infrastructure upgrades, and targeted communication of long-term benefits. EU funding may serve as a critical enabler for initial deployments and cross-sector partnerships.

3. RESEARCH RESULTS AND BUSINESS MODEL

3.1. ENVIRONMENTAL BENEFITS: REDUCTION OF CARBON FOOTPRINT. IMPROVEMENT OF AIR QUALITY AND OPTIMIZATION OF RESOURCES.

The implementation of a “smart pole” platform provides significant environmental opportunities aligned with the ESG (Environmental, Social, and Governance) frameworks. From an environmental standpoint, reducing carbon emissions and energy consumption are priorities, but additional attention must also be given to the full lifecycle impact of the platform - from production and deployment to maintenance and recycling (Bibri 2021).

IoT devices are designed for low energy consumption, utilizing energy-efficient SoCs (System-on-Chip) and LED-based lighting systems with adaptive control. Integrating renewable energy sources such as solar panels may further decrease reliance on grid electricity, albeit with implications for lifecycle carbon footprint. Data centers powering platform operations also contribute to the total energy use and must be factored into environmental assessments.

The adoption of OTA (Over-the-Air) software updates extends device usability, supporting sustainability goals. Hardware end-of-life must comply with EU regulations, including Directive 2012/19/EU and Bulgaria’s Waste Management Act.

Smart poles, constructed with recyclable metals, enhance urban sustainability through energy savings, emissions reductions, and improved public service efficiency. By collecting real-time data, municipalities can optimize traffic, public safety, and urban planning, thereby enhancing residents’ quality of life while creating entrepreneurial opportunities.

The use of the “smart pole” platform will lead to the improvement of urban infrastructure, reduction of carbon footprint, increase of energy efficiency, as well as save time, public resources and reduction in environmental pollution. With the help of the collected data, the city administration will be able to make informed decisions about limiting pollution, optimizing transport flows, including public transport, and generally improving the quality of life of the residents. The “smart pole” platform will also bring economic benefits and increased business opportunities with the creation and use of various software applications for the end users. As an example, we can point to an application that shows in real time the free parking slots in a given urban area or street(s). This will save time (no need to drive around, looking for a parking space), reduce pollution (less traffic), as well as improve health and safety for both residents and travelers. Also, the data collected by the platform can be used to create new products and services or to sell anonymized data to third parties for various purposes.

3.2. MARKET ANALYSIS AND KEY STAKEHOLDERS IN BULGARIA

Bulgaria’s IoT market is poised for steady expansion through 2030, driven by technological advancement, increased sectoral adoption, and favourable policy frameworks. Major contributing segments include hardware components (sensors, processors), software platforms (data analytics, monitoring, security), and managed services (Zanella et al. 2014).

As the main trend, we can define the stable growth of the IoT devices in Bulgaria. The number of connected IoT devices continues to grow, with a significant increase expected in the coming years. Technologies such as LPWAN (Low-Power Wide-Area Network) and LEO (Low Earth Orbit) satellite communications will play an important role in the development of the market. Dominant technologies such as Wi-Fi, Bluetooth, and cellular IoT connections are the main that drive the market today, but this could change in the near future. The adoption of new standards such as Wi-Fi6/Wi-Fi6E also improves the efficiency and reliability of the IoT communications that can influence the market. There are a few components that play a key role to the IoT market:

- IoT components. Include processors, connectivity integrated circuits, memory, sensors, and logic devices. The demand for these components is due to their critical role in the overall functioning of the IoT devices. There is no local production in Bulgaria, and almost all significant global vendors are represented and components are available for local ordering.
- Software solutions. The IoT software solutions market in Bulgaria is segmented into data management, real-time streaming analytics, network bandwidth management, remote monitor-

ing, and security solutions. These solutions are essential for managing and protecting the vast amounts of data generated by IoT devices. In the last years Bulgaria is positioned as an IT hub in Europe with many, well prepared and skilled software developers. From one side this is good if you want to create new software solutions but makes very strong competition and at the same time is very challenging if you want to get significant market share.

- **Platforms.** IoT platforms in Bulgaria are categorized into device management, application management, and network management, providing the necessary infrastructure for the implementation and maintenance of IoT applications.
- **Services.** Professional and managed services are vital for the implementation and ongoing operation and maintenance of the IoT systems, ensuring that businesses can effectively use IoT technologies.

3.3. MARKET SEGMENTATION

IoT applications are widely adopted in various sectors, such as: ([Lasse Lueth](#))

- **Healthcare.** The implementation of IoT in healthcare improves patient monitoring and improves the efficiency of healthcare services.
- **Automobiles and transport.** IoT is fundamental to the advancement of intelligent transport systems and automotive innovation.
- **Building and construction automation.** IoT solutions are used to optimize energy consumption, improve security in the buildings, reduce operating costs, and improve productivity. Smart sensors and RFID tags help identify potential risks and optimize resources.
- **Production.** Smart manufacturing processes are driven by the IoT technologies, increasing production efficiency and reducing costs.
- **Retail.** IoT is transforming the retail sector through improved inventory management and personalized customer experience.
- **Agriculture.** Smart farming solutions help increase agricultural productivity and sustainability.
- **Energy.** IoT solutions help monitor and manage energy resources, resulting in more efficient energy use and reduced carbon dioxide emissions.

3.3.1. COMPETITIVE ENVIRONMENT AND CHALLENGES

The Bulgarian IoT market is competitive, with several key players contributing to its growth. These companies focus on technical and operational benchmarking to stay ahead in the market. Strategic recommendations include investing in research and development, expanding the offered services, and increasing customer engagement to maintain a competitive advantage. IoT market in Bulgaria provides many opportunities, especially in the fields of smart manufacturing, smart transportation, smart energy, and connected healthcare. Some of the companies in Bulgaria that are actively developing IoT solutions are listed below.

- **“A1 Bulgaria”** - A1 is the first telecom in Bulgaria that offers mobile Narrowband-IoT (NB-IoT) solutions. The company have multiple projects, including water consumption monitoring, waste management, smart city lighting, and smart parking. ([A1](#))
- **“Smart IT”** - MFG’s technology hub, Smart IT, is working on various IoT projects, including the development of software products in a variety of fields. These projects include features such as remote access and control of various sensors and devices. ([SmartIT](#))
- **“Techno Logica”** - This company has many years of experience in the IT sector and works on projects and solutions aimed at Bulgarian society and economy. ([TechnoLogica](#))
- **“DataArt”** - With own inovative project, they won an award in the category “Internet of Things Smart City” at the IoT Adventure Awards. The project includes smart elevators that use IoT technologies to improve efficiency and safety. ([DataArt](#))
- **“Devision”** - This company develops cloud-based IoT software for a leading international company in the field of smart home & building automation. Projects include intelligent management of private homes and business buildings. ([Devision](#))

It is also worth mentioning some successful startups that are developing innovations in the field of the IoT:

- “Melissa Climate” - This company is known for its smart home climate management solutions. They offer devices that allow remote control of air conditioners and other appliances through a mobile application. ([Mclimate](#))
- “Shelly” - Known for their Shelly products, which include smart relays and sensors for home automation. Their devices are popular both in Bulgaria and on the international market. ([Shelly](#))
- “Develiot” - Develops IoT solutions for air and water quality monitoring. Their products are used to collect real-time data and provide analytics to improve the environment. ([Develiot](#))
- “Bosch Startup Harbour” - The Bosch.IO program in Bulgaria supports numerous startups, including Efemarai and QuarkXR, that work in the field of machine learning and augmented virtual reality. ([Bosch-digital](#))

These companies demonstrate how Bulgarian companies can be innovative and compete on the Bulgarian and international markets. Overall, the IoT market in Bulgaria is set for significant growth, driven by technological advancements and growing adoption in various sectors. Businesses and stakeholders need to focus on innovation and strategic planning to harness the full potential of the IoT in Bulgaria.

3.3.2. IOT TECHNOLOGY MARKET - REVENUE AND VOLUME

The revenue in the Internet of Things market in Bulgaria is projected to reach \$764.31 million in 2025 where the automotive IoT sector dominates the market with a projected market volume of \$206.17 million in 2025. It is expected that the revenue will show an annual growth rate (CAGR 2025-2029) of 9.06%, resulting in a market volume of \$1.08 billion by 2029. Bulgaria is emerging as a key player in the Internet of Things market with its growing number of tech startups specializing in IoT solutions. ([IoT Bulgaria](#))

Significant growth is expected also across various segments with expected Consumer IoT projected to reach \$169.85 million in 2025, with a compound annual growth rate (CAGR) of 8.30% from 2025 to 2029 ([Consumer IoT](#)). Smart Cities expected to generate \$56.54 million in revenue by 2025, growing at a CAGR of 8.46% from 2025 to 2029 ([Smart Cities](#)) and other IoT segments anticipated to reach \$9.03 million by 2025, with an annual growth rate of 11.39% from 2025 to 2029. Overall IoT market volume in Bulgaria is also expanding rapidly and is expected to reach \$684.40 million in 2024 and rise to \$1,081 million by 2029, with an annual growth rate of 9.57%. ([Other IoT](#))

The growth is driven mainly by the proliferation of smart devices, sensors, and connected appliances. Along with devices, the market for IoT platforms and services is expanding rapidly. Companies are investing in platforms that offer device management, analytics, and security solutions that are essential for managing the growing volume of IoT devices. Improvements in connectivity (such as 5G), data analytics, and AI enable more complex IoT applications, which in turn are driving market growth.

The IoT market in Bulgaria is experiencing increasing growth, both in terms of revenue and the number of connected devices. The expansion of the market is supported by technological advancements and growing adoption in various sectors. The positive outlook implies continued investment and innovation in IoT technologies in the coming years.

3.3.3. KEY CUSTOMER AUDIENCE

Determining the key customer audience for IoT products and the “smart poles” in this case is a key step for the successful implementation and marketing. We need to perform the following steps: demographic analysis, psychographic analysis, creation of user personas, market segmentation, competition research and feedback collection.

Due to the specifics of our platform/product/service, we have a specific, strictly limited target audience – state/municipal institutions, such as direct end users/clients or we can work with partners enabled to deliver the platform to their end customers. In limited cases, customers can be also private organizations or private companies serving facilities for public events, private parking lots, large factories, smart buildings or similar. We will focus only on competition research and collecting

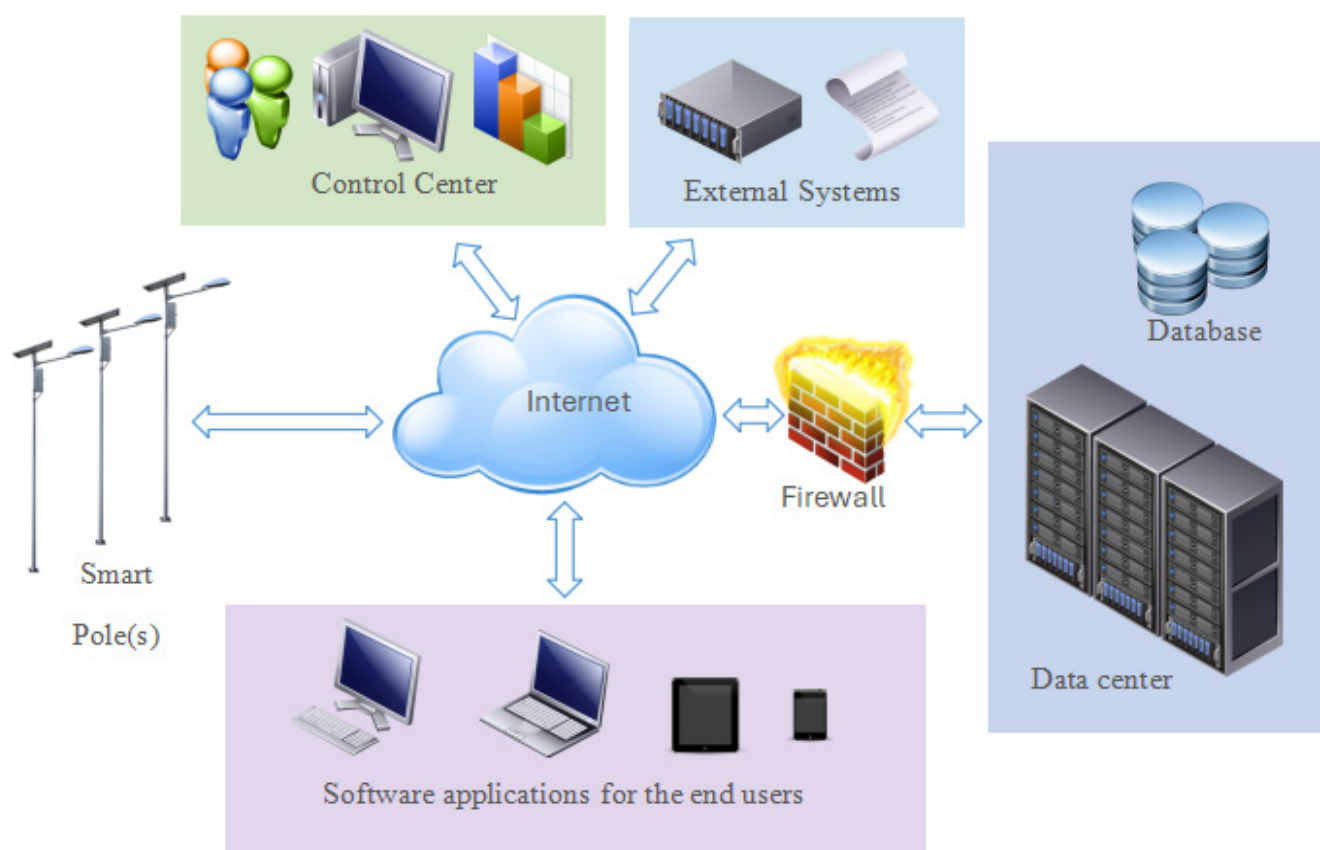
feedback and conducting surveys, interviews with our target audience to get direct feedback from our potential customers.

3.4. SMART POLE TECHNICAL ARCHITECTURE AND BUSINESS MODEL

3.4.1. TECHNICAL IMPLEMENTATION

The “smart pole” ecosystem is composed of five integrated subsystems: physical infrastructure, centralized data center, operational control center, external system interfaces, and user-facing applications. Each pole is equipped with modular components including sensors for air quality, lighting, traffic monitoring, and emergency communication (Figure 7).

Figure 7. Smart pole platform architecture



Source: Created by the author

Table 1 presents the key smart pole modules.

Table 1. Key Smart Pole Modules

Module	Main Function
Control Module	Manages all pole functions and modules; supports communication and system health monitoring
Communication Module	Connects the pole with the data center via WiFi, 4G/5G, or LoRAWAN
Power Supply Module	Supplies electricity to all modules and monitors power consumption
Lighting Module	Automatically and remotely controls street lighting based on ambient light or schedule
Audio Module	Plays preloaded audio messages for emergencies, public info, or ads
Video Module	AI-enabled cameras for surveillance, object counting, parking management, and license plate recognition
Display Module	Displays video messages or ads using various types of screens
Meteorological Module	Measures temperature, humidity, pressure, and optionally wind speed
Air Quality Module	Monitors air pollution levels; visualized via color indicators or digital display
SOS Module	Emergency button for immediate audio connection to the Control Center

Source: Created by the author

The data center aggregates and processes information through a secure, scalable architecture that can be hosted on public clouds (AWS, Azure) or private infrastructure. Access to data is governed through custom APIs, ensuring role-based segmentation and data integrity (Gubbi et al. 2013).

The control center provides 24/7 monitoring, lifecycle management, and diagnostics. Through proprietary software, responsible staff can manage assets, respond to incidents, and generate insights. End-user apps deliver urban data (e.g., air quality, free parking spaces) via mobile and web interfaces, enhancing public transparency and civic engagement.

As any other IoT system “Smart pole” platform comply with the General Data Protection Regulation (GDPR) and manage data securely. The platform is designed with privacy and security at its core following the industry’s best practices. Platform is not user centric and will not require collection of personal data. All data collected from the IoT devices will be available and accessed by the users without explicit registration. Users will give clear, informed consent before any personal data is collected (like agreeing to share their current location, for better user experience) and only will collect the data when is strictly necessary for the application(s) to function. Users will be informed what data is being collected and why with the possibility to access, correct, or delete their data, including withdraw consent at any time. Communication between the IoT devices and the data center is encrypted and not accessible eternally. Regular IoT firmware and software updates are considered to avoid vulnerabilities. In cases where public cloud is used partners should be also GDPR compliant. If a data breach occurs, will notify the relevant authority within a predefined period.

3.4.2. MONETIZATION AND BUSINESS MODEL

The “smart pole” platform will be offered in two main models – *as a platform and as a service*. It is possible also to have a combination between the two models, depending on the requirements and needs of the market and the customers. For example, the installation of the poles infrastructure is covered by the customer and the management/maintenance part is covered by the platform vendor. Both models have their advantages.

Smart pole “Platform” model

The customer pays one-time for the delivery of:

“Smart poles” – the price is determined depending on the number and functions of the poles (new or modernized existing poles).

Right of Use, license covering software for “Data Center”, “Control Center”, “External Systems”, “Software Applications for the end users”.

Licensing is based on the number of poles with a predefined step for “Control Center” (100, 200, 500, 1000+ poles), and the license for “Software applications for the end users” is based on application and number of subscribers. The license includes a warranty period (2 years), software updates (1 time per year), limited technical support (software and spare parts supply) during normal business hours, with a predefined response time.

In this model, the client takes over the construction of the entire infrastructure, the installation and management of the software, the provision of the necessary personnel for the operation and maintenance of the system.

Additionally, for a fee, staff training and the opportunity to develop custom functionalities on behalf of the customer (new modules, applications, optimizations, applications for end users, etc.) can be provided.

Smart pole “Service” model

When used as a service, the customer receives the entire platform of “smart poles” (including infrastructure), software, staff for operation and maintenance of the system directly ready for use, paying a subscription annual fee. With this model, customers get more value and more quality for their investment. The minimum term for using the service is 5 years

These hybrid deployment models accommodate different budget cycles and operational capacities, enabling broader adoption of smart urban infrastructure. (Table 2).

Table 2. Monetization and business model comparison

Component	Platform	Service
Smart pole infrastructure – installation & setup	Performed by the client	Included
Infrastructure Software	Provided by the client	Included
Software / Data Center	Licensed per number of poles	Included
Software / Control Center	Licensed per number of poles	Included
Software / External Systems	Licensed per number of clients	Included
Software / End-user applications	Licensed per functional module and number of clients	Included
Smart pole support	Limited. Spare parts during working hours	Full, 24/7
Software support	Limited. Remote assistance during working hours	Full, 24/7
Software updates	Once a year	2+ times a year
Adding new functionalities	Upon request, based on client assignment (charged separately)	Upon request, based on client assignment (charged separately)
Personnel using the platform	Provided by the client	Included
Personnel training	10 people	Not required
Licensing	One-time (perpetual license)	Annual fee

Source: Created by the author

Before the platform becomes operational and stable, the focus will be on the “Service” monetization model and building the first reference customer. For this case “smart pole” platform with 100 smart poles is considered, ready to use with the related software applications. Estimated costs are listed in (Table 3).

Table 3. Estimated cost for building and operationalize “smart pole” platform

Expense Category	Cost Estimate (€)
Initial development and productization (software, IoT modules, practice – installation and maintenance, tests)	200 000 (one time)
Rent & Utilities	3 000 (per month)
Equipment for maintenance staff and developers	15 000 (one time)
Public data center (5 VPS, 1000€ per VPS/year)	5 000 (per year)
Marketing	1 000 (per month)
Staff Salaries and spare part management service	30 000 (per month)
Miscellaneous	2 000 (per month)
Smart poles installation, setup, configuration, acceptance	55 000 (one time)
Maintenance, upgrade, parts replacements	5 500 (per year)
Inflation, salaries adjustments	8000 (per year)
Total:	
Total Startup Cost (for the first year)	712 000 €
Total Yearly Cost (after the first year, one customer)	450 000 €

Source: Author`s calculations

Estimated revenue is calculated based on annual fee for 5 years where the “smart pole” platform is provided ready to use plus additional income from selling anonymized data collected from the IoT devices. At this first stage additional partnerships, 3th party software revenue is not considered due to adding of additional complexity without clear and reliable income predictions. Two customers are considered under the same conditions, and the second customer will be engaged from the second year. Estimated revenue is listed in (Table 4).

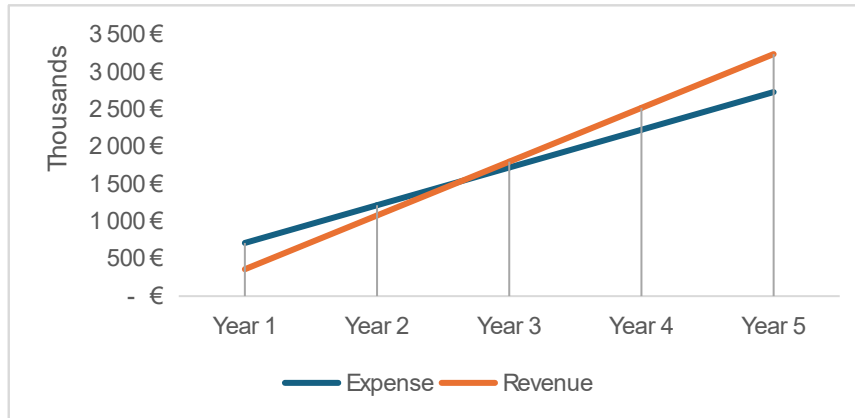
Table 4. Estimated Revenue

Revenue Category	Revenue Estimate (€)
Annual fee for one year (per customer)	350 000 (per year)
Selling anonymized data, collected from the IoT device (per customer)	10 000 (per year)

Source: Author`s calculations

Break-even is in the middle of the 2nd year, when the revenue equals costs. It is vital to have the second customer as early as possible to be sustainable (Figure 8).

Figure 8. Break-even chart



Source: Author`s calculations

Profit margin for the scenario described is 22% and can be considered as decent for some industries, like service-based businesses, retail, and manufacturing. For software companies and specialized consulting firms, usually the target is higher (above 30%). If we can start and operate with 3 customers at the same time under the same conditions, Profit margin will increase to 48%. If our business consistently reaches 15% profit margin, it can be considered as a stable that allows reinvestment.

4. CONCLUSION

The conducted research on the implementation of smart IoT technologies - particularly the concept of “smart poles” - in the Bulgarian urban environment confirms the initial working hypothesis: that the integration of IoT solutions into existing infrastructure contributes not only to economic sustainability by reducing operational costs but also to environmental improvement and long-term urban resilience. The empirical study reveals a substantial readiness and interest in adopting smart city technologies, albeit with certain reservations regarding infrastructure and maintenance.

The analysis clearly demonstrates multiple economic benefits. Among the most cited by respondents were reductions in electricity consumption due to smart lighting control, increased efficiency in urban services, and the creation of new entrepreneurial opportunities through data monetization and platform-based business models. Furthermore, the ability to modernize existing lighting infrastructure without large-scale investment makes the solution both cost-effective and scalable, especially in the context of constrained municipal budgets.

From an environmental perspective, the “smart poles” platform offers significant positive outcomes. These include lower carbon emissions, improved air quality monitoring, and optimization of traffic and energy flows. The modular design, energy-efficient hardware, and integration of renewable energy sources (e.g., solar panels) further reinforce the ecological value of the system. Additionally, the ability to collect and process environmental data in real-time equips city administrations with powerful tools for data-driven governance and sustainable planning.

Despite these advantages, several challenges remain. The research identifies critical barriers such as the lack of trained personnel for the IoT system maintenance, concerns about data privacy and cybersecurity, and the outdated state of much of the existing urban infrastructure. Addressing these obstacles will require a coordinated effort involving public authorities, private technology providers, and

academia. In particular, the establishment of training programs, strategic partnerships, and regulatory frameworks supporting secure and ethical data usage will be crucial for sustainable deployment. The validation of the working hypothesis opens avenues for future research and practical implementation. One promising direction involves the development of specialized pilot projects in mid-sized Bulgarian cities to further evaluate the real-world performance, maintenance demands, and community acceptance of smart poles. These pilot initiatives can serve as testbeds for innovation, generating valuable feedback for optimizing both the technology and business model. Additionally, longitudinal studies are recommended to monitor the environmental and socio-economic impact of IoT adoption over time. Another future research direction lies in the expansion of the IoT platform's functionalities through integration with artificial intelligence (AI) and machine learning (ML). Predictive analytics could enhance the value of collected data, supporting advanced urban planning scenarios such as predictive maintenance, dynamic traffic rerouting, and emergency response optimization. Moreover, the development of open APIs for third-party developers will foster the creation of complementary services and applications, stimulating innovation and entrepreneurial ecosystems.

At present the platform is available as prototype running most of the use cases with selected hardware vendors, communication protocols, over-the-air upgrades, compliance with data privacy and security standards. To make it ready for commercial use will have to establish public-private partnerships for funding, finalize development for control center and the end user applications, draft contracts with clear governance terms, get ops personnel, pilot deployment and tests, gather user feedback and refine system. Once this is done, we can proceed with onboarding of commercial customers and full-scale rollout. After the platform is fully operational will go in Monitoring/Optimization and Innovation/Expansion phases, with adding new modules and features, explore monetization and scale to other customers and regions.

In conclusion, the implementation of smart IoT technologies in Bulgaria represents a realistic, innovative pathway toward more sustainable, intelligent, and economically vibrant cities. The “smart poles” initiative serves not only as a technological advancement but also as a strategic opportunity to reimagine urban living. Through informed policy decisions, stakeholder collaboration, and continuous research, Bulgaria can position itself as a regional leader in smart city innovation, aligning national development with global environmental and digital transformation goals.

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GREEN INNOVATIONS AND THEIR APPLICATION IN MODERN BUSINESS

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ABSTRACT

Rapid industrial and technological development has significantly impacted the natural environment. As a result, environmental protection has become an imperative. In response to growing ecological awareness and regulatory pressure, companies are adopting innovative practices across their operations. Green innovations now play a key role in reducing the environmental footprint of business activities. Green innovation involves implementing eco-friendly products and processes, improving resource efficiency, and minimizing environmental harm. These innovations often require new or improved business methods, technologies, and materials aimed at maximizing positive impact. In practice, this includes new production equipment, sustainable raw materials, and cleaner manufacturing techniques. Renewable energy is gaining ground, driven by innovations that lower costs and increase efficiency. As renewables begin to replace fossil fuels, they offer lower carbon emissions and reduced pollution, which are essential for addressing the climate crisis. Green innovation is therefore crucial for managing renewable energy sources and achieving sustainable business models. Industries with high environmental impact are more likely to adopt green innovations. The automotive industry, one of the major polluters both during production and through its products, has introduced green technologies to reduce its footprint. Companies like General Motors and Tesla are leading examples of this transformation, demonstrating how green innovation supports long-term environmental and economic sustainability.

Keywords: green innovations, sustainable business, environmental protection, renewable energy sources, General Motors, Tesla

1. INTRODUCTION

Green innovations refer to the adoption of business practices aimed at developing environmentally friendly products and processes, improving resource efficiency, and reducing environmental impact. They involve the development and social implementation of new technologies, production processes, and sustainable business models, ultimately enabling companies to reduce overall greenhouse gas emissions, control environmental pollution, and chart a path toward sustainable growth. Today, dozens of innovative projects and tools help reduce carbon emissions. Companies that often contribute to CO₂ emissions due to reliance on fossil fuels in their energy consumption and production processes see green technologies as an effective way to mitigate these impacts. For instance, many companies in the transportation sector, particularly in the U.S. and the European Union, are investing in electric vehicles (EVs) as a greener alternative to traditional internal combustion en-

gine vehicles. The paradigm in many industrial sectors has shifted toward energy efficiency and the use of renewable energy. Renewable energy production generates far lower emissions compared to burning fossil fuels (Nurgaliuly & Smagulova, 2025). Transitioning from fossil fuels, which currently account for the majority of emissions, to renewable energy is crucial for tackling the climate crisis. Solar panels, a well-known example of green innovation, have been widely adopted by businesses across sectors to harness solar energy. Solar-powered companies are an innovative way to apply green technology in urban areas, showing positive environmental impacts while adding economic value. This paper aims to provide a detailed analysis of green innovations and their application in modern business. Green innovations are seen as drivers of economic progress in recent years, as growing environmental challenges have led to increased interest and major shifts in business practices aligned with ecological standards. They play a key role in mitigating the environmental impacts of business operations and serve as a strategic accelerator for achieving sustainable development. In line with green innovation as a modern business concept, companies must evaluate their internal capacities, increasingly strict standards and regulations, as well as organizational, technological, and environmental challenges when applying green technologies. Environmental performance improves through the adoption of environmental management practices, adherence to ecological policies, pollution reduction, and the implementation of environmental standards across industries. The goal of this paper is to highlight the importance of adequately analyzing green innovations and their application in modern business. Green innovations, in line with ecological standards, imply new or improved methods of organizing and utilizing company resources. Therefore, this research aims to demonstrate the importance of integrating green innovation methods into business practices, which is positively correlated with raising environmental awareness. The significance of the research lies in expanding scientific knowledge in the field of green innovations and their application in modern business. Its scientific justification is reflected in enhancing the understanding of the specific role of green innovation in improving business performance. By formalizing their application, the success of green innovations in business can be evaluated. Describing trends and effects of their implementation enriches the scientific body of knowledge. The social relevance of this research stems from the fact that the knowledge gained through the analysis of green innovations is essential for companies operating in today's business environment. The insights from this study can serve as a fundamental tool for making informed decisions by all stakeholders involved in modern business.

2. LITERATURE REVIEW AND RESEARCH QUESTION SPECIFICATION

The rapid industrial and technological development, particularly characteristic of the second half of the 20th century, has left—and continues to leave—a significant impact on the natural environment. Most modern civilizational activities imply global changes that are either currently occurring or will occur in the future. In the era of globalization, changes in people's lifestyles, accompanied by the emergence of new industries competing in product innovation, have increased production to meet consumer demands, leading to uncontrolled exploitation of natural resources, which negatively affects the environment. Emissions from industrial waste by-products harm both the environment and human health. The excessive use of fossil fuels also contributes to the greenhouse effect, resulting in global warming. As such, the protection of nature and its values is now seen as imperative. This concern has led to the establishment of legal and institutional frameworks for environmental protection in many countries. These frameworks regulate the sustainable use of natural resources and environmental conservation, depending on the level of development and overall societal progress.

Rising environmental awareness and global health concerns are causing businesses to shift from traditional models to more sustainable and eco-friendly approaches. This has led to the emergence of sustainable business practices, which reveal environmental issues to the public while raising awareness about the importance of green corporate behavior.

Sustainability refers to both the sustainability of development itself and the practices or policies that can lead to a better, more stable quality of life. To achieve long-term sustainability, it is necessary to pursue a green economy and seek solutions to resource limitations (Idris & Rahman Razak, 2025). While there are various definitions of sustainable development, there is broad consensus that it

meets the needs of the present without compromising the ability of future generations to meet their own (Streimikiene & Kacerauskas, 2020).

In the business context, sustainability extends beyond environmental protection. It refers to conducting business in a way that does not negatively impact the environment, community, or society as a whole. Business sustainability encompasses company strategies and actions aimed at reducing the environmental and social impacts of operations in a specific market. Environmental, social, and economic requirements are considered the three pillars of sustainable business. In the corporate world, this is often referred to as the “triple bottom line,” a framework for assessing a company’s environmental, social, and economic impact. These three categories are commonly represented by the acronym ESG—Environmental, Social, and Governance. ESG is another framework that helps companies document their sustainable practices, progress, and the associated risks and opportunities as part of their sustainability efforts. Companies can measure success in these areas using various ESG metrics and report the results publicly. ESG rating agencies use disclosures and other data to assign companies ESG scores, which investors and other stakeholders consider when evaluating organizations (Blowfield & Murray, 2014).

Business sustainability refers to a company’s strategy and actions aimed at reducing the negative environmental and societal impacts that result from its operations. Sustainable business covers a wide range of practices such as reducing emissions, lowering energy consumption, ensuring proper disposal of physical waste, and minimizing the company’s carbon footprint. Examples of sustainable business practices include improving energy management efficiency by using alternative energy sources and carbon accounting, introducing infrastructure that reduces greenhouse gas (GHG) emissions, conserves water resources, and eliminates waste, managing dynamic and efficient supply chains to support a circular economy, encouraging reuse, designing out waste, promoting sustainable consumption, and protecting natural resources. Sustainability also involves assessing risks and improving resilience while complying with external regulations and development goals (Antonioli et al., 2013).

Green innovations (GIs) are seen as a driver of economic progress in recent years, especially as growing environmental challenges have increased interest in and significantly influenced business transformations in favor of environmental priorities. Green innovations are a key strategic accelerator for achieving sustainable development, particularly through technological innovations in energy conservation, pollution prevention, and waste recycling. These approaches improve resource efficiency, reduce costs, and protect the environment. Green product innovations involve the use of materials that have a lower environmental impact, require less energy and fewer resources, and result in environmentally friendly products that can be easily recycled, reused, or biodegraded. Green process innovation enhances efficiency by reducing raw material usage and the generation of hazardous substances and waste, as well as minimizing electricity, water, and oil consumption. Green organizational innovation includes the creation of new and valuable ideas for green products, processes, services, and behaviors that can strengthen business models and shift managerial attitudes toward establishing a green organizational identity (Abbas & Sagsan, 2019). Green innovations, therefore, refer to the adoption of business practices aimed at developing environmentally friendly products and processes, improving resource efficiency, and reducing environmental impact.

They play a crucial role in mitigating the negative environmental effects associated with business activities. These issues range from carbon emissions to resource consumption, encouraging companies worldwide to focus on innovation as the key to improving environmental performance, reducing their carbon footprint, and boosting competitiveness in rapidly changing markets. There are several definitions of green innovation in the literature. Some suggest that innovation is the sum of “design + product.” Accordingly, GIs can be defined as the sum of “eco-design + eco-production,” as they involve developing ecological products or processes and applying innovations in technologies that include energy saving, pollution prevention, and green product design. Similarly, some authors define GIs as innovations that focus on achieving sustainable development and preserving natural resources by developing more environmentally friendly products and services (Song & Yu, 2018). Many also define green innovation as the development of sustainable products and processes through the use or adoption of eco-friendly raw materials during the production or design phase.

This process includes applying eco-design or eco-production principles—where the environment is considered from the moment a product or process idea is conceived, not just at the end of its life cycle. Accordingly, although GIs have mainly focused on manufacturing processes, some companies have extended this trend by redesigning not only production but also their entire processes, including distribution channels and after-sales services. Thus, GIs are innovations embedded throughout the business cycle—in design, production, supply, and end use of commercial products—which significantly contribute to environmental sustainability (Weng et al., 2019).

Green innovation is a form of innovation that focuses on reducing environmental impact and maximizing sustainability. This can include the development of new technologies, processes, products, services, or business models that have a positive impact on the environment. Green innovation is the use of creative solutions to reduce negative environmental impacts and maximize sustainability. This includes the development of new technologies, processes, products, services, or business models that are more environmentally friendly than those they replace. Green innovations can also improve resource efficiency by reducing waste or enhancing energy efficiency. By finding innovative ways to reduce environmental impact, natural resources can be used responsibly and remain available for future generations. Green innovation refers to the adoption of business practices aimed at developing environmentally friendly products and processes, increasing the efficiency of resource use, and reducing environmental impact. Green innovations involve the development and social implementation of new net-zero technologies, production processes, and sustainable business models, which ultimately enable enterprises to reduce overall greenhouse gas emissions, control environmental pollution, and set a path toward sustainable growth (Tang et al., 2018).

The terms “sustainable innovation” and “green innovation” are often used interchangeably, but the two are not entirely the same. Green innovations, although they deal with societal well-being as a whole, primarily focus on the environment, while sustainable innovations place more emphasis on ethical and social aspects. Some examples of green innovations include: geothermal energy – a method of collecting renewable energy through dry steam power; solar energy – a way of generating electricity using solar panels and UV rays; wind energy – a form of renewable energy production using wind turbines; hydropower – a method of generating renewable energy through water power and the use of hydroelectric plants; green infrastructure – not only is green infrastructure beneficial for economic growth, but it can help reduce environmental impact; smart farms – new technologies used within sustainable agriculture help reduce greenhouse gas emissions; sustainable packaging – efforts to find new ways to package products in materials that do not contribute to landfill waste are a great example of ecological innovation; smart grids – these electrical grids help maximize the use of electricity to preserve limited resources; carbon capture and storage systems – specifically designed to remove excess carbon dioxide emissions from the atmosphere, carbon capture and storage systems (also known as CCS) are perhaps a defining example of ecological innovation (Schiederig et al., 2020). Green innovation can be classified as green product innovation, green process innovation, or green organizational innovation. The first, green product innovation, includes environmental improvements such as recycling. The second, green process innovation, aims to minimize energy consumption and maximize efficiency in the use of resources. Finally, green organizational innovation reflects the development of new ideas, behaviors, processes, and innovative management systems that contribute to reducing environmental harm (Hottenrott et al., 2016). Companies can better utilize their resources while reducing costs, which can increase their recognition of the potential for green product innovation, all of which fosters ecological organizational innovations.

According to some studies, green organizational innovation reflects compliance with management norms and environmental regulations, so investing in green innovations can foster ecological organizational identity, environmental commitments, and legitimacy. At the same time, eco-innovative actions improve and support environmental actions by introducing new production processes, products, and services that reduce or prevent ecological risks such as pollution and any other negative impacts during resource use in the implementation of these actions (Gurlek & Tuna, 2018). In business, this translates into new equipment, new ideas integrated into the production line, and of course, new raw materials for maximum positive impact.

Green innovations play a crucial role in mitigating the negative environmental impacts associated with business activities. These environmental issues range from carbon emissions to resource consumption, prompting companies globally to focus on innovation as the key to improving their environmental performance, reducing carbon footprints, and strengthening competitiveness in rapidly changing markets. Green innovations involve the development and social application of new net-zero technologies, production processes, and sustainable business models, which ultimately enable companies to reduce overall greenhouse gas emissions, control environmental pollution, and chart a path toward sustainable growth.

In recent years, the global trend of introducing renewable energy sources has been increasing, aiming to achieve sustainability and protect the environment. The pathways toward a 100% renewable energy (RE) sector are also emerging. This is a significant challenge, as industry increasingly contributes to climate change and must reduce fossil fuel usage. On a global level, energy challenges vary depending on the stage of development. Developing countries often face greater energy limitations due to limited infrastructure, inadequate access to modern technologies, and similar factors. In contrast, developed countries are focused on optimizing energy use, reducing emissions, and integrating renewable energy solutions. To achieve reliable and environmentally acceptable renewable energy alternatives, the energy sector requires a comprehensive transformation by adopting renewable sources.

Today, with innovative and more affordable ways to capture and store wind and solar energy, renewables are becoming a more significant energy source. Renewable energy is on the rise, as innovations lower costs and begin to fulfill the promise of a clean energy future. This means renewables are increasingly displacing “dirty” fossil fuels in the energy sector, offering the advantage of lower carbon emissions and other types of pollution. Sustainable energy production requires low-carbon energy systems that do not cause negative social and environmental impacts.

Renewable energy has gained importance and plays a crucial role in the decarbonization of the energy sector, as it is produced using natural resources that are constantly replenished and cannot be depleted. Renewable energy sources include biomass, hydropower, tidal and wave energy, solar photovoltaic energy, wind, and geothermal energy. Renewable energy, often called clean energy, comes from natural sources or processes that are continually replenished. The definition of renewable energy is energy that is sustainable—something that cannot run out or is infinite, like sunlight (Twidell, 2021). The term “alternative energy” is also commonly used to refer to renewable energy sources, although other energy types may also be considered alternative. Renewable energy refers to energy that differs from the most commonly used unsustainable sources, such as coal.

Renewable energy is energy derived from natural sources that replenish themselves more quickly than they are consumed (Twidell, 2021). Sunlight and wind, for example, are such sources that are continuously renewed. Renewable energy sources are abundant and all around us. Fossil fuels like coal, oil, and gas, on the other hand, are non-renewable resources that take hundreds of millions of years to form. When burned for energy production, fossil fuels cause harmful greenhouse gas emissions, such as carbon dioxide. Renewable energy production generates far lower emissions compared to burning fossil fuels. The transition from fossil fuels, which currently account for the majority of emissions, to renewable energy is essential for addressing the climate crisis. Renewable energy sources are now cheaper in most countries and generate three times more jobs. Solar energy is the most abundant of all energy resources and can even be harnessed on cloudy days. The rate at which the Earth intercepts solar energy is approximately 10,000 times greater than the rate at which humanity consumes energy. Solar technologies can deliver heat, cooling, natural lighting, electricity, and fuels. These technologies convert sunlight into electricity either through photovoltaic (PV) panels or by using mirrors that concentrate solar radiation (Ehsanul & Pawan, 2018). The cost of producing solar panels has dropped over the last decade, making them not only affordable but often the cheapest form of electricity.

Wind energy harnesses the kinetic energy of moving air using large wind turbines located on land or offshore in seas or freshwater. Wind energy has been used for millennia, but onshore and offshore wind technologies have advanced significantly in recent years to maximize electricity production using taller turbines and larger rotor diameters (Twidell, 2021).

Hydropower uses the energy of water moving from higher to lower altitudes. It can be generated from reservoirs and rivers. Reservoir-based hydroelectric plants rely on stored water, while run-of-the-river hydro plants generate energy from the natural flow of the river (Twidell, 2021). This energy source is often more reliable than solar or wind power and also allows energy storage for use during peak demand. However, the infrastructure needed for hydropower can negatively impact ecosystems. For this reason, many consider small-scale hydro plants a more environmentally friendly option, particularly suitable for remote communities.

Ocean energy comes from technologies that use the kinetic and thermal energy of seawater—such as waves or currents—to generate electricity or thermal energy. Ocean energy systems are still in the early development stage, with numerous prototypes of wave and tidal energy devices under investigation. The theoretical potential of ocean energy far exceeds current human energy needs.

Bioenergy is generated from various organic materials, known as biomass, such as wood, charcoal, manure, and other animal waste to produce heat and electricity, as well as agricultural crops for liquid biofuels. This involves converting solid fuel made from plant materials into electricity. Although it typically involves burning organic materials to produce power, today it is a much cleaner and more energy-efficient process. By converting agricultural, industrial, and household waste into solid, liquid, and gaseous fuels, biomass generates energy at significantly lower economic and environmental costs. While burning biomass does emit greenhouse gases, these emissions are lower than those from burning fossil fuels like coal, oil, or gas.

Fossil fuels are not a renewable energy source because they are finite. Additionally, they release carbon dioxide into the atmosphere, contributing to climate change and global warming. Burning wood instead of coal is somewhat better but remains complex. On one hand, wood is a renewable resource—if sourced from sustainably managed forests. On the other hand, burning wood releases particles into the atmosphere.

As the world's population grows, so does the demand for energy to power homes, businesses, and communities. Innovation and expansion of renewable energy sources are essential to maintaining a sustainable energy level and protecting the planet from climate change. Renewable energy sources today account for 26% of global electricity, but according to the International Energy Agency (IEA), their share is expected to reach 30% by 2024 (Braun & Glidden, 2014).

Companies, which often contribute to CO₂ emissions due to their reliance on fossil fuels in energy consumption and production processes, see green technologies as an effective way to mitigate these impacts. For example, numerous companies in the transportation sector—particularly in the U.S. and the European Union—are investing in electric vehicles (EVs) as a greener alternative to traditional internal combustion engine vehicles. The paradigm has shifted in many industrial sectors toward energy efficiency and the use of new energy sources from renewables, such as solar and wind. Energy storage technologies, for instance, optimize the use of solar energy, reducing dependence on fossil fuels for energy production. Solar panels, a well-known example of green innovation, have been widely adopted by businesses across various sectors to harness solar power. Solar-powered companies represent innovative applications of green technology in urban areas, demonstrating a positive environmental impact while also adding economic value.

Renewable resources, therefore, can be used indefinitely only if they are exploited responsibly and managed appropriately. Establishing proactive environmental policies within companies and adopting adequate models for managing renewable energy sources and sustainable development undoubtedly lead to competitive advantages, better financial performance, and the minimization of risk and uncertainty in green investments.

Based on previous studies, the following research questions (RQ) are formulated:

1. Does the concept of sustainability, driven by environmental issues, encourage companies to implement green innovations in their business operations?
2. To what extent are renewable energy sources, as innovative approaches, increasingly displacing “dirty” fossil fuels by offering the advantage of lower carbon emissions and other types of pollution?
3. Do companies from industries with negative externalities, such as the automotive industry, consider green innovations an effective way to mitigate environmental impact?

3. METHODOLOGY

The empirical research is based on data on the application of green innovations in the automotive industry in the USA. Since our main goal is to examine the effect of green innovations in integrating new methods into the company's business practice, an in-depth analysis of case studies pointed to the application of green innovations as a model of renewable energy management in the example of General Motors, and green product innovations in the example of Tesla. The implementation of emission reduction technologies is taken as a variable. Car manufacturers have made significant progress in reducing emissions through the implementation of emission control systems. Catalytic converters, advancements in engine design, and improvements in fuel efficiency have played a key role in reducing air pollution and minimizing the environmental impact of vehicles. Recycling and sustainable materials are taken as a variable. Recycling plays a vital role in reducing the environmental impact of the automotive industry. Car manufacturers are increasingly using sustainable materials in vehicle production, such as recycled plastic and bio-based materials. However, there are challenges in recycling processes, including the complexity of vehicle disassembly and the development of innovative recycling technologies. Renewable energy sources are taken as a variable. The automotive manufacturing sector is increasingly turning to renewable energy sources such as wind, solar energy, biogas, and electricity to support its operations, as the industry moves toward sustainability and carbon neutrality. The transition to electric vehicles (EVs) is taken as a variable. The adoption of electric vehicles has gained momentum due to their environmental advantages, including zero exhaust emissions. Governments have provided incentives and support to encourage the production and adoption of electric vehicles. However, challenges related to EV charging infrastructure and battery disposal must be addressed in order to enable widespread adoption.

4. RESULTS

The automotive industry plays a significant role in global emissions and environmental impact and is an industry with negative environmental externalities. Automakers are often considered among the largest polluters, both in the production process and with their final products. Sustainability is currently one of the main issues, especially in the automotive industry, with topics such as electric vehicles, lightweight construction, and CO₂ emission reduction becoming key concerns. The rapid development of innovation is particularly evident in the automotive industry. The industry as a whole has developed a number of green technologies to ensure sustainability and reduce the negative effects of the industry on the planet. The introduction of electric vehicles, the development of hydrogen technology, and the recycling of materials used in vehicle production are just some of the measures being taken to protect the environment.

General Motors is a global company headquartered in the USA, focused on advancing an all-electric future that is inclusive and accessible to all. One of the key ways the company is working to reduce CO₂ emissions is through alternative energy sources that do not produce greenhouse gas emissions. The company supports the growth of renewable energy generation through direct investments, on-site electricity production, green tariffs, and power purchase agreements. Through changes in all areas from production to finalization, the company is working to achieve carbon neutrality in global products and operations by 2040. In 2022, the company reported its Scope 1 and 2 emissions at 3.5 million mtCO₂e and Scope 3 emissions at 208.6 million mtCO₂e. For 2035, it set a goal of 1.6 mtCO₂e and 155.2 mtCO₂e for Scope 1 and 2 and Scope 3 emissions. As part of its strategy to reduce Scope 1 and 2 greenhouse gas emissions, the company is working to reduce energy consumption by improving the energy efficiency of its facilities through a global energy management system (EMS) ([General Motors, 2024](#)). General Motors' commitment to using electricity from renewable sources began more than two decades ago. Initially, General Motors decided to seek help outside the company and chose Altenex, an Edison Energy Company, to support its efforts in finding renewable energy sources. Altenex helps energy users like General Motors navigate electricity markets and specializes in monitoring, analyzing, and negotiating renewable energy projects that meet tailored economic goals, risk management targets, and sustainability objectives. General Motors and Altenex worked together to develop the blueprint for an "ideal" renewable energy transaction. The result was a formalized process that delivered the best market opportunities for General Motors ([Jaderna & Prikrylova, 2018](#)). Today,

General Motors has made significant progress in building its energy portfolio based on an analytically rigorous methodology aligned with the company's long-term business plans. Renewable energy initiatives are being successfully integrated into the company's brand and operational planning and have received tactical support from senior leadership across the organization.

In 2022, the company announced that it had finalized energy sourcing agreements needed to supply 100% of the electricity required to power all its U.S. sites with renewable electricity by the end of 2025, with expectations to culminate by 2035 when the company plans to achieve 100% renewable electricity globally ([General Motors, 2023](#)). For this purpose, General Motors opened its first battery manufacturing plant, Ultium Cells LLC, in Warren, Ohio, with plans for additional facilities. Additionally, General Motors joined the First Movers Coalition through a commitment to low-carbon concrete, cement, aluminum, and steel.

As part of its innovation efforts, General Motors established General Motors Energy, a new business unit aimed at providing a holistic ecosystem of connected energy management solutions for residential, commercial, and EV customers. General Motors achieved its goal of diverting more than 90% of its total operational waste from landfills, incinerators, and waste-to-energy facilities three years ahead of its 2025 target ([General Motors, 2023](#)). General Motors is investing in energy-efficient systems and renewable energy strategies to reduce Scope 1 and 2 emissions and is implementing energy projects focused on both base and variable energy consumption to achieve lower intensity as vehicle volume stabilizes.

In 2023, the company held an industry-leading position in sustainable energy among all manufacturing companies, becoming the top renewable energy buyer through power purchase agreements. With these acquisitions, the company ranked as the highest-listed automaker on the EPA's Green Power Partners list. In 2023, the use of renewable energy in the U.S. rose to 59%. In 2023, the company's global renewable energy consumption reached 2.2 million MWh, an increase compared to 2022. Additionally, the company's share of global renewable energy use rose to 39% ([General Motors, 2023](#)).

With an annual global energy consumption of 9 terawatt-hours, or 9 billion kilowatt-hours, General Motors' energy portfolio is massive. General Motors operates 350 plants, warehouses, technical centers, and offices in 59 countries worldwide and seeks the right energy mix to power each site. For this purpose, General Motors has explored on-site and off-site renewable energy opportunities and is focused on sourcing the "right blend" of renewables to power its operations. Two of its landfill gas projects were awarded Green Power Leadership Awards by the U.S. Environmental Protection Agency. Twenty-four solar projects located at General Motors facilities around the world generate 48 megawatts (MW) of energy. Furthermore, General Motors has signed power purchase agreements (PPAs) totaling 30 MW of wind energy in Mexico and completed power procurement contracts of 30 MW (2015) and 50 MW (2016) in Texas ([Environmental Protection Agency U.S., 2022](#)). General Motors' use of renewable energy has saved the company \$80 million over the past two decades. General Motors currently operates 17 renewable energy plants across 11 states, making it the largest renewable energy buyer in the automotive sector by capacity.

General Motors' strategy and changes for renewable energy, based on four pillars, focus on ensuring that the total amount of electricity will ultimately come from 100 percent renewable energy sources ([General Motors, 2024](#)):

- **Energy efficiency** - through investments in new technologies and daily efforts to save electricity in facilities. General Motors spends about 20 million dollars annually on energy efficiency and energy demand projects.
- **Procurement of renewable sources** - through various methods such as on-site projects, power purchase agreements (PPAs), and green tariffs. General Motors' locations in Michigan are powered by renewable energy from new projects in the state, which led to the creation of around 1,200 jobs in Michigan. In 2020, General Motors implemented the largest solar project of 300 megawatts in Michigan through a green tariff agreement, so that all General Motors sites in southeastern Michigan are served by DTE with renewable energy, including the headquarters in Detroit and the Warren Technical Center, as part of DTE's MIGreenPower program, which provides 500 megawatts of solar energy.

- **Energy storage** is a reliable way to help solve the challenge of intermittency. General Motors operates the largest and most advanced battery testing laboratory in the United States and uses the global capabilities and resources of this technology in various potential applications, including the reuse of EV batteries after their initial use in vehicles.
- **Policy and the company's scope of influence**, with efforts such as the Renewable Energy Buyers Alliance (REBA), help implement organizational changes. Green tariffs and collaboration with electric utilities to enable companies and consumers to access more renewable electricity through fixed-rate pricing are part of the company's renewable energy plan. Vehicle-grid integration and services related to electrification offer complementary strategies for reimagining local distribution networks.

The solar agreement in Arkansas is the company's first project to procure panels from First Solar in Ohio, a U.S. solar panel manufacturer. With the help of First Solar, their circularity, and sustainable panel technology, General Motors is helping define the future of solar energy in the United States. By the end of 2022, the largest facility in North America—Spring Hill Manufacturing—was powered 100 percent by solar energy, enabled by a green tariff agreement with the Tennessee Valley Authority, which supplies up to 100 megawatts of solar energy annually.

The latest report shows that General Motors signed a 15-year renewable energy power purchase agreement with NorthStar Clean Energy to support its operations at three assembly plants located in Michigan and Missouri. The agreement will enable General Motors to source renewable electricity from NorthStar's 180-megawatt solar project in Newport. The solar PPA will support General Motors' operations at Lansing Delta Township Assembly and Lansing Grand River Assembly plants in Michigan, as well as the Wentzville Assembly plant in Missouri (Mirza, 2024).

The automotive industry as a whole has developed a range of green technologies to ensure sustainability and reduce the negative effects of the industry on the planet. Some companies have done this better than others. Innovative green technology is most often associated with Tesla, as a company accelerating the transition to sustainable energy. Tesla is considered the leading electric vehicle manufacturer on the market. It was the first company to recognize the need for a more sustainable vehicle than traditional gasoline-powered cars and offered its solution to the market. The company combined electric energy generation via solar panels and other products from SolarCity with its vehicles, giving it a competitive advantage no other competitor has. Tesla's cars are the result of continuous investment in research and development and a forward-thinking approach. Through its innovations, the company has made such an impact that it has influenced the direction of its competitors and the industry as a whole. As part of the green economy movement, Tesla was definitely one of the pioneers that influenced companies in other industries and inspired them to adopt a greener and more sustainable approach.

Tesla was founded in 2003 by a group of engineers who wanted to prove to the world that electric vehicles were not a fiction, by creating the world's first purely electric vehicle powered by lithium-ion batteries (Chang, 2014). Using innovative technologies and sustainable practices, Tesla not only revolutionized the automotive industry but also pioneered a new era of sustainable transport. Tesla offers electric vehicles and infinitely scalable clean energy generation and storage products. The company focuses on developing sustainable technology that can influence existing trends. Tesla emphasizes that electric cars are significantly more sustainable because they are not powered by fossil fuels.

Martin Eberhard and Marc Tarpenning, who had previously co-founded the successful company NuvoMedia, established Tesla Motors in July 2003, and Elon Musk joined as the main investor in early 2004. The founders of Tesla Motors realized that they could benefit from outsourcing the manufacturing and assembly of most standard components, thereby avoiding initial capital expenditures required for setting up their own production facilities (Abrams, 2006). At the beginning, a specialized manufacturer in the United Kingdom, who had a high-speed vehicle called the Lotus Elise, was ready to assist in designing and assembling the Tesla Roadster vehicle at their UK plant. In this way, the Tesla Roadster was based on the initial drivetrain technology licensed from AC Propulsion and built into a modified version of the Lotus Elise (Rechtin, 2007). The carbon fiber/epoxy composite body designed for the Tesla Roadster by Lotus Engineering and employees hired by Lotus

for Tesla Motors UK enabled low production volumes, a higher level of performance, and design flexibility (Rechtin, 2007). The company first focused on developing the Roadster, a premium EV sports car based on the Lotus Elise platform. The intention was to replace the internal combustion engine (ICE) drivetrain with an electric one, consisting of lithium-ion batteries. This type of battery can store twice as much energy per pound as the nickel-metal hydride batteries used in older electric cars and current hybrids. Tesla used standard 18,650 battery cells and combined them by the thousands in parallel to form a battery pack. After launching its first electric car, the Roadster, in 2008, Tesla officially introduced its state-of-the-art battery technology and electric drivetrain.

After launching the Roadster in 2008, Tesla acquired its own factory in Fremont, California, and later bought the GM-Toyota NUMMI plant in 2010. Initially, it renovated a small part of the NUMMI factory with innovative production equipment and high automation, launching the aluminum-bodied Model S sedan in 2012 (Chang, 2014). Model S was the first luxury EV sedan with high performance, accelerating faster than many sports cars. Model S also included many innovations from the IT sector, including a digital dashboard and a touchscreen that allowed users to control all vehicle functions. Built-in IT functionality enabled features such as summon, auto-parking, and autopilot. The combination of more electronic components, fewer moving parts, and online connectivity meant that Tesla's vehicles could be significantly upgraded via software, unlike conventional ICE vehicles (Chang, 2014). Tesla began building Superchargers in the United States and Europe, where Tesla owners could quickly charge their vehicle batteries for free.

The Model X SUV followed in the fall of 2015. The launch of each model gradually targeted larger market segments. Tesla Motors' market capitalization grew as a result of this strategy and continued to rise. By continually improving its technologies through incremental innovation, Tesla expanded into other market segments, commercializing the Model S in 2012 and the Model X in 2015.

Tesla's strategy evolved in several phases. Key elements of Tesla's strategy include: proprietary integrated electric drivetrain; vertical integration from development to production and retail; significant incorporation of IT capabilities in the vehicle; uncompromising focus on battery electric vehicles; building a Supercharger network and offering free charging to customers (Thomas & Maine, 2019). Tesla's electric cars are designed to minimize their carbon footprint. In fact, since 2008, Tesla vehicles have saved over 3.5 million tons of CO₂ emissions. The company's factories also prioritize sustainability. For example, the Gigafactory in Nevada is powered 100% by renewable energy, and the Gigafactory in Shanghai uses solar arrays and other green solutions (Thomas & Maine, 2019). Tesla also holds the highest level of innovation in the automotive world. The company has more control than any of its competitors over the production processes and quality—not only of its own products but also those of its suppliers—because it is vertically integrated with SolarCity. This integration provides the company with additional flexibility and space for innovation. The company's research is also focused on improving safety, which has paid off, as Tesla vehicles are considered the safest cars in the world. This is supported by the U.S. government's New Car Assessment Program, where tests for the Model S, Model X, and Model 3 achieved the lowest overall probability of injury of any vehicle ever tested. Tesla's performance is exceptional on all levels, making the company a powerful symbol of innovation and a "car of the future." The innovative nature of the company gives it a high profile in the electric vehicle industry and makes it the number one.

In addition to manufacturing environmentally friendly vehicles, Tesla is also focused on energy generation and storage solutions. Tesla's pursuit of sustainability goals has also driven its efforts in digital transformation. The company's commitment to reducing greenhouse gas emissions and promoting the adoption of renewable energy sources has sparked innovation in energy storage and solar technologies. Tesla has expanded its digital ecosystem through the development and integration of sustainable energy solutions, offering users integrated platforms for energy management and storage. Tesla's causal connection between digital transformation and sustainability has resulted in significant positive outcomes and global impact. The company's solar products, such as the Solar Roof and solar panels, aim to reduce reliance on fossil fuels for electricity generation. Tesla's energy storage solutions—Powerwall, Powerpack, and Megapack—enable the storage of renewable energy, further promoting the adoption of sustainable energy sources (Lu, 2024).

Tesla is a leading example of how businesses can reduce their environmental impact and contribute to a cleaner and healthier planet. By investing in sustainable practices, Tesla is helping to shape the future of transportation and energy. Tesla produces zero-emission transportation and energy products. Tesla vehicles are popular due to having the highest energy efficiency of all modern electric vehicles. Its digital mindset and focus on sustainability have attracted a loyal customer base and created a strong brand identity associated with technological advancement and environmental stewardship. Tesla's electrification revolution is a testament to the transformative power of integrating digital transformation and sustainability. By using advanced technologies and a commitment to sustainable practices, Tesla has not only disrupted the automotive industry but also launched a movement toward a more sustainable future. The causal relationship between digital transformation and sustainability has led to outstanding results for Tesla, including market leadership, emission reductions, and global influence in shifting the automotive industry—one of the industries with negative externalities—toward innovative and sustainable practices.

5. DISCUSSION

This section discusses the findings obtained in the context of the main objective and research questions. Green innovations play a key role in mitigating the negative environmental impacts associated with business operations. These environmental issues range from carbon emissions to resource consumption, encouraging companies globally to focus on innovation as the key to improving their environmental performance, reducing carbon footprint, and enhancing competitiveness in rapidly changing markets. Green innovations involve the development and social application of new net-zero technologies, production processes, and sustainable business models, which ultimately allow companies to reduce overall greenhouse gas emissions, control environmental pollution, and pave the way toward sustainable growth.

Changes, or rather green innovations, in line with environmental requirements primarily represent innovations that require new or improved ways of conducting business and using resources. Green innovations in business practice imply the implementation of innovative processes both within the company and externally, which includes the application of innovative strategies and the development of practices for managing the entire supply chain. Green innovations generate technological changes, which may include process redesign to improve environmental performance. The introduction of new practices also refers to embedding creative ideas into modern business to improve procedures, practices, or products. Integrating new methods into the company's business practice contributes to the application of green innovations by following innovative strategies for organizing the entire business process. Therefore, the introduction of so-called green practices is positively associated with raising environmental awareness and green innovation.

Green product innovations refer to the use of materials that have a lower environmental impact, require less energy and fewer resources, and to the provision of environmentally friendly products that are easily recyclable, reusable, or biodegradable. Green process innovation delivers efficiency by reducing the use of raw materials and the generation of hazardous substances and waste, as well as by minimizing the consumption of electricity, water, and oil. Green organizational innovation includes the creation of new and valuable ideas for green products, processes, services, and behaviors that can strengthen business models and shift management attitudes toward establishing a green organizational identity. In business, this translates into new equipment, new ideas that go into the production line, and, of course, new raw materials for maximum positive impact (Kozina et al., 2019).

As a result of increasing environmental regulations, stakeholder pressures, and competition, companies must be prepared to cope with expected changes by investing in green projects. Additionally, competitive pressures stimulate enterprises to increase their market share and competitive advantages, as well as to maintain their environmental image through efficient production processes and economical use of materials and energy. Innovative change is more likely in industries with significant environmental impact and strong stakeholder pressure.

In line with this trend, companies operating in so-called “dirty industries” are those in sectors recognized as having the highest pollution intensity, or negative externalities. In this way, they have great-

er opportunities to benefit from environmental regulations by improving resource usage and process control. Since they are subject to higher levels of environmental regulation, they may find that unit compliance costs are actually lower compared to less polluting industries. This aligns with Porter's hypothesis, which suggests that companies producing higher levels of pollution have greater opportunities to eliminate inefficiencies ([World Economic Forum, 2022](#)). Therefore, companies with negative externalities are more inclined to organize their activities through the adoption of green practices in order to improve their corporate image in the marketplace by aligning with environmental protection regulations, while also responding to stakeholder pressure. To survive in the market, companies with negative externalities are required to innovate by becoming cleaner, whereas companies in clean industries already meet the norms. Thus, companies with negative externalities are more likely to adopt green innovations due to their need to be more innovative in general and as a reflection of potential pressure from and imposition of environmental regulations and consumer demands.

Industrial greening, especially in industries with negative environmental externalities, includes the application of sustainable production practices that minimize negative environmental impacts. Car manufacturers are often considered among the largest polluters, both in the production process and with their final products. The automotive industry plays a significant role in global emissions and environmental impact and is an industry with negative environmental externalities ([Wells & Nieuwenhuis, 2019](#)). Therefore, the automotive industry has developed a range of green technologies to ensure sustainability and reduce the industry's negative effects on the planet. The automotive industry is adopting green technology at an unprecedented rate, driven by the urgent need for sustainable transportation solutions. As one of the largest polluters, but also a pioneer in introducing green practices and transformations, the automotive industry is currently showing good results in implementing green innovations as a modern business concept, as demonstrated by companies such as General Motors and Tesla.

General Motors continuously evaluates and takes steps to reduce the environmental impact of its products and operations. For example, General Motors focuses on energy management, reducing carbon and waste intensity, conserving resources, and developing more efficient vehicles through technological advancement, global scale, and employee innovation. These areas of change help the company reduce its environmental footprint. General Motors supports the growth of renewable energy production through direct investments, on-site electricity generation, green tariffs, and power purchase agreements. General Motors' 100% commitment to renewable energy, along with its pursuit of electrified vehicles and efficient manufacturing, is part of the company's approach to addressing climate change. General Motors has developed an implementation strategy that includes various energy generation technologies and financing approaches to achieve success. In developing its long-term plan for 100% renewable energy, General Motors focused on four pillars: energy efficiency, procurement, energy storage, and supportive policy development. General Motors currently operates 17 renewable energy power plants in 11 states, making it the largest buyer of renewable energy in the automotive sector by capacity.

Innovative green technology is most often associated with Tesla, which has accelerated the shift to sustainable energy. Tesla is considered the leading electric vehicle manufacturer on the market. It was the first company to recognize the need for a more sustainable vehicle than traditional gasoline-powered cars and offered its solution to the market. The company's core mission has been to accelerate the world's transition to sustainable energy through the production of electric vehicles (EVs) and renewable energy solutions. Tesla's electric vehicles are significantly more sustainable, as they are not powered by fossil fuels. Tesla's innovative approach to electric vehicles and sustainable energy solutions has positioned the company as a market leader in the rapidly growing EV industry. By using innovative technologies and sustainable practices, Tesla has not only revolutionized the automotive industry but also pioneered a new era of sustainable transportation. Tesla's success can be attributed not only to its cutting-edge technology but also to a change in design principles. Tesla has redefined the perception of electric vehicles, moved the industry forward, and paved the way for a greener and more sustainable future. Green product innovations have led to exceptional outcomes for Tesla, including

market leadership, emission reductions, and a global influence in shifting the automotive industry—as one of the industries with negative externalities—toward innovative, sustainable practices.

The use of renewable energy sources is increasing worldwide to achieve energy production sustainability. Managing renewable or sustainable energy is the process by which an organization focuses its energy use on alternative, renewable sources. Renewable energy production generates far lower emissions compared to burning fossil fuels. The transition from fossil fuels, which currently account for the majority of emissions, to renewable energy is essential for addressing the climate crisis. Innovation and the expansion of renewable energy sources are crucial for maintaining a sustainable energy level and protecting the planet from climate change.

Following climate change and the climate crisis, the role of the private sector in reducing carbon emissions has never been more significant. Businesses, which often contribute to carbon dioxide emissions due to their reliance on fossil fuels in their energy consumption and production processes, consider green technologies an effective way to mitigate these impacts. The paradigm in many industrial sectors has shifted toward energy efficiency and the use of new energy sources from renewables, such as solar and wind power. Energy storage technologies, for instance, optimize the use of solar energy, reducing reliance on fossil fuels for electricity generation. Solar panels, a well-known example of green innovation, have been widely adopted by businesses across various sectors to harness solar power. Solar-powered companies represent innovative applications of green technology in urban environments, showing a positive environmental impact while simultaneously adding economic value (Fraanje et al., 2019).

Renewable energy is on the rise, as innovations reduce costs and begin to fulfill the promise of a clean energy future, meaning that renewables are increasingly displacing “dirty” fossil fuels in the energy sector, offering the advantage of lower carbon and other pollutant emissions. Sustainable energy production requires low-carbon energy systems that do not cause negative social and environmental impacts. Solar and wind energy sources are currently popular around the world, contributing to the reduction of greenhouse gas emissions and the dependence on fossil fuels. Electric vehicles and public transportation are also examples of more environmentally friendly solutions. Energy consumption can be significantly reduced through green building techniques, such as the use of sustainable materials and energy-saving equipment. Carbon emissions as well. Organic and precision farming are examples of sustainable agricultural methods that support healthier ecosystems and conserve water supplies. Innovations in waste management, such as recycling and waste-to-energy technologies, help conserve resources and minimize environmental pollution. Green innovations based on renewable energy sources are essential to addressing environmental problems. Through the use of renewable energy in its production processes, General Motors has made an impact in the automotive industry, as one of the industries with negative externalities, moving toward innovative, sustainable practices.

6.CONCLUSION

Green innovations encompass all types of innovations that contribute to the creation of key products, services, or processes aimed at reducing harm, impact, and environmental degradation, while simultaneously optimizing the use of natural resources. This type of innovation plays a key role today as it channels the appropriate use of natural resources to improve human well-being. Furthermore, the creation and incorporation of changes into products and production processes contribute to sustainable development.

The accelerated industrial and technological development, particularly characteristic of the second half of the 20th century, has left—and continues to leave—significant marks on the natural environment. In the 1980s, global warming became a dominant topic in scientific circles, and it was unequivocally proven that the greatest contributor to the observed warming was the increase of carbon dioxide in the atmosphere and that human influence has been the dominant cause of this warming since the mid-20th century. As a result, today, environmental protection is governed by a legislative and institutional framework that allows the use of natural resources in a sustainable way, albeit differently across countries. A new relationship with the environment has become an imperative of modern society. Ecological awareness represents a lifestyle pattern that respects and harmonizes

with natural laws, encouraging people to take from nature only as much as is necessary to meet basic human needs. Thus, ecological ethics represents a moral relationship between humans/technosphere and nature/biosphere.

With the globalization of the economy, environmental issues are becoming increasingly prominent on a global scale. In recent years, as carbon neutrality and peak carbon goals continue to be promoted, a growing number of companies have become aware of the importance of environmental responsibility. These companies not only aim to save energy and reduce emissions by setting green targets that limit their production activities, but also seek green changes in their management models to reduce potential environmental hazards.

In response to the rise of environmental awareness, institutional pressures, and the emergence of a segment of green consumers, companies are implementing certain changes in all aspects of business to improve their performance by differentiating their products and promoting process efficiency, thereby gaining a competitive advantage. Accordingly, companies are introducing a range of innovative practices not only to meet regulatory requirements but also to signal their commitment to the environment. Green innovation refers to the adoption of innovative practices aimed at developing environmentally friendly products and processes, increasing resource efficiency, and reducing environmental impact.

Green innovations are becoming attractive across several industries such as energy, construction, transportation, agriculture, and more. Solar and wind energy sources are currently popular worldwide, contributing to the reduction of greenhouse gas emissions and reliance on fossil fuels. Electric vehicles and public transportation are also examples of more environmentally friendly solutions. Energy consumption can be significantly reduced through green building techniques, such as using sustainable materials and energy-saving equipment. Carbon emissions, too. Organic and precision farming are examples of sustainable agricultural methods that support healthier ecosystems and conserve water supplies. Innovations in waste management, such as recycling and waste-to-energy technologies, preserve resources and minimize environmental pollution. Green innovations are essential for solving environmental problems and providing economic opportunities, which ultimately improve the standard of living.

Green innovations can help companies reduce costs, access new markets, and promote process efficiency—all of which positively impact their financial status. This requires updating their business models and practices and investing more effort into the careful use of resources and the introduction of new, environmentally friendly products and processes. Establishing proactive environmental policies and innovative practices undoubtedly leads to competitive advantages, improved financial performance, and minimized risks and uncertainties associated with investments in green projects.

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TYPOLOGY OF STUDENTS ACCORDING TO LEARNING STYLES: INSIGHTS FOR ECONOMIC INNOVATION

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ABSTRACT

This paper presents and justifies a typology of students in the fields of Economics and Administration and Management based on their learning styles, using a sample of undergraduate and graduate students at the University of National and World Economy, Sofia. Learning style is understood as a set of stable cognitive patterns through which students prefer to receive, perceive, process, and understand information in the learning process. In line with this understanding, four key dimensions of student interaction with information are defined: receiving information (visually or verbally), perceiving information (concretely or abstractly), processing information (actively or reflectively), and understanding information (linearly or globally).

A representative empirical study was conducted using a stratified-cluster sample of 720 students. Data were collected through a self-administered questionnaire consisting of a battery of 16 Likert-scale items. The measurement instrument successfully passed the tests for validity and reliability. The results of the study indicate the distribution of students across the four key dimensions and reveal five distinct clusters of students with different learning profiles. The cluster analysis confirms that dominant learning styles influence student engagement and academic performance.

The findings provide valuable insights for adapting teaching methods, curricula, and programs to better align with the dominant learning styles among students. Understanding these preferences can enhance creativity, adaptability, and sustainable growth in an evolving global economy. This study highlights the strategic importance of educational innovation in preparing students for future challenges.

Keywords: *Learning styles, Theories of learning styles, Educational innovation, Cluster analysis, Student engagement*

1. INTRODUCTION

In a rapidly changing global economy, aligning educational strategies with students' learning styles is essential for fostering innovation and adaptability. Understanding how students receive, perceive, process, and apply information allows for the development of more effective teaching methods. This study explores the typology of learning styles among students in Economics and Administration & Management, highlighting the connection between educational approaches and innovative thinking. Adapting teaching strategies to dominant learning preferences can enhance student engagement and prepare future professionals for the challenges of a sustainable economy. The findings emphasize the role of tailored educational practices in building capacity for creativity and long-term growth.

In the present paper, the theoretical and methodological frameworks of different learning styles theories are used to study students' learning styles. The aim is to develop a typology of learning styles based on an empirical study conducted among students in the two main fields of study at UNWE – Economics and Administration and Management.

The theories of learning styles were particularly actively developed in the 1980s and 1990s, although their roots can be traced earlier in the works of Carl Jung on archetypes, for example. Below we briefly outline the main authors and their works.

Experiential Learning Theory (ELT) by David Kolb (1984). Kolb's Experiential Learning Theory proposes a cyclic model of learning consisting of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. According to Kolb, learning styles are formed based on individual preferences for different combinations of these stages. "Learning is the process whereby knowledge is created through the transformation of experience." (Kolb, 1984). He identifies four primary learning styles: convergers, divergers, assimilators, and accommodators.

Felder-Silverman Learning Styles Model (FSLSM) (1988). Developed by Richard Felder and Linda Silverman, this model classifies learning styles along four dimensions: active/reflective, sensing/intuitive, visual/verbal, and sequential/global. FSLSM is particularly popular in the field of engineering and technical education, emphasizing how different students process and perceive information. "Different students have different learning styles, and teachers can best reach all of them by understanding the differences." (Felder & Silverman, 1988).

Honey and Mumford's Learning Styles (1986). Peter Honey and Alan Mumford adapted Kolb's model and identified four learning styles: activists, reflectors, theorists, and pragmatists. According to them, individuals prefer certain styles depending on how they approach new information and experiences. "Learning is most effective when it is matched to an individual's preferred learning style." (Honey & Mumford, 1986, p. 15)

VARK Model (Fleming, 1992). Developed by Neil Fleming, the VARK model focuses on learners' sensory preferences: visual, aural, reading/writing, and kinesthetic. This model is widely used in educational practice to develop personalized learning strategies. "VARK helps students understand how they prefer to learn, which can lead to more effective study habits." (Fleming, 1992)

Study Process Questionnaire (SPQ) by John Biggs (1987). SPQ assesses students' approaches to learning through three main categories: deep approach, surface approach, and strategic approach. This model examines the relationship between motivation, cognitive strategies, and learning outcomes. "Students approach learning tasks with different intentions, which shape the strategies they adopt." (Biggs, 1987).

Inventory of Learning Styles by Vermunt (1996). The ILS applies a systematic approach to studying the cognitive and motivational aspects of learning by identifying different styles according to how students—and learners more generally—perceive, process, evaluate, and use information. "Learning styles represent coherent patterns in learning activities, influenced by cognitive and affective factors." (Vermunt, 1996). Vermunt identifies four primary learning styles: directive (characterized by a strong dependence on the teacher); reproductive (focused on memorizing and reproducing information); meaning-Directed (encourages active searching for meaning and understanding of the learning material); self-regulated (emphasizes learners' ability to manage their own learning, including planning, monitoring, and evaluating their progress). These styles are not mutually exclusive. Learners can demonstrate elements of different styles depending on the learning context and content.

Approaches and Study Skills Inventory for Students (ASSIST) (Entwistle, 2000). ASSIST is an instrument developed by Noel Entwistle and colleagues to assess learning approaches. It identifies three main approaches: deep, strategic, and surface—similar to Biggs's model but with a more detailed examination of motivational factors. "The quality of learning outcomes is closely related to the approach students take to studying." (Entwistle & McCune, 2000).

2. METHODOLOGY

The present report is based on an empirical study conducted as part of a broader scientific research project funded by the Scientific Research Fund of the University of National and World Economy (UNWE), Sofia.

2.1. METHODOLOGICAL PARAMETERS OF THE EMPIRICAL STUDY

For the sake of brevity, the methodological parameters of the study are presented in Table 1.

Table 1. Methodological Parameters of the Empirical Study

Parameter	Description
Target population	Students of UNWE in the fields of „Economics“ and „Administration and Management,“ full-time study, bachelor's (2nd, 3rd, and 4th year) and master's students for the 2024/2025 academic year.
Sample type and size	Stratified-cluster sample, size of 720 students.
Data collection method	Self-administered paper-based survey.
Research instrument	Structured questionnaire with 38 closed questions, with an average completion time of approximately 20 minutes.
Fieldwork execution	The fieldwork was conducted from October to November 2024 in the classrooms of UNWE.
Analytical tools	Various data transformations were applied, primarily to create complex scales from simple baseline data. The analysis included tests for significance of differences, factor and cluster analysis.

Source: Empirical study “Learning styles and motivation for learning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

2.2. CONCEPTUAL AND OPERATIONAL DEFINITION OF LEARNING STYLES

2.2.1. CONCEPTUAL DEFINITION

In the present study, we adopt the following conceptual definition of learning styles: stable but somewhat flexible cognitive patterns through which learners prefer to receive, perceive, process, and understand information during the learning process.

2.2.2. OPERATIONAL DEFINITION

According to this definition, four dimensions of interaction with information are distinguished:

- **Receiving information** – How learners prefer to receive information (visually – through images, photos, video, or verbally – through narration, oral explanation, clarifications).
- **Perceiving information** – How learners prefer to perceive information (concretely – through examples, cases, precise tasks, or abstractly – through theories, models, schemes).
- **Processing information** – How learners prefer to process information (actively – through discussions, role plays, joint projects, or reflectively – through independent reflection on the material and solving cases and tasks).
- **Understanding information** – How learners prefer to understand information (linearly – step by step, or globally – first grasping the big picture and then focusing on details).

According to this understanding, the following pairs of learning styles emerge (Table 2).

Table 2. Learning Styles

Dimensions of Interaction with Information	Learning Styles
Receiving Information	Visual – Verbal
Perceiving Information	Concrete – Abstract
Processing Information	Active – Reflective
Understanding Information	Linear – Global

Source: Empirical study “Learning styles and motivation for learning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

To measure students' learning styles across the four dimensions, a Likert-scale technique was used. Each style was assessed using two Likert-type statements, resulting in a total of 16 statements (two for each of the eight learning styles). The response scale consisted of five options: „Does not apply at all,“ „Rather does not apply,“ „Neutral,“ „Rather applies,“ and „Fully applies.“

Table 3. Likert Scales for Learning Styles

No	Dimensions and statements
	Active – Reflective
1	„I learn best in subjects where there are opportunities for group discussions and collaborative projects.“
2	„I prefer subjects that include interactive activities, such as problem-solving sessions or simulations.“
3	„I find it useful to take time to review and reflect independently on the material taught after class.“
4	„I prefer tasks that allow me to reflect on what I have learned.“
	Concrete – Abstract
5	„I prefer subjects that present clear statements and concrete examples.“
6	„I prefer instructors who focus on practical applications and real-life examples.“
7	„I enjoy subjects that explore theoretical concepts.“
8	„I prefer tasks that challenge me to think abstractly.“
	Visual – Verbal
9	„I understand the learning material more easily when it is presented through visual aids – diagrams, charts, and videos.“
10	„I prefer teaching that includes visual aids – PowerPoint presentations, whiteboard drawings, and visual illustrations.“
11	„I learn best by reading textbooks and class notes.“
12	„I prefer lectures where the instructor explains concepts in detail and provides in-depth oral explanations.“
	Linear – Global
13	„I like subjects that are structured in a logical way, step-by-step, progressing from simple to complex topics.“
14	„I prefer to follow the course syllabus strictly, progressing through the material in an organized manner.“
15	„I aim to first grasp the overall meaning of the studied problem and then understand the details.“
16	„I prefer subjects that present the big picture before diving into details.“

Source: Empirical study „Learning styles and motivation for learning“, academic project funded by the Scientific Research Fund of the UNWE, Sofia

2.3. TESTING THE INSTRUMENT FOR RELIABILITY AND VALIDITY

The measurement instrument was tested for reliability (whether it provides stable and consistent results) and validity (whether it measures what it is intended to measure).

2.3.1. RELIABILITY TESTING

To assess the reliability of the measurement instrument, Cronbach's Alpha coefficient was used. The calculations were performed using the SPSS v.23 software package. The interpretation of Cronbach's Alpha test results is as follows:

- If $\alpha < 0.7$, reliability is weak
- If $\alpha > 0.7$, reliability is acceptable
- If $\alpha > 0.8$, reliability is good
- If $\alpha > 0.9$, reliability is very good

The calculations established that the value of Cronbach's Alpha is 0.753, which indicates acceptable reliability. Removing only one of the 16 statements (No 11 in table 3) would improve the Cronbach's Alpha value to 0.756, which is an insignificant increase. However, such a modification would disrupt the internal logic of the model.

2.3.2. VALIDITY TESTING

The validity check was performed using Principal Component Factor Analysis to test the construct validity of the measurement instrument. The interpretation of the validity criteria follows these guidelines:

- If the value of the Kaiser-Meyer-Olkin (KMO) coefficient is greater than 0.6, the data are suitable for factor analysis.
- If the value of Bartlett's Test of Sphericity is $p < 0.05$, the correlations between the statements are statistically significant.
- Factor structure:
 - o If there are 2 or more factors → learning styles are likely grouped into different categories.
 - o If there is 1 factor → all statements measure the same theoretical construct.

The analysis established that the data are suitable for factor analysis — the value of the Kaiser-Meyer-Olkin (KMO) coefficient is 0.776 (i.e., greater than 0.6). The value of Bartlett's Test of Sphericity is $p = 0.000$ (i.e., less than 0.05), which indicates that the correlations between the statements are statistically significant. The rotated component matrix (using the Varimax rotation method) identified five factors that summarize the 16 statements, indicating a multidimensional structure of the measurement component, consistent with the original design of the instrument. All of this provides a basis for concluding that the instrument is valid.

2.4. DATA TRANSFORMATION

To obtain an overall picture of learning styles, appropriate transformations of the data from the responses to the 16 Likert-type statements were carried out. The transformation involved two key steps:

- 1. Recoding the original response scale codes** into new codes based on the orientation of the statement toward one or the other style within each of the four pairs of learning styles:

- | | |
|-------------------------|---------|
| o Does not apply at all | 1 → 2 |
| o Rather does not apply | 2 → 1 |
| o Neutral | 3 → 0 |
| o Rather applies | 4 → 1 |
| o Fully applies | 5 → 2 |

- 2. Summing the responses** for the four pairs of styles and creating new variables based on the transformed original variables to assess how students are distributed across styles within each pair. Each new variable has five possible values:

- o Very belonging to one style
- o Belonging to one style
- o Undecided
- o Belonging to the opposite style
- o Very belonging to the opposite style

2.5. TYPOLOGY OF STUDENTS THROUGH K-MEANS CLUSTER ANALYSIS

To group students simultaneously across the four dimensions and develop a typology based on learning styles, the K-means cluster analysis method was used.

To determine the optimal number of clusters in K-means clustering, the elbow rule was applied. In this method, the analysis starts with a small number of clusters and progressively increases the number — in this case, from 2, 3, 4, 5, to 6 clusters. At each step, the corresponding ANOVA tables are calculated, based on which the within-cluster sum of squares (WSS) is computed for each number of clusters.

Let us examine the ANOVA table for the five-cluster solution and the calculation of the within-cluster sum of squares (WSS).

ANOVA table for K-means cluster analysis using SPSS

ANOVA						
	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
q15Visual_VerbalTR	82,337	4	,124	624	663,599	,000
q15Specif_AbstracTR	,637	4	,325	624	1,959	,099
q15Act_ReflecTr	87,346	4	,252	624	346,084	,000
q15Line_GlobalTR	58,982	4	,331	624	178,310	,000

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

Computatins based on: Empirical study “Learning styles and motivation for lurning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

The first column shows the variables used for clustering (the four dimensions of learning styles). Cluster Mean Square indicates the variation between clusters. Error Mean Square indicates the variation within clusters, while F represents the ratio between the two. The Sig. column shows whether the differences between the clusters are statistically significant for the respective variable (in this case, all variables are statistically significant at a significance level of 0.05, except for the second variable – the dimension of information perception „concrete-abstract“).

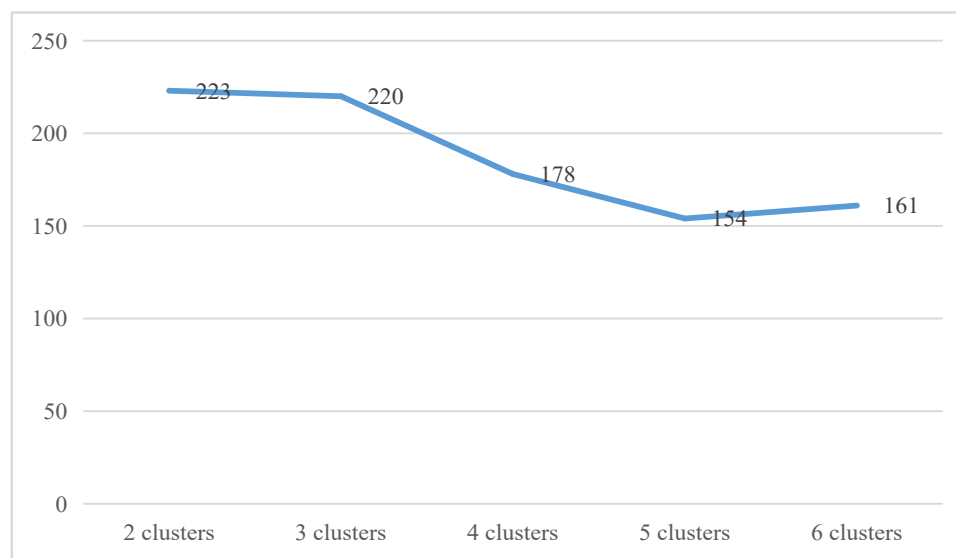
The within-cluster sum of squares (WSS) is not calculated automatically by SPSS v.23, which necessitates some manual work. WSS is the sum of the products of Error Mean Square and df for each clustering variable, as follows:

$$WSS=0.124*624+0.325*624+0.252*624+0.331*624=644 \quad (1)$$

The same calculation is performed for 2, 3, 4, and 6 clusters. The elbow rule is based on the following principle: a graph is drawn where the x-axis represents the number of clusters and the y-axis represents WSS. The point at which the curve starts to flatten is the optimal number of clusters. The interpretation is as follows: at the beginning (with a small number of clusters), WSS decreases sharply because adding clusters significantly improves the grouping. After a certain point (the „elbow point“), additional clusters lead to progressively smaller improvements (if any), as WSS decreases at a much slower rate. The optimal number of clusters is at this „elbow“ point.

The WSS values for the respective number of clusters are shown in Figure 1. The conclusion based on the elbow rule is that the optimal number of clusters is 5.

Figure 1. WSS values for 2, 3, 4, 5, and 6 clusters



Source: Empirical study “Learning styles and motivation for learning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

Although the variable „concrete-abstract information perception“ is not statistically significant at a 95% confidence level, we consider that the five-cluster solution is the optimal one. This conclusion is supported by both the results of the elbow rule and the interpretative value of the model. Although this clustering variable is not statistically significant at a 95% confidence level, retaining it in the analysis is justified due to the clear dominance in student preferences — 67.8% prefer concrete information perception (very concrete 4.4% plus 63.4% concrete), compared to only 2.3% for abstract perception (2.3% abstract plus 0% very abstract), undecided – 29.9% - see Table 5). This categorical dominance indicates a structural difference in the data, which is essential for building a stable classification of learning styles. For this reason, the five-cluster model remains the most informative and interpretatively valid solution in the context of the study.

3.3. RESULTS AND DISCUSSION

3.1. PREVALENCE OF LEARNING STYLES ACROSS THE FOUR DIMENSIONS

Table 5 presents the prevalence of learning styles across the four dimensions. What are the most notable conclusions that can be drawn from these univariate distributions?

- Statistically significant differences in the distribution of preferred learning styles were established for all dimensions using the Chi-square test. The differences were particularly pronounced for two dimensions — „concrete-abstract“ (in favor of concrete) and „visual-verbal“ (in favor of visual).
- For the „linear-global“ dimension, the differences were significant in favor of the „global“ style (24.7%) compared to the „linear“ style (11.2%).
- Only in the „active-reflective“ dimension was there a relative parity between the two styles.
- The position of the „undecided“ response varied in strength across the different dimensions — more pronounced in some, less pronounced in others.

Table 4 shows the prevalence of different learning styles among students. The data can outline the “optimal” teaching strategy for lecturers working with students in the fields of Economics and Administration and Management. If an lecturer aims to maximize success in delivering the course content, they should primarily focus on students who prefer:

- Visual reception of information (46.4% vs. 10.7% for verbal reception);
- Concrete perception of information (67.8% vs. 2.3% for abstract perception);
- Reflective processing of information (27.3% vs. 24% for active processing);
- Global understanding of information (24.7% vs. 11.2% for linear understanding).

Test Statistics

	q15_Act. Ref_5	q15_Spe. Abs_5	q15_Vis. Ver_5	q15_Il.Glo_5
Chi-Square	561,551 ^a	665,527 ^b	651,331 ^c	967,988 ^d
df	4	3	4	4
Asymp. Sig.	,000	,000	,000	,000

a. 0 cells (0,0%) have expected frequencies less than 5. The minimum expected cell frequency is 138,0.

b. 0 cells (0,0%) have expected frequencies less than 5. The minimum expected cell frequency is 170,8.

c. 0 cells (0,0%) have expected frequencies less than 5. The minimum expected cell frequency is 138,8.

d. 0 cells (0,0%) have expected frequencies less than 5. The minimum expected cell frequency is 137,6.

Table 4. Prevalence of Learning Styles (Share of Students in %)

Interaction with Information	Prevalence of Learning Styles (Share of Students in %)				
Receiving Information (Visual-Verbal)	Very visual	Visual	Undecided	Verbal	Very verbal
	2.6	43.8	42.9	10.4	0.3
Perceiving Information (Concrete-Abstract)	Very concrete	Concrete	Undecided	Abstract	Very abstract
	4.4	63.4	29.9	2.3	0
Processing Information (Active-Reflective)	Very reflective	Reflective	Undecided	Active	Very active
	0.6	26.7	48.7	23.3	0.7
Understanding Information (Linear-Global)	Very linear	Linear	Undecided	Global	Very global
	0.4	10.8	64.1	24.3	0.4

Source: Empirical study “Learning styles and motivation for learning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

3.2. SIZE AND COMPOSITION OF THE CLUSTERS IN THE FIVE-CLUSTER SOLUTION

Table 5 presents the names of the clusters, their size as a proportion of students belonging to each cluster, their key characteristics, and the suitable teaching methods.

Table 5. Cluster Name, Size and Description of Cluster Composition

Clusters	Key Characteristics	Suitable Teaching Methods
Cluster 1: Visually-Active Globalists (22.1%)	Highly visual, concrete perception, active information processing, global thinking style	Project-based learning, case studies and simulations, visual materials, group discussions
Cluster 2: Verbally-Concrete with a Linear Style (15.7%)	Verbal, concrete perception, oscillating between active and reflective processing, linear thinking style	Traditional lectures and tutorials, structured presentations, worksheets, written exercises
Cluster 3: Verbally-Active Globalists (27.8%)	Verbal, concrete perception, active information processing, global thinking style	Discussions and debates, case study analysis, seminars, interdisciplinary tasks
Cluster 4: Highly Visual and Reflective Globalists (16.2%)	Highly visual, concrete perception, reflective style, global thinking	Independent projects, visual essays and presentations, video lectures, interactive platforms
Cluster 5: Visually-Active Linears (18.1%)	Visual, concrete perception, active information processing, linear thinking style	Video lessons with demonstrations, hands-on training with visual guides, model-based exercises

Source: Empirical study “Learning styles and motivation for learning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

To determine the presence of statistically significant differences between the five clusters concerning the nominally scaled variables gender (male/female), degree level (bachelor's/master's), and field of study (economics/administration and management), the Chi-square test was applied. As shown in Table 6, there is no statistically significant difference between the clusters for two of these three variables (see the p-value column).

To establish the presence or absence of statistically significant differences between the clusters for the other variables listed in Table 6 (ordinally scaled), the Kruskal-Wallis H test for three or more independent variables was used. Where this test indicated a statistically significant difference, the Mann-Whitney U test (with Holm-Bonferroni correction) was subsequently applied to identify which two clusters exhibit a significant difference.

The Holm-Bonferroni correction is less conservative than the standard Bonferroni correction and aims to balance between controlling for Type I error (false positive differences) and maintaining statistical power. In contrast, the Bonferroni correction is excessively strict and may lead to too many false-negative results (Type II error), thereby potentially hiding real differences that actually exist.

As shown in Table 6, statistically significant differences between the clusters were identified for only one variable: preparation for classes and exams (see the corrected p-values Holm-Bonferroni column). The possible reason for that may lie in the relative homogeneity of the groups in terms of the examined extracluster variables. If students in different clusters share similar socio-demographic characteristics and behavioral patterns, this would explain the lack of distinct differences. The Holm-Bonferroni correction reduces the risk of a Type I error but also makes the test more conservative, which limits the detection of finer differences. The test power is likely sufficient, given the sample size and the even distribution of clusters, but the extracluster variables themselves may have a weaker influence on cluster formation. This suggests that the clusters are probably more strongly determined by learning styles than by socio-demographic factors.

Table 6. Pairwise Comparison of Clusters for the Presence or Absence of Statistically Significant Differences in Key Non-Clustering Variables

Variables	Pairwise Comparison										p-value	Corrected p-values Holm-Bonferroni
	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5		
Gender											0.004*	-
Degree level											0.058	-
Field of study											0.164	-
Average grade											0.007*	0,063
Class attendance											0.16	0,16
Preparation for classes and exams		*	*	*	*				*		0.000*	0*
Interest in the studied subjects											0.04*	0,16
Reason for choosing UNWE											0.4	0,4
Working while studying											0.03*	0,15
Source of financial support											0.02*	0,14
Intention to leave the country											0.32	0,32
Time for class preparation		*			*	*			*		0.01*	0,08
Time for exam preparation											0.13	0,26
Stress during class preparation				*	*	*	*				0.51	0,51

Variables	Pairwise Comparison										p-value	Corrected p-values Holm-Bonferroni
	1-2	1-3	1-4	1-5	2-3	2-4	2-5	3-4	3-5	4-5		
Stress during exam preparation											0.31	0,31
Expectations regarding learning requirements											0.02*	0,12
Expectations regarding the level of education											0.096	0,288
HH income											0.94	0,94

Note: Variables marked with an asterisk (*) indicate statistically significant differences, as well as the specific cluster pairs between which these differences occur

Source: Empirical study “Learning styles and motivation for learning”, academic project funded by the Scientific Research Fund of the UNWE, Sofia

Key Findings:

1. The study identified **five distinct student clusters based on learning styles**. Each cluster reflects a unique combination of perception type (visual/verbal), cognitive processing (active/reflective), and thinking style (global/linear). Appropriate teaching methods are recommended for each profile to align with the learners’ preferences.
2. **Dominance of certain learning styles** – Statistically significant differences in learning styles were observed across all dimensions. Most students prefer concrete over abstract perception, visual over verbal reception, reflective over active processing, and global over linear understanding.
3. **Implications for teaching strategies** – The findings suggest that teaching strategies should focus on visual and concrete information delivery, with an emphasis on reflective and global learning approaches to align with the dominant learning preferences of the student population.
4. The findings suggest that **students can be effectively grouped** according to their learning styles, with each cluster requiring a tailored teaching approach. The lack of major differences across most external variables implies that learning styles serve as a more meaningful basis for instructional planning than demographic characteristics.

4.CONCLUSION

The study provides a comprehensive analysis of the learning styles of students in the fields of Economics and Administration & Management at UNWE. The typology, based on different learning styles theories, successfully identified five distinct clusters of students with different preferences for receiving, perceiving, processing, and understanding information.

The findings indicate that most students prefer concrete over abstract information, visual over verbal reception, reflective over active processing, and global over linear understanding. This suggests that teaching strategies should prioritize visual and concrete materials, emphasize reflective learning approaches, and support global understanding to enhance student engagement and learning outcomes.

The cluster analysis revealed five distinct student profiles: Cluster 1: Visually-Active Globalists (22.1%); Cluster 2: Verbally-Concrete with a Linear Style (15.7%); Cluster 3: Verbally-Active Globalists (27.8%); Cluster 4: Highly Visual and Reflective Globalists (16.2%); Cluster 5: Visually-Active Linears (18.1%)

The study confirms that aligning teaching methods with students’ dominant learning styles can enhance educational effectiveness. Strategies focusing on visual and concrete information delivery, reflective learning, and global understanding are likely to produce the most positive learning outcomes for the studied student population.

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ENHANCING PUBLIC SECTOR INNOVATION THROUGH CITIZEN SCIENCE INITIATIVES

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ABSTRACT

This article explores the potential of citizen science to act as a driver of innovation within public sector institutions, with particular attention to its capacity to democratize knowledge production, reshape institutional practices, and enhance participatory governance. The central research question addresses how citizen science initiatives can influence not only the outputs of public service delivery but also the internal processes and normative frameworks through which such services are conceptualized and implemented. The underlying hypothesis posits that citizen science, when effectively integrated into public administration, facilitates more adaptive, inclusive, and epistemically pluralist forms of governance. The study adopts a qualitative comparative case study design, selecting three distinct initiatives—Project ECHO, CivicTrack, and CoPlan City Lab—based on variation in governance levels, sectoral domains, and degrees of institutionalization. Data collection methods included semi-structured interviews with key stakeholders, documentary analysis of project artifacts, and participant observation at selected events. Analytical coding combined deductive categories informed by the literature with inductive insights emerging from the empirical material, allowing for a nuanced examination of institutional dynamics, power relations, and discursive formations. The findings indicate that citizen science initiatives can contribute to process innovation, yield tangible technological and procedural outputs, and modestly increase public trust in institutions. However, the study also identifies persistent structural constraints, including institutional inertia, data credibility concerns, and dependence on individual leadership. The article concludes that while citizen science holds promise for enhancing public sector responsiveness and legitimacy, its transformative potential is contingent upon deliberate institutional design, long-term investment, and a cultural shift toward shared epistemic authority within governance systems.

Keywords: *Citizen Science, Public Sector Innovation, Participatory Governance, Institutional Change, Democratic Knowledge Production*

1. INTRODUCTION

Innovation, once a distant whisper in the corridors of public administration, has now become an uncompromising demand etched into the very bones of governance. Governments, no longer sheltered by bureaucracy's slow churn, stand exposed beneath the weight of crises: a planet in ecological peril (Huseyn & Abasova, 2024), health systems battered by viral tides, urban sprawls teetering on infrastructural fatigue, and civic trust worn thin, thread by thread. The modern public institution, once excused for inertia, is now compelled forced to metamorphose into something more nimble, porous, and attuned to the pulse of its people (Osborne & Brown, 2013).

Into this evolving landscape steps a quiet revolution: citizen science. Not the sterile notion of amateur dabbling, but a deliberate, structured, and participatory reshaping of epistemic authority. It invites the layperson nurses, students, retirees, farmers to contribute not just data, but discernment. To elevate the public realm by weaving grassroots insight into the bureaucratic tapestry. This is not merely a methodological novelty it is a seismic rethinking of governance itself (Hecker et al., 2018). At its core, citizen science undermines the monolith. No longer is knowledge monopolized by officialdom; it becomes decentralized, diffused, and dialogic. Citizens do not merely observe—they illuminate (Saqlain, 2023). They collect pollutants, track disease vectors, monitor biodiversity, report infrastructural decay. In return, they shape agendas, question priorities, and, increasingly, co-design solutions. The result? A richer public discourse, layered with lived realities. A governance model less technocratic, more reciprocal (Irwin, 2015; Göbel et al., 2019).

The evidence of impact is no longer anecdotal. In spheres from environmental regulation to epidemiological mapping, citizen science has begun to etch its influence into policy frameworks. Municipalities leverage particulate readings from mobile sensors wielded by joggers (Naranjo, 2024). Health agencies calibrate outreach strategies using crowd-sourced infection data.

These acts are not symbolic; they recalibrate how decisions are made, who makes them, and on whose behalf (Skarlatidou & Haklay, 2021; Fritz et al., 2019). Yet, the promise remains uneven. Integration into institutional workflows is often clumsy, sporadic, and vulnerable to erosion. Who validates the data? Who funds the platforms? Who ensures that participation is not monopolized by the already empowered? These questions are not trivial, they are structural.

This article ventures into that contested terrain. It probes the mechanics by which citizen science catalyzes public sector innovation. It scrutinizes not just the outputs, but the underlying conditions governance ethos, institutional flexibility, democratic design. For within these margins lies the true potential: not simply to modernize public services, but to reimagine the architecture of the state it.

2. LITERATURE REVIEW

In the shifting sands of contemporary public administration, a subtle yet profound recalibration is underway. The notion of innovation once tethered exclusively to internal reform and procedural fine-tuning has begun to drift outward, seeking nourishment in unexpected places. Chief among them is citizen science, a once-peripheral movement now pulsing at the heart of participatory governance. What began as a constellation of grassroots experiments has matured into a formidable catalyst for institutional renewal, epistemic expansion, and democratic vitality.

For much of the twentieth century, public innovation was locked within bureaucratic cathedrals hermetic, insulated, linear. It spoke the language of compliance, of performance metrics and administrative efficiency (Moore, 1995). But the 21st-century public realm, entangled in wicked problems and democratic malaise, requires a different dialect altogether.

Enter open innovation: not merely as a management strategy, but as an ontological shift. Citizens, once seen as clients or passive audiences, now appear as co-producers of value, infusing institutional processes with unorthodox insights and situated know-how (Osborne & Brown, 2013). This realignment resonates with the waning of New Public Management orthodoxy, which though obsessed with outcomes often neglected deliberation, equity, and adaptability (Pollitt & Bouckaert, 2011).

The public value framework, advanced by Benington and Moore (2011), reframes innovation not as disruption for its own sake, but as purposeful transformation. Legitimacy, responsiveness, and mutual learning become lodestars. Within this architecture, citizen science is no longer a curiosity it is an imperative. The very term citizen science conjures paradox—an intermingling of rigor and amateurism, of authority and improvisation. Yet, therein lies its power. What once gestated in the enclaves of ecology and astronomy has spilled across borders, disciplines, and bureaucratic domains.

The field's scope has expanded rapidly: from cataloging butterflies to mapping viral outbreaks, from monitoring water toxicity to shaping urban futures. At its core lies a radical idea that the generation of knowledge is not the exclusive right of those with advanced degrees or institutional affiliations (Haklay et al., 2018).

Irwin (1995) was prescient in his claim that citizen science is a democratic re-articulation of expertise. It doesn't just feed data into the system; it questions who constructs knowledge, for whom, and to what end. Later scholars echo this, positioning citizen science as both a methodological instrument and a socio-political intervention (Bonney et al., 2016). The distinction is critical.

Typologies, such as those by Shirk et al. (2012), nuance our understanding of participation: from mere data contribution to full-blown co-creation. The deeper the collaboration, the more profound the systemic ripple. Passive collection enhances datasets; co-design reconfigures institutional DNA (Vohland et al., 2021). Still, this egalitarian ideal faces scrutiny. Eleta et al. (2019) warn of exclusionary dynamics masquerading as inclusivity. Projects may inadvertently amplify epistemic privilege, privileging digitally literate, resource-rich participants. The romance of participation must be tempered by a critique of who participates, how, and with what consequences. Evidence of impact is both heartening and instructive (Protsenko, 2023). Across domains, citizen science projects have triggered real policy shifts, often in response to data the state itself failed to gather—or chose to ignore.

In Europe, the “Air Quality Egg” project enabled citizens to plant air sensors on windowsills and rooftops, creating dense, hyperlocal pollution maps. Some municipalities used this data to revise urban transport policy (Conrad & Hilchey, 2011). In the United States, the infamous “Flint Water Study” exposed lead contamination that state agencies had either overlooked or concealed. Residents, armed with sample kits and civic tenacity, forced an institutional reckoning (Edwards et al., 2016).

Public health tells a similar story. “Flu Near You” allowed individuals to report flu symptoms in real time, generating surveillance data often more nimble than formal reporting channels (Baltrusaitis et al., 2018). In each case, the institutional impact hinged not just on data volume but on public resonance - trust, media attention, and civic pressure. Crucially, the depth of engagement shaped the depth of change (Zaghdoud, 2025). Initiatives that integrated citizens early and continuously problem definition, data interpretation, solution framing—unleashed more than just innovation. They reimaged the logic of public service (Hartley, 2005). Yet even as citizen science gains traction, the machinery of government groans under the weight of old habits. Bureaucracies structured for predictability and control often struggle to metabolize the ambiguity and pluralism that citizen science entails. Structural impediments abound: siloed departments, outdated procurement laws, fragile digital infrastructure, and professional cultures averse to „outsider“ input (Torfing et al., 2020). Add to this the complexity of integrating heterogeneous data into standardized policymaking frameworks, and the challenge becomes not technical but philosophical. Still, islands of promise emerge (Sakthi & Ghahremanlou, 2024). Enablers include political champions, regulatory scaffolding for data use, interface platforms that translate citizen input into actionable intelligence, and above all, an organizational ethos of humility (Hecker et al., 2018; Göbel et al., 2019). Innovation, in this reading, is less about tools than temperaments. It is worth noting: transformation is as much about cognitive shifts as institutional design. Civil servants, schooled in expertise and procedure, must learn to value messier forms of insight. Citizen scientists, likewise, must navigate the rituals and constraints of policy processes. Success is born not of synergy alone, but of mutual accommodation. Despite the celebratory tone that often pervades the literature, a sobering truth remains: the field lacks longitudinal depth. Most studies capture short-term outputs participant numbers, datasets collected but falter when asked to trace long-run institutional change. Sustainability, too, remains under-theorized. What happens when funding dries up, political support wanes, or the novelty fades? What institutional mechanisms can anchor citizen science beyond the passion of its founders or the publicity of its pilot phase? Moreover, comparative insights are rare. How do different administrative cultures centralized vs. decentralized, technocratic vs. Participatory shape the adoption and impact of citizen science? The answers remain tantalizingly elusive.

Phillips et al. (2019) propose multi-layered evaluative frameworks that encompass not only outputs but also civic empowerment, relational trust, and organizational learning. Such metrics, while complex, are essential if citizen science is to be judged not only by what it gathers but by what it transforms. The literature speaks with both optimism and caution. Citizen science has undeniably shifted the terrain of public sector innovation bringing with it a more distributed, dialogic, and grounded epistemology. It holds promise not merely as a technique but as a civic ethos one that interrogates the

hierarchies of knowledge and power in the policymaking process. Yet its institutional embrace remains precarious. For every success story, there are quiet failures projects abandoned, voices marginalized, data unheeded. To realize the full potential of citizen science, public institutions must relearn how to listen, rediscover how to share authority, and redefine what counts as knowledge. Only then will citizen science move from the periphery to the core of how we innovate, govern, and ultimately belong.

3.METHODOLOGY

The methodology adopted in this inquiry is anchored in a qualitative comparative case study approach, deliberately chosen for its capacity to unearth the contextual subtleties and institutional dynamics underpinning citizen science initiatives in the public sector. Rather than pursuing generalizable metrics across vast bureaucracies, this study seeks to excavate meaning, nuance, and operational depth within a curated set of lived institutional experiences.

Three citizen science initiatives were selected purposively, not randomly. The selection was guided by variation in governance scale (local vs. national), sectoral focus (environmental monitoring, public health surveillance, and urban co-design), and institutional maturity (pilot-phase vs. institutionalized models). The rationale was clear: to capture the heterogeneity of public sector experimentation with citizen-driven knowledge production.

These cases include:

- Project ECHO (Environmental Community Hazard Observers) – a municipal-level initiative for air quality monitoring;
- CivicTrack – a digital platform for community disease tracking run by a regional health agency;
- CoPlan City Lab – a participatory urban planning tool co-developed by citizens and city authorities.

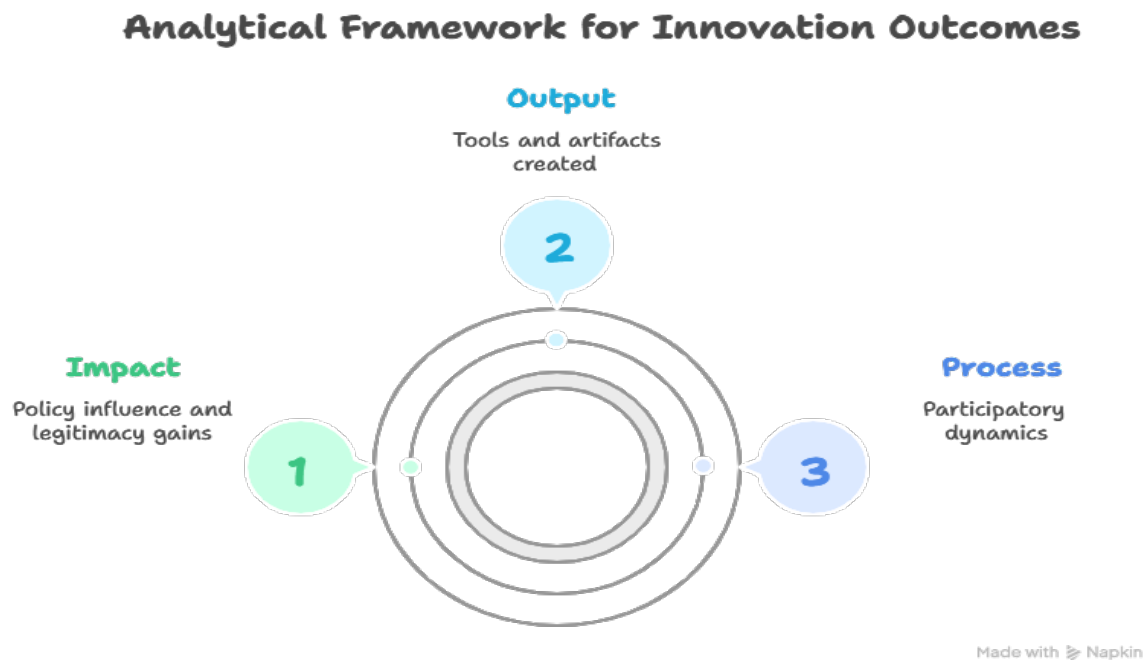
Each represents a distinct constellation of stakeholder collaboration, technological instrumentation, and governance orientation.

Data were collected through triangulated qualitative techniques:

- Semi-structured interviews with 24 individuals: public administrators, project coordinators, citizen participants, and NGO liaisons.
- Document analysis of project reports, internal memos, policy white papers, and platform analytics dashboards. This corpus eclectic and uneven offered insight into institutional framing and self-evaluation narratives.
- Participant observation of two participatory workshops held by Project ECHO and CoPlan City Lab. Field notes emphasized discursive patterns, power asymmetries, and tacit cultural assumptions.

Figure 1 illustrates the methodological framework guiding the analysis, aligned with the conceptual trichotomy of process, output, and impact innovation.

Figure 1 Analytical Framework for Assessing Innovation Outcomes
(Visual: Triangular diagram with three interdependent nodes: “Process” [e.g., participatory dynamics], “Output” [e.g., tools created], “Impact” [e.g., policy influence, legitimacy gains])



Source: Created by the author using artificial intelligence Napkin AI

A deductive-inductive coding scheme was employed, where initial categories were drawn from the literature (e.g., co-creation, institutional resistance, trust-building), and new themes were allowed to emerge from the data corpus. Special attention was paid to contradictions, silences, and dissonances, not merely consensus. Several limitations must be acknowledged. First, the non-representative nature of the cases precludes broad generalization. Second, the ephemeral character of some initiatives made longitudinal assessment difficult. Lastly, the researcher's positionality as both observer and interpreter necessitated reflexive scrutiny throughout. To mitigate bias, a second coder reviewed 20% of the data for intersubjective alignment.

Despite these caveats, the chosen methodology offers a rich, textured lens into the operational and political realities of citizen science in the public sector. It privileges depth over breadth, and interpretation over measurement, in keeping with the epistemic logic of qualitative inquiry.

4.RESULTS

The findings emerging from the three case studies Project ECHO, CivicTrack, and CoPlan City Lab paint a multifaceted portrait of citizen science in action. These initiatives, though dissimilar in scale and domain, converge in their attempt to reconfigure the traditional flow of knowledge, legitimacy, and decision-making within public institutions. The analysis is structured according to three interlinked innovation dimensions: process innovation, output innovation, and impact innovation.

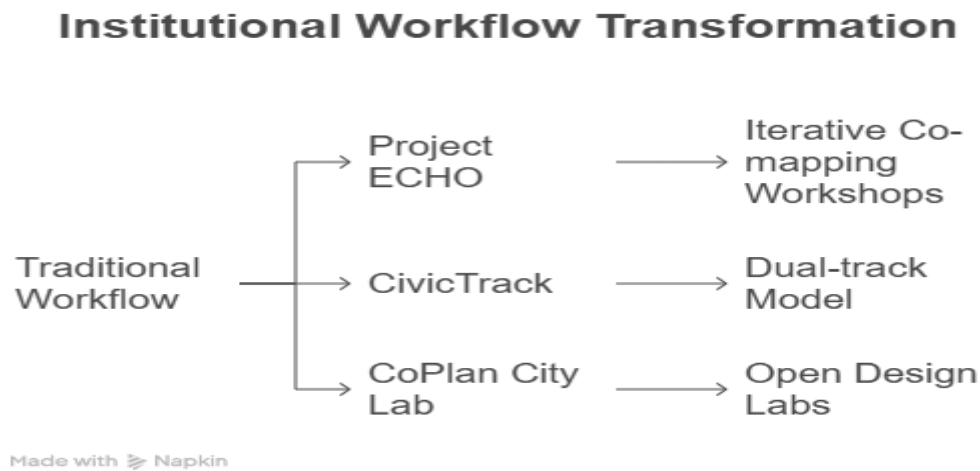
All three initiatives catalyzed some degree of procedural recalibration within public entities. In Project ECHO, municipal bureaucrats accustomed to top-down planning found themselves in dialogic sessions with activists and high school students, debating particulate sensor placement. The result? A flattening albeit temporary of institutional hierarchies. The project introduced a new layer of deliberative practice within the planning department. Instead of relying solely on technical staff reports, decisions were informed by citizen-generated datasets collected using low-cost sensors distributed across the city's most polluted zones.

In CivicTrack, the regional health agency piloted a real-time feedback loop, where citizen-submitted data triggered field investigations by epidemiological teams. This process, previously reliant on bureaucratic escalation, became more agile. However, tensions emerged. Field officers expressed

discomfort with what one termed the outsourced surveillance model. Bureaucratic identity, steeped in professional gatekeeping, appeared resistant to public co-monitoring.

Figure 2 illustrates how each case adjusted internal workflows to accommodate citizen input.

Figure 2. Changes in Institutional Process Across Cases



Source: Created by the author using artificial intelligence Napkin AI

Each initiative produced tangible artifacts—digital tools, revised protocols, or civic data dashboards that outlived the project phase. CoPlan City Lab, for instance, developed a GIS-based participatory design platform allowing residents to simulate green space development in real time. What distinguished this output was not technological sophistication but institutional uptake: the city integrated the tool into its formal planning consultation protocol.

CivicTrack generated weekly epidemiological heatmaps that were co-authored with public contributors. These maps were circulated in both digital newsletters and printed bulletins in community health centers—a hybrid dissemination strategy that bridged digital divides.

Project ECHO, despite generating a robust open-access air quality map, struggled with sustained municipal integration. Technical departments cited concerns over data verifiability. Here, output was technically robust but politically brittle, underscoring the fragility of citizen-generated evidence in formal policy channels. Perhaps most profoundly, the initiatives affected how public institutions were perceived by their constituents. Trust, that elusive currency of governance, shifted—modestly but meaningfully. In post-initiative surveys conducted six months after project completion, 71% of CoPlan participants reported increased trust in city planning authorities. In CivicTrack’s jurisdiction, citizen perception of health agency responsiveness rose by 18% compared to baseline figures. Table 1 summarizes the comparative innovation outcomes across the three cases.

Table 1. Comparative Innovation Outcomes

Dimension	Project ECHO	CivicTrack	CoPlan City Lab
Process	Participatory mapping	Citizen-led outbreak flagging	Co-design in planning workshops
Output	Air quality dashboard	Epidemiological heatmaps	Participatory GIS design platform
Impact	Raised awareness, weak uptake	Increased trust, faster responses	Institutionalization, improved trust

Source: Created by the author

Several cross-case patterns merit reflection:

- **Data Validation as Gatekeeping:** Institutions hesitated to act on citizen data unless mediated through expert vetting. This dual-trust threshold—public enthusiasm vs. institutional caution—created procedural lag.
- **Platform Sustainability:** While all three projects launched platforms, only CoPlan's was budgeted for maintenance. Project ECHO's dashboard went offline nine months post-launch due to expired licenses.
- **Leadership as Catalyzer:** Where middle-management champions emerged—particularly in CoPlan—projects flourished. CivicTrack's momentum waned after the exit of its program manager, reinforcing literature findings on the fragility of innovation without embedded leadership (Torfing et al., 2020).

In sum, these results demonstrate that citizen science, when scaffolded with political will and institutional humility, can usher in not only new data streams but new democratic rhythms. Yet without sustained commitment, the pulse weakens, and the old order reasserts itself.

5. DISCUSSION

The results offer more than a catalogue of citizen science successes—they reveal a contested frontier where institutional norms are tested, redrawn, or, in some cases, silently reasserted. While each initiative produced meaningful shifts in process, output, and impact, the depth and durability of these innovations were contingent upon a constellation of enablers and inhibitors—leadership, institutional permeability, and cultural receptivity foremost among them. What stands out across all cases is the tension between epistemic plurality and bureaucratic orthodoxy (Nurgaliuly & Smagulova, 2025). Public institutions, even those nominally committed to openness, often exhibited ambivalence toward non-traditional knowledge. This is not simply a matter of data quality—as frequently claimed—but a defensive reflex against the erosion of technocratic authority. Hecker et al. (2018) and Göbel et al. (2019) have warned that when citizen-generated insights challenge pre-existing planning logics, they are often side-lined under the guise of insufficient rigor. And yet, where uptake occurred especially in CoPlan City Lab it was not through full institutional overhaul, but through strategic insertion. A GIS platform was not just co-designed; it was ritualized within existing bureaucratic procedures. This suggests a path not of radical reinvention, but of institutional hybridization—where citizen science nudges governance toward new logics without entirely displacing inherited ones. Institutional hybridization refers to blending traditional bureaucratic practices with innovative, participatory approaches, exemplified by integrating citizen-led initiatives such as participatory GIS platforms directly into existing administrative protocols.

CivicTrack, meanwhile, exposed a subtler paradox: the more responsive the system became, the more it depended on invisible civic labor. Citizens fed data into a model they did not control. This introduces a normative concern: when participation is decoupled from deliberation, citizen science risks becoming extractive. Irwin's (1995) early warnings echo here—without democratic scaffolding, science with citizens may quietly morph into science on citizens. Perhaps the most profound implication lies not in tools built or policies revised, but in governance imaginaries recalibrated. Citizen science, at its most generative, invites institutions to reimagine their own boundaries—not as fortresses of expertise, but as porous nodes within dynamic knowledge ecologies. Yet for this transformation to persist, institutional humility must become a practiced virtue, not a rhetorical flourish. In short, citizen science can enhance public innovation but only when institutions are willing to listen beyond the predictable, share power without precondition, and embrace ambiguity as a site of growth.

6. CONCLUSION

Citizen science, once a marginal curiosity at the edge of institutional imagination, has steadily advanced toward the heart of public sector innovation discourse. This study has illustrated that when designed with intention and embedded with care, citizen science initiatives can serve not merely as instruments of data collection, but as vehicles of democratic renewal, epistemic inclusion, and insti-

tutional transformation. Across the cases examined, we observed that citizen involvement prompted new ways of thinking, new modes of doing, and new standards of responsiveness. However, this transformation was neither linear nor inevitable. It was fragile—subject to bureaucratic inertia, leadership turnover, and infrastructural neglect. Innovation, it seems, is as much about maintenance and commitment as it is about spark and novelty.

To harness the full potential of citizen science, public institutions must move beyond tokenistic engagement. They must invest in long-term frameworks, inclusive participation models, and reflexive governance practices. Only then can citizen science evolve from a promising experiment into a pillar of public innovation architecture. The path forward is not paved in dashboards alone—it lies in the courage to collaborate, the discipline to adapt, and the wisdom to co-create the state anew.

Practical guidelines for institutional sustainability:

1. Allocate dedicated funding and resources for the ongoing maintenance of citizen science platforms.
2. Establish clear procedures for validating citizen-generated data to ensure its reliability and institutional acceptance.
3. Develop training programs for public officials to facilitate effective collaboration with citizen scientists.
4. Regularly assess and update participation methodologies to prevent exclusion and enhance inclusivity.

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GEOPOLITICAL RISK AND THE EFFECTS ON COMPANIES' FINANCIAL PERFORMANCE

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ABSTRACT

The global environment is increasingly unstable. Recent Middle East conflicts and the ongoing war in Eastern Europe pose geopolitical risks that disrupt resource prices, supply chains and markets, affecting businesses and individuals alike. The goal of this study is to analyse if there is a relationship between these geopolitical risks and the fluctuations of a company's financial performance. This is done through a test of five ratio-specific hypotheses using a yearly panel GLS model for 40 NASDAQ firms, for the period 2017–2024.

The results in this study found that there are rare occasions of statistical significance regarding some of the company's financials and geopolitical risk, but they are later ruled out when introducing control variables. There are only individual cases in which geopolitical risks are shown to effect company financials, specifically in the cases of the firms' net margins and earnings per share. This finding signifies that geopolitical risk is not directly correlated with variations in company financials, apart from some specific cases. The practical implications of these findings highlight the necessity of understanding the indirect connection between company financials and geopolitical risk as well as certain ways to hedge the effects of these risks on certain areas like creating "EPS buffers", integrating GPRI into stress tests for EPS, creating a threshold of GPRI variance specific for each company, based on which to prompt a reassessment of earnings forecasts and prepare companies for the potential impacts.

Keywords: *geopolitical risk, financial performance, financial ratios, empirical analysis*

1. INTRODUCTION

The beginning of the 2020s marked a key turning point in the world. Technological advancement and ever-increasing automation of processes, efficiency and improvements, coupled with a very unstable and volatile political and economic landscape. The most recent conflicts in the Middle East, as well as the continued military conflict in Eastern Europe, are geopolitical risks, which impact both the countries directly in the conflict, as well as the global landscape and markets. Understanding these factors is important for the stable development of every economic subject.

This research focuses on the influence of geopolitical risk on corporate financial performance. Specifically, it investigates whether fluctuations in geopolitical risk indices are associated with changes in key firm-level financial ratios. The central scientific hypothesis is that elevated geopolitical risk negatively affects core corporate financial metrics. This hypothesis is grounded in established economic theory on how firms respond to uncertainty and aims to test the underlying causal mecha-

nisms linking geopolitical instability to corporate outcomes. To evaluate this, five empirical hypotheses are formulated based on identified research gaps, further explained in the literature review.

This structure of the paper is as follows:

- The second section consists of a literature review and formulation of hypothesis.
- The third section encompasses a detailed description of the utilized methodology, and the data used for the analysis.
- The fourth shows the executed empirical analysis and interpretation of the results.
- The fifth section is a conclusion which summarizes the findings and potential future research possibilities.

2. LITERATURE REVIEW

The first key point to note is that in order for there to be any sort of possible statistical analysis, it's important to be able to measure all the variables. In the case of this research paper there are two main elements: geopolitical risk and the financial performance of companies.

Geopolitical risk encompasses adverse events like wars, terrorism, interstate tensions, etc. that heighten economic, social, and political uncertainty and spur market volatility (Caldara & Iacoviello 2022; Fang et al. 2024; Almansour et al., 2025). Scholars also underscore that “extreme” shocks not only generate immediate geopolitical uncertainty but cascade into broader economic and policy uncertainty (Kim & Lee 2024; Kuai & Wang 2024).

Different authors have noted that geopolitical risks have both a macro and micro impact. At the macro level, elevated geopolitical risk drives capital-market volatility and disrupts international capital flows, slowing economic recovery (Apergis et al. 2018; Bouri et al. 2019; Caldara & Iacoviello 2022). On the other hand, on a micro-level, studies reveal firm-specific responses. Examples of such reactions are heightened M&A activity, as companies seek synergies in uncertain times (Shen et al. 2021), increased cash holdings for precautionary motives (Cho 2023), and broader shifts in corporate decision-making under uncertainty (Li & Cheng 2024).

The second element, which needs to be defined is the financial performance of companies (Aryati & Susilawati, 2025). Damayanti and Assagaf (2021) mention in their paper, that the assessment of a company's well-being is done through the analysis of its financial statements and financial reports, which serve as an extremely important and key indicator of its performance. Financial performance is the evaluation of a company's profitability and stability over time. This is typically performed using key financial ratios. As Kusumawardani et al. (2021) and Putri et al. (2024) note, these ratios distil a firm's revenue-generation and cost-management efficiency, while Hartoyo et al. (2023) emphasize their role in investor decisions and long-run sustainability. In this paper, the focus is on Current Ratio, ROE, Net Margin, EPS and Debt-to-equity as the primary performance metrics.

In order to understand the interaction between these two elements, it is necessary to quantify the geopolitical risk. This is done through the use of geopolitical risk indices. These indices are derived in different ways. One way is the proposed by Caldara and Iacoviello, who analyse and construct the index based on media reports in newspapers, containing discussions about geopolitical threats (Caldara & Iacoviello, 2022). Another interesting methodology is that of BlackRock, which they use in their “Global Risk Dashboard”. In it they quantify geopolitical risk based on two different measures of risk:

- based on the market attention to risk events
- based on the market movement related to these events.

The methodology described by Caldara and Iacoviello is a “text-based” approach, where specific key words are searched for in articles, news, etc. This methodology is taken in the first measure used by Blackrock, but as per information from their geopolitical risk dashboard it is further improved by including a language-based machine learning model (Blackrock investment institute, 2025). Both these indices are used in this paper to compare the significance related to a company's financial performance.

After analysing these two elements, it is important to understand how other authors have compared and analysed the interaction between them and what conclusions they have come to. Firstly, on a firm level, single-firm and sectoral papers establish that quantified geopolitical risk indices appear to influence the corporate world and changes in the indices are meaningful to companies. [Kejriwal \(2024\)](#) uses Caldara & Iacoviello's index to show a predominantly negative effect on IBM's profit margins over 2009–2023, though he cautions that company-specific factors and time-varying correlations may limit generalizability. [Shen et al. \(2021\)](#) find that elevated GPRI boosts M&A activity in the energy and power industries - particularly for firms with lower leverage. This suggests a "refuge in consolidation". [Cho \(2023\)](#) documents precautionary cash hoarding across firms during certain "high-risk episodes", and [Li & Cheng \(2024\)](#) demonstrate shifts in broader corporate decision-making under elevated geopolitical stress.

On a more macro perspective, specifically on a market level, [Jia Ji \(2025\)](#) links geopolitical risk index spikes to increased investor risk aversion, distorted risk-return trade-offs, and market hesitancy. However, this leaves unresolved how firm-level financial ratios themselves respond.

Most current research on the topic of geopolitical risk defends the understanding that geopolitical risk does influence margins, cash holdings, and M&A, but they are confined to single firms or industries and cover at most two metrics (e.g., only the profit margins for IBM; M&A for activity in energy firms, etc.). This shows a lack of an in-depth look on company financial statements and whether this effect is directly associated with geopolitical risk, or the effects are more on a macro-level and don't affect companies directly. The studies which highlight statistical significance between the geopolitical risk indices and financial ratios, capital structure, etc. are very limited to the number of firms and ratios utilized. No study to date has conducted a multi-industry panel analysis to quantify how GPRI fluctuations translate into changes in key financial ratios – Current ratio, ROE, net margin, EPS, and Debt-to-equity, across diverse firm sizes.

To fill this research gap and address these untested dimensions, a yearly panel of 40 NASDAQ companies has been assembled with data from 2017 to 2024 and several GLS models are applied to quantify how GPRI fluctuations translate into core financial ratios. Each of these ratios is selected, because macro-level uncertainty shocks - like spikes in the geopolitical risk prompts firms to delay investment and hoard cash ([Opler et al., 1999](#)), while at the same time, elevated geopolitical risk increases required risk premia ([Pástor & Veronesi, 2013](#)). This usually leads to eroding net profit margins and EPS via higher financing costs and lower sales. Finally, under greater uncertainty, firms may deleverage to avoid covenant violations ([Myers, 1977](#)), leading to reductions in Debt-to-Equity. Despite theory predicting liquidity hoarding, margin compression, and deleveraging under uncertainty, no study has tested these channels jointly in a multi-industry panel, which helps further with the derivation of the hypothesis, which will be tested.

Each ratio is selected with the purpose of testing the classic understanding and to cover a broader spectre of firm financials. The analysis includes:

- One Liquidity ratio (Current ratio) – the main reason for selecting this ratio is to see how the company's ability to pay off its short-term liabilities changes because of geopolitical risks and also based on the analysis of Li and Cheng and the effects on the behavioural decisions of a company, in this case maintaining high current ratio. ([Li & Cheng, 2024](#)).
- Two Profitability ratios (Return on equity and Net profit margin) – the reason for selecting these ratios is because Return on equity is, as described by Nenkov and Hristozov, a fundamental ratio ([Nenkov & Hristozov, 2024](#)) and it can provide information on the efficiency of the company. The net profit margin would give information that would build upon the knowledge in the article by Kejriwal ([Kejriwal, 2024](#)), by assessing the impact on various companies and not just one.
- One Market ratio (Earnings per share) – once again is selected, as it is stated to be a fundamental ratio for companies ([Nenkov & Hristozov, 2024](#)) and will provide information how the net income earned for each share outstanding changes based on the geopolitical risks and also provide a view of the companies' market performance.

- One Leverage ratio (Debt-to-Equity) – this ratio is selected to check if companies are more inclined to increase their debt during times of high geopolitical risks and would broaden the knowledge of the impacts these risks could have on capital structure as well.

Through the help of the literature review, the main scientific hypothesis is established, in order to address the gaps in previous research.

“Geopolitical risk negatively effects core corporate financial ratios and does indeed follow the classical understanding”

The literature review helps formulate the following hypothesis, with which to test whether a multi-industry panel will follow the classic understanding of geopolitical effects on company ratios and performance:

H_1 : A one-point increase in the geopolitical risk index lowers the companies' Current Ratio, diminishing the company's ability to pay its short-term debts.

H_2 : A one-point increase in the geopolitical risk index lowers the companies' ROE, evidencing diminished overall profitability and efficiency.

H_3 : A one-point increase in the geopolitical risk index lowers the companies' Net Profit Margin, reflecting squeezed operating performance under heightened uncertainty.

H_4 : A one-point increase in the geopolitical risk index lowers the companies' EPS Ratio, indicating direct earnings erosion during geopolitical shocks.

H_5 : A one-point increase in the geopolitical risk index lowers the companies' Debt-to-Equity Ratio, portraying a lower reliance on debt during geopolitical shocks.

3. RESEARCH METHODOLOGY

For the purpose of the below analysis, the geopolitical risk indices used will be the one provided by Caldara and Iacoviello, as well as the one provided by the BlackRock Investment institute. This will act as both a comparison between the two indices and analyse what impact they would show regarding the company's financial performance. This will also provide a more solid basis on which to make conclusions regarding said impact.

The selected ratios will give an overview of the firm's financial performance in a few different areas of its financial statements and also possibly broaden understanding and provide information on the significance of the effect of geopolitical risk in these areas. The analysis will include 40 companies chosen at random from the Nasdaq-100 index, the 100 largest companies listed on the Nasdaq Stock Market. The companies selected span over 10 total industries (Information technology; Communication services; Consumer discretionary; Consumer staples; Healthcare; Financial industry; Industrial materials; Real estate; Utilities). There are three main reasons for using this list of enterprises:

- They are firms which span across multiple industries.
- They operate in the USA, which is a big market and has much more reliable data.
- They have available and up-to-date data in their financial reports, allowing for a more current view of the analysed relationship.

The period in which the empirical analysis is performed will include 2017 to 2024. The data for the companies is collected from the audited consolidated financial reports, as well as trading platforms, which have listed financial ratios for each company. The full list of selected companies and their average financial ratios for the period 2017-2024 is included in an appendix to this research. The average value for the ratios is given for the sake of brevity and representation (Appendix 1), while the analysis is done on the basis of annual data, as mentioned below. They are selected randomly by giving each company an index from 1 to 100 and using software, which randomly selects a number between 1 and 100. On the other hand, the data used for the geopolitical risk index is summarized in the tables below as follows:

Table 1. Geopolitical risk index as per BlackRock Investment Institute

	BlackRock Geopolitical Risk Indicator							
	2017	2018	2019	2020	2021	2022	2023	2024
Max	1.22	0.90	0.93	0.68	0.10	0.80	0.31	0.81
Min	0.01	-0.41	0.53	0.08	-0.20	-0.05	-0.11	0.20
Average	0.62	0.32	0.71	0.44	-0.09	0.26	0.07	0.40

Source: BlackRock Investment Institute, personal calculations

Table 2. Geopolitical risk index as per Caldara and Iacovello

	Geopolitical Risk Indicator as per Caldara and Iacovello							
	2017	2018	2019	2020	2021	2022	2023	2024
Max	138.53	125.67	106.59	138.42	105.35	318.95	197.89	163.74
Min	82.72	64.49	73.08	64.07	58.42	111.20	98.63	92.39
Average	107.38	98.55	90.95	77.29	82.07	157.58	121.71	134.19

Source: Dario Caldara and Matteo Iacovello, personal calculations

The two indices are different in terms of value, but this is due to the different methodology used in both cases. The BlackRock index encompasses an analysis market attention and market movement by grading the likelihood and impact of 10 main geopolitical risks and how they could affect the markets. The index by Caldara and Iacovello is calculated by counting the number of published articles, which are related to the occurrence of adverse geopolitical events in newspapers for each month.

The data presented from the two indices has been aggregated and calculations were performed to show their maximum, minimum and average values for the specific year, based on the monthly data. This is performed in order to create homogeneity in the dataset, as the data for the companies is on a yearly basis. Averaging the amounts for the indices for each year encompasses the geopolitical landscape throughout the entirety of the specific year and would allow for a better analysis when paired with the company data. For the sake of brevity, the term geopolitical risk index has been shortened to the abbreviation – GPRI.

The analysis is done through a panel data (Random effects Generalized Least Squares) regression model. The panel data regression model is performed using specialized statistical software. The chosen methodology for regression is the Random effects (GLS) regression method, with the main goal of this being to illustrate the causal relationship between the financial ratios and geopolitical risk. It is chosen over the Fixed effect (FE) model, as for each individual regression a Hausman test is performed to compare whether using a Fixed effects model or Random effects would be more appropriate, and in every case the null hypothesis could not be rejected, showing that the Random effects is the better choice, and there is no benefit to using the more restrictive FE model. For every regression, the difference in coefficients is not systematic and the test summary for each ratio is as follows:

Table 3. Hausman test for each ratio for the BlackRock GPRI

Financial ratio	Hausman test probability and χ^2	Hypothesis
Current ratio	P=0.9931; $\chi^2=0.09$	Ho – cannot be rejected
ROE	P=0.9302; $\chi^2=0.45$	Ho – cannot be rejected
Net margin	P=0.9995; $\chi^2=0.02$	Ho – cannot be rejected
EPS	P=0.4162; $\chi^2=2.84$	Ho – cannot be rejected
Debt-to-Equity	P=1.0000; $\chi^2=0.00$	Ho – cannot be rejected

Source: Company financials and personal calculations

Table 4. Hausman test for each ratio for the Caldara and Iacovello GPRI

Financial ratio	Hausman test probability and χ^2	Hypothesis
Current ratio	$P=0.9967$; $\chi^2=0.05$	Ho – cannot be rejected
ROE	$P=0.9409$; $\chi^2=0.40$	Ho – cannot be rejected
Net margin	$P=0.9951$; $\chi^2=0.07$	Ho – cannot be rejected
EPS	$P=0.5679$; $\chi^2=2.02$	Ho – cannot be rejected
Debt-to-Equity	$P=0.9999$; $\chi^2=0.00$	Ho – cannot be rejected

Source: Company financials and personal calculations

The tables summarized that there is no statistical reason to prefer the Fixed effects model and that every ratio is more efficient under H_0 .

The analysis is done by selecting the financial ratios as dependent variables and each of the indices separately as an independent variable. For every regression model the number of observations is 320, split into groups of 40, which is the number of companies, each with data for 8 years, split in equal intervals, creating a strongly balanced panel dataset. Each regression is performed twice, where the first instance is with the only independent variable being the geopolitical risk index and the second instance with the inclusion of 2 control variables. These control variables are “company size (based on market capitalization in billions USD)”, because the size of companies very often is a driver for their control over their financials and “inflation rate”, because it is a key driver for margins, it is closely related to the geopolitical landscape and it is often a problem faced by each and every company. The models were also tested with 2 more control variables (“GDP growth rate” and “Foreign direct investments”), but they showed no statistical significance and after performing a Wald test, the 2 variables were not contributing in any way to the model and were removed from testing. The inclusion of industry dummy variables to control for unobserved, time-invariant differences across sectors was considered, however, with 40 firms spanning across ten sectors, it would create a risk of over-parameterizing the panel. This would create a potential risk of multicollinearity. Instead, the random-effects GLS model includes a firm-level random intercept that subsumes both individual and industry fixed effects. Tables with descriptive statistics and a correlation matrix can be found in Appendix 2 and Appendix 3. Future research could benefit from the inclusion of other control variables, such as supply-chain exposure, clusters of companies, etc.

Of course, it is important to consider the limitations of this analysis. The main one is the statistical group. It is a rather small group of sizeable companies. They are only 40, over diverse industries. Utilizing smaller companies could yield different results. Another limitation is the usage of aggregated annual indexes rather than monthly could also be creating a distortion of results. Analysing the data on a monthly basis, could show results, which are hidden in the annual data. The lack of more control variables, which could further improve the results of the analysis or potentially uncover omitted variables, could also be treated as an important limitation. The lack of cluster testing could also be hiding potential relationships, currently not visible.

4. EMPIRICAL ANALYSIS OF A COMPANY'S FINANCIAL PERFORMANCE AND ITS INTERACTION WITH GEOPOLITICAL RISKS

The first ratio analysed is the current ratio. The table with the main outcomes from the statistical analysis can be found below as follows:

Table 5. Random effects panel regression for the financial ratio – Current ratio

Current ratio					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	2.44	1.65	1.48	0.14	0.0048
Constant	1.95	1.04	1.88	0.06	
GPRI as per Caldara and Iacovello	-0.02	0.02	-1.42	0.16	0.0044
Constant	5.23	1.93	2.71	0.01	

Source: Company financials, GPRI as per both sources, personal calculations

There are a few main points to note from this analysis. The first and most important is that there is no statistical significance for either of the two indices. This suggests that the model is missing key determinants, which better explain the variation of the selected ratio. This is further proven by the significantly low R-squared value of just 0.0048 in the first case and 0.0044 in the second. This means that only 0.48% or 0.44% of the variance in this ratio is explained by the selected independent variables. Due to the lack of statistical significance and negligible explanatory power, the relationship between GPRI and the current ratio cannot be supported. In order to check whether there is a possible omitted variable bias, a second panel regression is performed with the above specified control variables.

Table 6. Random effects panel regression for the financial ratio – Current ratio with control variables

Current ratio					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	2.21	2.27	0.97	0.33	0.0072
Company size (market cap)	-0.00	0.00	-0.33	0.74	
Inflation rate	-3.08	33.50	-0.09	0.93	
Constant	3.08	2.12	1.45	0.15	
GPRI as per Caldara and Iacovello	-0.02	0.02	-0.79	0.43	0.0067
Company size (market cap)	-0.00	0.00	-0.42	0.67	
Inflation rate	-2.94	36.24	-0.08	0.94	
Constant	5.53	2.71	2.04	0.04	

Source: Company financials, GPRI as per both sources, Macrotrends, personal calculations

As seen in the table, even after adding control variables, the results still show a lack of statistical significance, which prevents the further validation of this relationship between the indices and the liquidity ratio. The derived conclusion is that this model does not explain any variances in the current ratio of the selected companies and there is no visible direct effect of geopolitical risks on the companies' ability to pay off their short-term debts. Therefore, it appears to be unnecessary for firms to focus on their liquidity during periods of geopolitical instability. When comparing these findings with those of [Cho \(2023\)](#), it appears that the hoarding, documented by him is more likely based on management decisions, rather than being affected by the geopolitical risk directly. Further research should include a qualitative study, together with a quantitative, in order to understand the reasons for these changes from the firms themselves. This means that the first hypothesis H_1 , could be ruled out, as no such effect is visible

The next two ratios analysed are the Return on Equity (ROE) and the Net profit margin ratios. The table with the main outcomes from the statistical analysis can be found below:

Table 7. Random effects panel regression for the financial ratio – Return on Equity

Return on Equity					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	-0.07477	0.03	-2.61	0.01	0.0237
Constant	0.27	0.01	22.04	0.00	
GPRI as per Caldara and Iacovello	0.00072	0.00	2.59	0.01	0.0235
Constant	0.16	0.03	5.30	0.00	

Source: Company financials, GPRI as per both sources, personal calculations

Upon analysing the GLS panel regression model there are some key points to note. In both cases there is statistical significance when using either of the two geopolitical risk indexes. The p-value is significantly lower than 0.05 in both cases, which would indicate that on average, a one-point increase in the geopolitical risk index provided by BlackRock would decrease the ROE with -0.075 percentage points, while on the other hand the same change in the index provided by Caldara and Iacovello, would increase the ROE with 0.00072 percentage points. In both cases the R-squared is

around 0.024, which would mean that only 2.4% of the variance in ROE is explained by this model. Similarly to the previous ratio, a second regression with the introduction of control variables is performed. The results can be found in the table below as follows:

Table 8. Random effects panel regression for the financial ratio – Return on Equity with control variables

Return on Equity					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	0.02	0.03	0.47	0.64	0.3352
Company size (market cap)	0.0001	0.00	11.8	0.00	
Inflation rate	0.70	0.48	2.10	0.04	
Constant	0.17	0.04	4.43	0.00	
GPRI as per Caldara and Iacovello	-0.02	0.02	0.48	0.64	0.3353
Company size (market cap)	-0.00	0.00	-0.42	0.67	
Inflation rate	0.49	0.40	2.02	0.04	
Constant	0.17	0.04	3.88	0.00	

Source: Company financials, GPRI as per both sources, personal calculations

The second regression shows an interesting change in the results. A substantial increase in explanatory power, but the GPRI is no longer statistically significant. This means that in the first regression there is an omitted variable bias and after adding the two control variables, we see that GPRI loses significance. The loss of GPRI significance and jump in explanatory power after adding control variables suggests that inflation and company size partially account for the previously attributed statistically significant effect. GPRI likely does not have an independent or direct effect on ROE. The two GPRI show an opposite correlation, but the lack of statistical significance limits this analysis in deriving any conclusions. With a degree of caution, the second hypothesis H_2 , could be ruled out due to a lack of proof regarding the relationship of the two variables.

The analysis of the net profit margin ratio yielded the following results:

Table 9. Random effects panel regression for the financial ratio – Net Profit margin

Net profit margin					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	-0.06311	0.0125	-5.06	0.00	0.0840
Constant	0.18	0.01	33.39	0.00	
GPRI as per Caldara and Iacovello	0.00034	0.0001	2.78	0.01	0.0269
Constant	0.12	0.01	8.45	0.00	

Source: Company financials, GPRI as per both sources, personal calculations

Once again both cases are statistically significant, when using both geopolitical risk indices separately. And as seen in the ROE, there is an opposite impact on the net profit. Following the data from the empirical analysis, based on the geopolitical risk index provided by BlackRock, a one-point increase in the index would lead to -0.06311 percentage points decrease in the net profit margin. The R-squared for this model is 0.084, which means that 8.4% of the variance in the net profit margin is explained by this variable. On the other hand, there is a significantly lower R-squared for the second index, with a value of 0.0269, which means that only 2.69% are explained. The second regression, including the control variables, yielded the following:

Table 10. Random effects panel regression for the financial ratio – Net Profit margin with control variables

Net profit margin					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	-0.003	0.02	-2.25	0.025	0.1754
Company size (market cap)	0.0001	0.00	5.37	0.00	
Inflation rate	0.387	0.17	2.22	0.027	
Constant	0.13	0.02	7.39	0.00	
GPRI as per Caldara and Iacovello	-0.00	0.00	-0.79	0.432	0.1624
Company size (market cap)	0.00	0.00	5.86	0.00	
Inflation rate	0.719	0.21	3.53	0.00	
Constant	0.13	0.02	6.18	0.00	

Source: Company financials, GPRI as per both sources, Macrotrends, personal calculations

There is statistical significance when utilizing the GPRI provided by BlackRock, while no significance is visible when using the GPRI from Caldara and Iacovello. The explanatory power is 17.54%, which, although small, leads to the assumption, that the GPRI, which the BlackRock calculates, could potentially be used further to describe variation in the net profit margin, although, as seen in the model, the effect is very minor. A one-point increase in GPRI, would lead to a 0.003 percent decrease in the net profit margin. While statistical significance does exist between the ratio and the BlackRock GPRI, the effect is economically negligible. The mean value of the net profit margin of the group is 15.43% and the median is 14.00% (Appendix 2), therefore a change of 0.003% could easily be treated as irrelevant. This shows an opposing result to [Kejriwal \(2024\)](#) and his findings about IBM's profit margins and opens the question whether there is a squeezed operating performance under heightened uncertainty and the results show that this is most likely not the case, at least in the selected sample. Therefore, with a great deal of caution, the third hypothesis H_3 could be ruled out, as although there is statistical significance, there is no economic significance, and geopolitical risk cannot be treated as a direct driving factor in diminishing company margins and operating performance.

The penultimate financial coefficient that is analysed is the earnings per share. The results from the test can be seen in the table below as follows:

Table 11. Random effects panel regression for the financial ratio – Earnings per share

Earnings per share					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	-5.22413	1.5644	-3.34	0.001	0.0384
Constant	8.52	0.6604	12.90	0.00	
GPRI as per Caldara and Iacovello	-0.00130	0.0154	-0.08	0.93	0.000
Constant	6.88	1.716	4.01	0.00	

Source: Company financials, GPRI as per both sources, personal calculations

The financial ratio's correlation with both indexes is negative in this case, as seen in Table 11, once again, one of the two indices is statistically significant (the index provided by BlackRock) and the second is not (the index provided by Caldara and Iacovello). The statistical significance of the first shows an R-squared of 0.0384, which means that this model explains 3.84% of the total variance in the EPS. Economically, it could be treated that a one-point increase in the geopolitical risk index would mean a -5.22 USD decrease in the earnings per share. On the other hand, the index by Caldara and Iacovello, shows a R-squared of 0, which means that there is no visible relationship between the two variables. The second regression yielded the following result:

Table 12. Random effects panel regression for the financial ratio – Earnings per share with control variables

Earnings per share					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	-3.91	1.92	-2.04	0.042	0.1196
Company size (market cap)	0.003	0.001	3.22	0.001	
Inflation rate	8.73	2.99	2.38	0.004	
Constant	6.68	1.87	3.58	0.00	
GPRI as per Caldara and Iacovello	-0.05	0.021	-2.45	0.014	0.1269
Company size (market cap)	0.004	0.001	3.78	0.00	
Inflation rate	80.16	26.46	3.03	0.002	
Constant	8.33	2.19	3.80	0.000	

Source: Company financials, GPRI as per both sources, Macrotrends, personal calculations

The second regression yielded an interesting result. With the addition of the control variables, both indices show statistical significance, with a substantial change visible in the index of Caldara and Iacovello's. The GPRI coefficients are now both statistically significant at the 5% level, but their economic impacts differ greatly. When looking at the GPRI as per BlackRock, a one-point increase would lead to 3.91 USD decrease in the earnings per share, while the GPRI from Caldara and Iacovello show a decrease of only 0.05 USD. The explanatory power of the model is still rather low – around 12%. The mean value of the EPS for the selected sample is 6.73 USD, while the median is 4.76 USD (Appendix 2). A one-point rise in BlackRock's GPRI predicts a 3.91 USD drop in EPS or roughly a 58% fall from the mean and an 82% fall from the median, which could be considered an economically large effect. By contrast, Caldara & Iacoviello's GPRI implies only a 0.05 USD decrease of the EPS or around 0.74% fall from the mean and 1.05% fall from the median. Overall, considering the modest explanatory power, these GPRI measures alone explain little of the variation in short-term profitability. It is noteworthy to discuss the set hypothesis in the beginning. In the case of the Earnings-per-share ratio, although with caution, based on the results, the fourth hypothesis H₄ is supported in the case of BlackRock's GPRI and can be accepted. For the Caldara & Iacoviello index, the result is statistically significant but economically weak, and may be driven by omitted variable bias in the unadjusted model. This highlights the superior sensitivity of the market-based GPRI to short-term earnings volatility. Therefore, the result is statistically significant but economically negligible and H₄ is supported only in the case of the BlackRock GPRI.

The final ratio to be analysed is the Debt-to-Equity ratio. The results from the test are as follows:

Table 13. Random effects panel regression for the financial ratio – Debt-to-Equity

Debt-to-Equity					
	Coeff.	Std. Error	t	p-value	R - Squared
GPRI as per BlackRock	-0.00963	0.2009	-0.05	0.962	0.000
Constant	0.89	0.0848	10.54	0.00	
GPRI as per Caldara and Iacovello	-0.00223	0.0019	-1.16	0.25	0.0027
Constant	1.13	0.216	5.25	0.00	

Source: Company financials, GPRI as per both sources, personal calculations

In both cases there is no statistical significance and nearly no impact from either of the two indices on the debt-to-equity ratio. The first index, provided by BlackRock, shows an R-squared of 0, which would signify no apparent relationship between the variables, while the second shows an R-squared of 0.0027, which means that only 0.27% of the variance in the debt-to-equity ratio could be explained by this model. The lack of statistical significance prevents reaching any conclusions regarding the relationship between these variables.

Table 14. Random effects panel regression for the financial ratio – Debt-to-Equity with control variables

Debt-to-Equity					
	Coeff.	Std. Error	z	p-value	R - Squared
GPRI as per BlackRock	-0.024	0.25	-0.10	0.924	0.0019
Company size (market cap)	0.00	0.001	-0.49	0.622	
Inflation rate	0.05	2.96	0.02	0.985	
Constant	0.91	0.209	4.28	0.00	
GPRI as per Caldara and Iacovello	-0.05	0.021	-1.65	0.100	0.0066
Company size (market cap)	0.000	0.001	-0.38	0.704	
Inflation rate	4.12	3.40	1.21	0.226	
Constant	1.25	0.26	4.80	0.000	

Source: Company financials, GPRI as per both sources, Macrotrends, personal calculations

In the case of the Debt-to-equity ratio, no obvious relationship can be found through the use of this model, and it is highly likely that other variables are necessary in order to explain these variances. Geopolitical risk appears to have no statistically significant effect on the ratio or the any changes to the companies' reliance on debt during geopolitical shocks. This means that the fifth hypothesis H5 can be ruled out, as there is no significance and no statistically or economically meaningful effect is detected in either model.

In summary, the empirical analysis reveals that geopolitical risk indices have limited explanatory power over firm-level financial ratios. Among the five tested ratios, only Earnings-Per-Share (EPS) showed both statistical and economic significance, particularly when using the BlackRock index. Net Profit Margin exhibited statistical but not economic significance, while the remaining ratios (Current Ratio, Return on Equity, and Debt-to-Equity) demonstrated no robust relationship with geopolitical risk. These findings suggest that geopolitical risk, as measured here, may affect firms indirectly through market channels, managerial decisions or rather than through direct financial ratio distortion.

Furthermore, the BlackRock index consistently outperformed the one provided by Caldara & Iacoviello, likely due to its market-based methodology that incorporates investor sentiment and market movements. The Caldara & Iacoviello index, being solely text-based, may lack sensitivity to real-time financial impacts.

It is also important to consider the hypothesis set at the beginning. Only one hypothesis could not be ruled out - the fourth H₄ (A one-point increase in the geopolitical risk index significantly lowers the companies' EPS, indicating direct earnings erosion during geopolitical shocks). Geopolitical risk showed a direct impact on EPS, which had both statistical and economic significance, unlike in the case of H₃, related to the net margin, where there is visible statistical significance, but almost not economic. This could be used to derive several practical implications, which could be useful for firm management, CFOs, risk-assessment departments and parties interested in precautionary methods, with which to mitigate the impact of geopolitical risk in the areas where it seems to have an effect, more specifically EPS. A number of recommendations are given as follows:

- Companies could establish a threshold for GPRI changes, based on which to build an "EPS buffer" in their dividend policies. For example, during calm periods they could cushion dividends against GPRI-driven EPS dips, reducing the likelihood of occurrence of major fluctuations.
- Firms might benefit from integrating GPRI into stress tests for EPS. This would work by adding a "what if" scenarios in quarterly stress-testing models to quantify potential EPS decreases caused by changes in GRPI. This could help ensure capital plans remain robust under heightened geopolitical risk.
- It would benefit both companies and industries as a whole to establish a threshold of GPRI variance. For example, if there is a 5-point rise in GPRI, that would automatically prompt a re-assessment of earnings forecasts and prepare companies for the potential impacts.

However, these applications should be approached with caution due to the limited explanatory power of the models used. Further research could be improved by adding multiple richer control variables, as well as comparing with different time periods, executing clustered analysis, monthly data granularity, adding qualitative studies, which could describe the reasons for deviations and compare them to the quantitative results, etc.

5. CONCLUSION

The growing scholarly interest in geopolitical risk highlights the need to understand its potential impact on corporate financial performance. This study aimed to investigate whether geopolitical risk indices meaningfully influence firm-level financial ratios. While the literature often supports a connection, particularly at the firm or industry level, prior research has been limited in scope, typically focusing on individual companies or a small set of performance metrics.

This paper addressed that gap by conducting a multi-industry panel analysis of 40 NASDAQ-listed firms from 2017 to 2024, using both the BlackRock and Caldara & Iacoviello geopolitical risk indices. Contrary to much of the existing literature, the empirical findings suggest that geopolitical risk, in contrast, the selected geopolitical risk indices, as currently quantified, do not exert a consistent or robust influence on most firm-level financial indicators. Only in the individual cases of analysing the variation in the market ratio EPS and the profitability ratio Net profit margin did the GPRI show statistical significance, and economic significance only in the EPS ratio. Based on this analysis, geopolitical risks do not seem to show apparent influence on company performance.

Only one of the five tested hypotheses (H_4), related to the EPS ratio could be supported, and only when using the BlackRock index. The other ratios (Current Ratio, Return on Equity, Net Profit Margin, and Debt-to-Equity) showed either no statistical significance or negligible economic impact. Of course, this is all done with a substantial degree of caution, due to the limitations of this analysis. It is also noteworthy that the models' explanatory power was consistently low, reinforcing the conclusion that GPRI alone cannot explain variation in corporate performance.

Two indices, quantifying geopolitical risk, were included in the analysis in order to show a comparison between them and if there is any merit to using one over the other. The results of the analysis were somewhat similar, with some outliers (The significantly higher economic impact in the EPS ratio and the statistical significance in the net margin ratio). Solely based on this, the GPRI provided by BlackRock seems to show more potential for this specific type of analysis, related to company financials. This is due to the fact that the index is extrapolated through an in-depth analysis of the geopolitical landscape and how it reflects on the markets by considering both market attention and market movement.

The main takeaway from this analysis is that while geopolitical risk may play a role in shaping company performance particularly through its effect on EPS, this influence is highly dependent on other factors. Without appropriate controls, models have a risk of attributing false significance to GPRI measures, as observed in the Return on Equity results. Thus, geopolitical risk should be viewed as one contributing factor among many, and not a standalone driver of financial outcomes.

Some noteworthy practical implications of this analysis are potential precautionary methods, that could be used to mitigate the impact of geopolitical risk in the areas where it seems to have an effect, more specifically EPS. These include establishing an "EPS buffer" in company dividend policies, integrating GPRI into stress tests for EPS, creating a threshold of GPRI variance specific for each company, based on which to prompt a reassessment of earnings forecasts and prepare companies for the potential impacts. Of course, the limited explanatory power of the models used should also be taken into account and interested parties should proceed with caution.

The main recommendations for future analysis on the topic would be to deepen the analysis by including more companies, from different markets through different or longer periods of time. Also, it is necessary to identify the proper factors related to company financial performance which would further be able to explain the variances through the incorporation of geopolitical risks, minimizing the risk of an omitted variable bias or "fictional" significance of the analysed geopolitical risks and increasing the explanatory power of the utilized models. An empirical analysis using monthly data,

rather than aggregated, could provide a more profound look on the changes in the financial performance, based on the geopolitical risk indices.

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Appendix 1. List of companies used for the analysis and their average financial ratios for the period 2017-2024

Company name	Current Ratio	Net Margin	ROE	Debt-to-Equity	EPS
Apple	1.16	23%	108%	140%	\$ 4.46
Microsoft	2.15	31%	38%	57%	\$ 6.90
Nvidia Corp	6.66	35%	45%	22%	\$ 4.90
Amazon	1.07	5%	18%	95%	\$ 20.53
Alphabet Inc.	3.23	22%	22%	4%	\$ 55.17
Tesla	1.36	3%	2%	105%	\$ -0.27
Berkshire Hathaway	1.15	13%	13%	33%	\$ 16.17
JPMorgan & Chase	1.04	27%	14%	145%	\$ 8.77
General Electric and Co	1.06	5%	11%	96%	\$ 1.41
AT&T	0.73	7%	10%	117%	\$ 2.11
Merck & Co Inc	1.43	20%	25%	75%	\$ 3.21
PepsiCo Inc	1.01	9%	27%	236%	\$ 4.11
Workday Inc	1.68	-6%	-1%	44%	\$ 0.15
Paypal Holdings Inc.	1.34	16%	18%	63%	\$ 2.34
Mariott International	0.88	9%	28%	234%	\$ 4.20
AutoZone Inc (AZO)	0.94	13%	57%	166%	\$ 13.29
CoStar Group Inc	8.83	16%	12%	12%	\$ 1.62
IDEXX Laboratories Inc	1.35	21%	31%	55%	\$ 6.60
Old Dominion Freight Line Inc	1.61	16%	24%	12%	\$ 4.63
Willis Towers Watson Plc	1.24	11%	16%	65%	\$ 5.57
Fair Isaac Corp	1.76	24%	29%	43%	\$ 5.75
Kimberly-Clark Corp	0.85	13%	24%	53%	\$ 6.64
Fastenal Co	4.35	18%	33%	8%	\$ 1.83
Exelon Corp	0.91	11%	13%	148%	\$ 2.32
Fiserv, Inc.	1.15	18%	22%	85%	\$ 3.83
Boeing Co	1.43	7%	28%	-28%	\$ 5.14
Accenture plc	1.53	11%	28%	18%	\$ 5.64
Verizon Communications Inc	0.85	13%	27%	202%	\$ 4.50
American Express Co	1.75	16%	29%	263%	\$ 8.76
Morgan Stanley	1.11	20%	12%	246%	\$ 5.96
Intuitive Surgical Inc	10.34	25%	15%	1%	\$ 10.22
Raytheon Technologies Corp	1.27	8%	14%	67%	\$ 5.35
Newmont Corp	1.74	9%	11%	52%	\$ 1.77
Vulcan Materials Co	2.11	11%	15%	48%	\$ 4.80
Paccar Inc	2.17	12%	19%	41%	\$ 4.93
Hershey Co	0.86	16%	50%	186%	\$ 7.04
Hartford Financial Services Group Inc	0.29	8%	10%	94%	\$ 4.97
Vici Properties Inc	34.23	52%	7%	57%	\$ 1.57
Constellation Brands Inc	1.24	23%	17%	132%	\$ 9.98
Tjx Companies Inc	1.40	7%	47%	67%	\$ 2.55

Appendix 2. Descriptive Statistics Table for all five ratios

The descriptive statistics are calculated as a summary, after analysing the mean, median, min, 1st and 3rd quartile, max and standard deviation for each year in the period and aggregated in 1 table for the sake of space and brevity.

Descriptive statistics	Current Ratio	ROE	Net Margin	EPS	Debt-to-Equity
Mean	2.78	24%	15.43%	6.73 USD	89%
Median	1.32	21%	14%	4.76	69%
Min	0.27	-37%	-18%	-18.36	1%
1st Quartile	1.04	13%	9%	2.48	38%
3rd Quartile	1.80	29%	20%	7.36	144%
Max	139.40	175%	70%	112.20	316%
Standard deviation	8.76	22%	11%	10.98	111%

Appendix 3. Correlation matrix of all 5 ratios

Correlation matrix	Current Ratio	ROE	Net Profit Margin	EPS	Debt-to-Equity	GPRI as per BlackRock	GPRI as per Caldara and Iacovello
Current Ratio	1.0000	-0.0819	0.3522	-0.0307	-0.0872	0.0691	-0.0664
ROE	-0.0819	1.0000	0.2664	0.0841	0.0873	-0.0844	0.0839
Net Profit Margin	0.3522	0.2664	1.0000	0.1709	0.0305	-0.1396	0.0790
EPS	-0.0307	0.0841	0.1709	1.0000	0.0243	-0.1182	-0.0031
Debt-to-Equity	-0.0872	0.0873	0.0305	0.0243	1.0000	-0.0022	-0.0519
GPRI as per BlackRock	0.0691	-0.0844	-0.1396	-0.1182	-0.0022	1.0000	-0.0880
GPRI as per Caldara and Iacovello	-0.0664	0.0839	0.0790	-0.0031	-0.0519	-0.0880	1.0000

THE POTENTIAL OF HYBRID LSTM-GENERATIVE AI ECO-MODEL IN FORECASTING FINANCIAL AND ECONOMIC INDICATORS

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ABSTRACT

This study presents the development and evaluation of The Hybrid LSTM-Generative AI ECO-Model for forecasting financial and economic indicators such as EUR/USD exchange rate, utilizing a combination of Long Short-Term Memory (LSTM) networks and generative AI models (GPT-2 and Llama-3.2-1B). The primary objective was to achieve high prediction accuracy while minimizing computational resource consumption and ensuring ease of use of the model on various devices. The model was trained and tested on historical financial and economic data, including exchange rates, macroeconomic indicators, commodity prices, and sentiment analysis of financial news.

Our findings indicate that traditional LSTM models outperform generative AI models in time-series forecasting tasks due to their ability to capture temporal dependencies. However, integrating generative AI for dataset refinement and model optimization significantly improved forecasting performance. The hybrid ECO-model, leveraging generative AI-driven parameter selection and sentiment analysis, demonstrated superior accuracy for long-term predictions. The most influential parameters included historical exchange rate trends, gold and oil prices and news sentiment.

By implementing an ECO-approach that optimizes dataset size, minimizes training iterations, and employs a lightweight model architecture, our study highlights a path toward efficient and sustainable financial forecasting. Future research directions include enhancing anomaly detection mechanisms, incorporating additional weak predictors, and refining the role of generative AI in hybrid time-series forecasting models.

Keywords: Financial forecasting, economic indicators prediction, LSTM-Generative AI model, currency exchange rate, hybrid AI modelling, sentiment analysis, ECO-model

1. INTRODUCTION

Financial and economic forecasting plays a critical role in shaping policies, business strategies, and investment decisions. Accurately predicting key indicators such as GDP growth, inflation, stock market trends, or currency exchange rates remains a complex task due to the dynamic, non-linear, and interconnected nature of financial systems. Historically, various statistical and econometric models have been employed to forecast economic trends. These include linear regression, ARIMA (Auto-Regressive Integrated Moving Average), and VAR (Vector Auto-Regression) models, which rely on historical data patterns to predict future outcomes. While these models have been instrumental, their inherent assumptions, such as linearity and stationarity, often limit their applicability in capturing complex economic behaviours.

In recent years, advances in machine learning and artificial intelligence have revolutionized financial forecasting. Technologies such as support vector machines (SVM), random forests, and neural networks have enabled models to capture non-linear relationships and adapt to high-dimensional datasets. These methods have outperformed traditional approaches in various contexts but often face limitations in their ability to process sequential and time-dependent data effectively. The further advancements in artificial intelligence (AI) have significantly revolutionized this field, enabling the development of predictive tools like Long Short-Term Memory (LSTM) networks and Generative AI models that outperform many methods that have been used before. The benefits of these technologies are manifold. LSTMs provide accurate short- and medium-term predictions by effectively handling the temporal dependencies in financial data, while Generative AI enhances robustness by modelling complex interactions and creating synthetic data for underrepresented scenarios. These technologies not only improve prediction accuracy but also offer tools to navigate uncertainties, optimize strategies, and mitigate risks.

Despite their individual strengths, LSTMs and generative AI models have limitations when used in isolation. LSTMs, for instance, may struggle with highly sparse or noisy datasets, while generative AI models may lack precise temporal alignment in predictions. To overcome these challenges, scientists are increasingly adopting hybrid approaches that integrate LSTMs with other forecasting tools, such as generative AI models, statistical methods, or machine learning techniques. Hybrid models leverage the strengths of complementary techniques to address the limitations of individual methods. For instance, combining LSTMs with generative AI allows for the simulation of complex data distributions, enhancing robustness and enabling probabilistic forecasting. Integrating statistical models can improve interpretability, while machine learning techniques contribute to feature selection and dimensionality reduction. These synergies lead to improved predictive accuracy, adaptability, and resilience in uncertain financial environments.

This paper examines the potential of a Hybrid LSTM-Generative AI ECO-Model to address the limitations of existing methods, proposing an innovative approach to achieve more accurate and scalable predictions. By exploring this hybrid framework, we aim to advance the field of financial and economic forecasting and contribute to the development of solutions that are both robust and practical in real-world applications.

1.1. LITERATURE REVIEW

Many scientists conducting research in this area are trying to find the optimal mechanism for constructing forecasts of macroeconomic indicators and develop universal models capable of producing the most accurate results. The use of machine learning in macroeconomic forecasting has been gaining traction, with particular focus on Long Short-Term Memory (LSTM) models and Generative AI models. This section reviews key studies comparing these approaches, providing insights into their relative strengths and weaknesses for predicting macroeconomic indicators such as GDP, exchange rate, inflation, and stock market trends. It is commonly known that LSTM model has the ability to capture long-term dependencies. The memory units in the LSTM can transfer and update the information between different time steps, which makes the neural network more suitable for time-series analysis and modeling (Aumeboonsuke, 2025). That is why many analysts consider LSTM-based models as a basis for making forecasts. Among them Hall (Hall, 2018), who underscores the adaptability of LSTM models in macroeconomic forecasting, highlighting their ability to capture long-term dependencies and nonlinearities in time series data. However, he also notes that LSTM models can be computationally expensive and may struggle when dealing with large datasets. Medeiros et al. (Medeiros et al., 2021) similarly highlight LSTM's superiority in capturing complex interactions between macroeconomic variables in data-rich environments, particularly in inflation forecasting. Kamolthip (Kamolthip, 2021) supports this view, finding that LSTM models handle mixed-frequency data effectively, which is a common challenge in macroeconomic data due to the varying frequencies of economic indicators. Despite LSTM's strong performance, Kamolthip acknowledges that its effectiveness diminishes in cases of severe frequency mismatches. The utility of LSTM models in forecasting volatile financial data is echoed by Shahi et al. (Shahi et al., 2020), who compared LSTM and Gated Recurrent Unit (GRU) models in stock price forecasting. Their findings suggest

that LSTM outperforms GRU in handling non-linear data patterns, which is relevant to macroeconomic forecasting given the similarly unpredictable nature of economic indicators like inflation and GDP. Nakamura came to the same conclusion when she compared the results of using the LSTM model and traditional methods in the process of forecasting inflation (Nakamura, 2005). His study demonstrates that LSTM can capture temporal dynamics better than other approaches. Comparing classical statistical algorithms to LSTM and GRU models Chang (Chang et al., 2024) claims that the latter can identify and retain important data sequences, enabling more accurate predictions. But his experimental results show that the GRU model outperforms the LSTM model in terms of prediction accuracy and training time across multiple metrics such as RMSE and MAE.

While the effectiveness of LSTM is widely recognized, several authors highlight its limitations. For instance, Kamolthip (Kamolthip, 2021) and Jahn (Jahn, 2018) note that LSTM models often struggle when faced with highly volatile or multi-frequency datasets, a common scenario in macroeconomic forecasting. This thought is supported by Lim and Zohren (Lim & Zohren, 2021), who point out that deep neural networks typically require time series to be discretized at regular intervals, making it difficult to forecast datasets where observations can be missing or arrive at random intervals. This is where generative AI models, particularly those using GANs, offer potential advantages.

Economists can reap significant productivity gains by taking advantage of generative AI to automate micro- and later macro-tasks. Large language models (LLMs) such as ChatGPT can assist economists by describing dozens of use cases in six areas: ideation and feedback, writing, background research, data analysis, coding, and mathematical derivations. That's why recent studies have begun to explore the potential of generative AI models in economic development (Korinek, 2023). But particular attention is paid to the analysis of the capabilities of Large Language models in macroeconomic forecasting. Thus, Staffini et al. (Staffini, 2022) argue that generative models can outperform LSTM in generating future scenarios, making them more suitable for long-term macroeconomic predictions. This position is supported by Liu and Motani (Liu & Motani, 2022) who suggest a generative model, GenF, that uses synthetic data to improve long-range forecasts. Their work highlights how generative models can outperform LSTM models in long-term forecasting by reducing bias and variance, particularly in scenarios that require predictions over extended time horizons. In turn, Yoshimatsu (Yoshimatsu et al., 2024) points out that similar to large language models (like ChatGPT) time series transformers become experts at picking up on subtle patterns of relationships between the values in these series with demonstrated success across a variety of domains. Author considers four popular foundation time series transformer models: Chronos, TimesFM, Moirai, TimeGPT and their effective use in identifying complex economic patterns through large-scale time-series data. The research results of Che et al. (Che et al., 2024) show that the conditional generative adversarial networks (cGAN) model can effectively capture the complexity of financial market data, and the deviation between the prediction results and the actual market performance is minimal, showing a high degree of accuracy. Lee also points out the transformative impact of finance-specific large language models (LLMs), the innovative use of generative adversarial networks (GANs) in synthetic financial data generation, but at the same time authors warn that there is a pressing necessity of a new regulatory framework to govern the use of GAI in the finance sector (Lee et al., 2024).

However, concerns remain about the reliability and interpretability of generative models as well. Thus, Hassani and Silva argue that while generative AI models show promise in surpassing traditional methods such as ARIMA, they still face challenges related to model interpretability and the "black-box" nature of their predictions (Hassani & Silva, 2024). This sentiment is echoed by Brynjolfsson and Li, who highlight that while generative AI models hold promise for improving financial forecasting, their lack of transparency may limit their adoption in high-stakes macroeconomic contexts (Brynjolfsson & Li, 2024). Emphasizing on the ability of LLM to help us better understand human beliefs and navigate possible patterns of irrational expectations, Bybee draws attention to the fact that LLM Macroeconomic Expectations exhibits the underreaction typically found in SPF consensus forecasts and its return expectations are extrapolative, disconnected from objective measures of expected returns, and negatively correlated with future realized returns (Bybee, 2023). Additionally, financial professionals should always keep in mind that generative AI has some current limitations that have

not yet been overcome like bias amplification, reliability of output including those regarding forecast indicators, security of information and sovereignty of data (Schaefer et al., 2023).

The question of which approach is better - LSTM or generative AI for macroeconomic forecasting remains open, since there is no clear solution that would satisfy everyone yet. In order to improve the performance and prediction accuracy of the models, scientists and engineers have been actively working on developing hybrid approaches, such as: adding and changing parameters in existing models, using a chain of ANNs, and combining the capabilities of LSTM and GAI. For instance, Nguyen et al. (Nguyen et al., 2021) suggest a hybrid approach, integrating LSTM with normalizing flows to capture non-linear temporal dependencies in macroeconomic data more effectively than either model could on its own. Smyl (Smyl, 2020) also developed a hybrid model combining LSTM with exponential smoothing, which proves effective in managing non-linear patterns in macroeconomic time series. Hamiane et al. (Hamiane et al., 2024) found out that hybrid models combining LSTM and ARIMA outperform standalone models in predicting GDP, especially when non-linear trends are prominent. A more complex approach suggests Atif (Atif, 2025) by combining the strengths of linear autoregressive integrated moving average (ARIMA) models with the memory-retaining capabilities of long short-term memory (LSTM) networks and temporal convolutional networks (TCN), and creating hybrid architectures that capture diverse patterns in GDP time series. Sarveswararao (Sarveswararao & Ravi, 2021), in turn, by using LSTM enhanced the Lower Upper Bound Estimation (LUBE) method in order to generate prediction intervals for quantifying uncertainty in macroeconomic variables and proved that modified LUBE can be more effectively applied to generate prediction intervals for financial and non-financial time series. Sagheer and Kotb further contribute to this discussion by demonstrating that LSTM models, when pre-trained in an unsupervised manner, can enhance accuracy in predicting multivariate economic indicators (Sagheer & Kotb, 2019). In a study of forecasting directional movement of Forex data focusing on macroeconomic indicators influencing currency values Yildirim (Yildirim et al., 2021) has proved that macroeconomic LSTM model when combined with technical indicator LSTM model into a one hybrid model, can be quite successful and effectively applied to financial forecasting. At the same time, according to Zhao, the introduction of the unbiased and the improved grey model which is weighted and averaged into the LSTM model can make a better scientific prediction of macroeconomic indicators like GDP and CPI (Zhao, 2024).

An example of the successful application of the combined LSTM-GAN model can be the work of Ngo (Ngo, 2021), who using adversarial training has tuned an LSTM prediction model and developed a system that predicted closing prices of stocks based on the previous timesteps' prices and movement as a whole. The approach by Kim et al. (Kim et al., 2024) that implies the use of AI-based generative news sentiment analysis for the improvement of LSTM and VAR models in real estate price prediction has proven to be quite effective as well. Another promising solution called the scheme of generative LSTM (GLSTM) has been suggested by Liu et al. (Liu, 2019). It consists of a generative model, to generate synthetic data for the next few time steps, and a predictive model, to directly make long-range predictions based on observed and generated data (Lemaallem & Saadi, 2025). This approach is aimed at achieving a significant increase in the accuracy of long-term forecasting of indicators with high variability.

The literature reveals a divide between the strengths of LSTM and generative AI models in macroeconomic forecasting. LSTM models are praised for their ability to capture long-term dependencies and handle non-linearities in data, making them suitable for short to medium-term forecasts. However, for long-term forecasting, generative models, particularly those that utilize synthetic data generation, offer a distinct advantage by reducing forecast bias and improving accuracy over extended horizons. Based on the literature review the future of macroeconomic forecasting may lie in hybrid approaches, combining the strengths of both LSTM and generative AI models to enhance predictive power and overcome the limitations of each approach individually.

While many authors in the process of developing LSTM-GAI combined models focus their attention more on one aspect of using the advantages of generative models to improve LSTM. In our opinion, this limits the predictive capabilities of hybrid models and leads to less accurate results when applying it. Our approach is distinguished by greater involvement of generative models in the forecasting

process, but at the same time we consider it important that our model remains economical (lightweight), as simple as possible, in terms of resource consumption and easiness of use. That's why we called it Hybrid LSTM-Generative AI Prediction ECO-Model.

1.2. METHODOLOGY

Building on the insights gained from the literature review, we aimed to investigate, implement, and evaluate a model designed to forecast financial and economic indicators. For the financial parameter, we selected the EUR/USD exchange rate due to its significance as a key financial indicator, characterized by frequent fluctuations compared to other economic metrics such as GDP, inflation, or unemployment rates. Furthermore, the EUR/USD exchange rate is publicly accessible and offers a reliable historical dataset, making it particularly well-suited for predictive modeling. Other financial parameters can similarly be predicted using our model, provided that datasets of equivalent quality are prepared.

Our objective was to develop an Eco-model that enables accurate forecasting of the EUR/USD exchange rate using lightweight models and limited computational resources. Specifically, we sought to achieve this with a standard workstation (Intel(R) Core (TM) i7-1355U 1.70 GHz, 32 GB RAM) without specialized GPU modules. Additionally, we aimed to minimize training time and reduce overall carbon dioxide emissions associated with the computational process.

In this study, we utilized a combination of experiment-based methods, modeling, training techniques and optimization procedures to forecast the EUR/USD exchange rate.

- *Experiment Method:* We conducted an experimental comparison between traditional (LSTM) and generative AI models (GPT-2 and Llama-3.2-1B) for time-series forecasting of the EUR/USD exchange rate. The models were evaluated on their ability to predict exchange rates over multiple time horizons (7, 30, 180, and 365 days), allowing us to compare the performance of these distinct model types.
- *Modeling Method:* We employed a structured modeling methodology to develop the architecture of the Hybrid LSTM-Generative AI Eco-Model. This approach involved systematic design and integration of Long Short-Term Memory (LSTM) networks with Generative AI components to enhance the model's predictive accuracy and adaptability in economic forecasting.
- *Synthesis and Analysis:* Through a thorough literature review, we synthesized existing research on the use of LSTM networks and generative AI models for time-series prediction. This analysis formed the basis for hypothesizing the potential advantages of generative models in forecasting financial data, motivating our exploration of Llama and GPT-2 in this context.
- *Quantitative Analysis for Data Processing:* We used quantitative evaluation metrics, namely Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE), to assess the models' prediction accuracy. These metrics provided a clear comparison between the performance of LSTM and generative AI models, with lower RMSE and MAE values indicating better predictive accuracy.

1.2.1. DATASET FORMATION

The quality of data preparation plays a pivotal role in the effectiveness of prediction model training. The accuracy of the predicted model is directly influenced by both the quantity and the quality of the data used. For the EUR/USD rate prediction, we have compiled extensive datasets of historical data beginning from January 1, 2010.

We utilized **various parameters** to construct the training datasets, which include: historical EUR/USD Exchange Rates; Financial News; Inflation Rates; GDP Growth Rates; Commodity Prices (Gold and Oil); Unemployment Rates; Economic News; Government Stability Index; Monetary Policy Statements; Interest Rates and Bond Yields; Trade Balance (EU-US Imports/Exports).

For the collection of historical EUR/USD exchange rates, as well as prices for oil and gold, we utilized the API provided by Yahoo Finance. This service allowed us to efficiently gather large-scale time-series data, essential for model training and analysis. Macroeconomic indicators, such as GDP growth, inflation rates, unemployment statistics, and government stability indices, were sourced from au-

thoritative government databases, specifically the Federal Reserve Economic Data (FRED) and Eurostat. These platforms offer reliable and up-to-date economic data from the US and EU regions.

To capture the influence of economic sentiment, we conducted sentiment analysis on relevant economic news articles. The news data was gathered from a wide range of media outlets, including social media platforms, financial news agencies, and specialized economic websites. We used the News API (<https://newsapi.org>), which aggregates data from various sources such as Google News. In addition, historical data was extracted from renowned economic portals like Bloomberg and Reuters. News articles were scraped and processed using a combination of APIs and web scraping techniques to ensure comprehensive coverage of economic events.

All collected data underwent an extensive analysis phase, where generative AI models were employed to process the information and extract meaningful insights. This AI-driven analysis provided us with aggregated output, which was further refined to ensure consistency and quality.

Prior to model training, rigorous data cleaning and scaling methods were applied to ensure the accuracy and relevance of the datasets. Data consistency checks were performed to identify and correct any discrepancies, and normalization techniques were used to scale numerical values for uniformity.

To automate the process of dataset creation and preparation, we developed a Dataset Generation Agent, which streamlined the entire data collection and preprocessing workflow. A detailed description of this agent, including its architecture and operational principles, is provided in Section 3.4.2.

Finally, the entire dataset was partitioned into three subsets: 70% of the data was allocated for training purposes, 20% for validation, and 10% for test. This partitioning ensures an unbiased evaluation of model performance and allows for robust model generalization.

1.2.2. MODELS' SELECTION AND TRAINING

Traditionally, statistical models and neural network architectures have been the predominant methods for forecasting sequential data in time-series prediction tasks. Based on our literature review, Long Short-Term Memory (LSTM) networks - a class of recurrent neural networks (RNNs) - have demonstrated considerable effectiveness due to their capacity to capture long-term dependencies and complex temporal patterns within sequential datasets. However, recent advancements in generative artificial intelligence have opened new avenues for time-series forecasting. In this context, we considered it essential to explore the applicability of state-of-the-art generative models for predicting time-series data, with a specific focus on the EUR/USD currency exchange rate. Models such as LLaMA and ChatGPT, which have shown exceptional performance in natural language generation and comprehension, motivated our investigation into their potential to model and forecast continuous time-series sequences.

In our study, we focused on testing two lightweight generative models: Llama-3.2-1b and GPT-2 correspond to the selected ECO approach that is described in Section 3.3.

The primary motivation behind using Llama and GPT-2 lies in their ability to process large sequences of data, and their underlying transformer architecture, which has demonstrated strong capabilities in learning complex patterns. By applying these models to consecutive time-series data like EUR/USD exchange rates, we aim to assess whether such generative approaches can yield competitive or even superior results compared to traditional models like LSTM.

Long Short-Term Memory (LSTM) networks and Generative AI models, specifically Llama-3.2-1B and GPT-2 were initially tested on historical EUR/USD exchange rate data without any optimization or additional parameters, with the goal of forecasting EUR/USD rates over time periods of 7, 30, 180, and 365 days. The results showed that the LSTM model outperformed the Generative AI models in terms of prediction accuracy (see Table 1).

Table 1. Predictions of the EUR/USD rates by LSTM, Llama-3.2-1B and GPT-2 before optimization

Model	7 days		30 days		180 days		365 days	
	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE
LSTM	0.06278	0.05789	0.07292	0.07145	0.0715	0.07086	0.06346	0.06336
GPT-2	0.08308	0.08286	0.08894	0.08851	0.12113	0.11861	0.1204	0.11876
Llama-3.2-1B	0.08211	0.08003	0.08653	0.08479	0.11905	0.11634	0.1173	0.11467

Source: Authors' calculation

To evaluate the performance of the selected models, we employed several evaluation metrics, including **Root Mean Squared Error** (RMSE) and **Mean Absolute Error** (MAE).

RMSE is a widely used metric that measures the average magnitude of the errors between predicted and actual values. It is calculated as the square root of the average of the squared differences between predicted and actual values, as follows:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (1)$$

where:

- n is the total number of observations,
- y_i is the actual value,
- $\hat{y}_i$ is the predicted value.

A lower RMSE value indicates better model performance, as it signifies that the predictions are closer to the actual values. RMSE is sensitive to large errors due to the squared term, making it suitable for cases where significant errors need to be penalized.

MAE is another commonly used metric that measures the average of the absolute differences between predicted and actual values. It is calculated as:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (2)$$

Unlike RMSE, MAE treats all errors equally, making it more robust to outliers. A lower MAE value suggests a model with higher accuracy.

For the loss function of the LSTM model was used MSE (Mean Squared Error) and for fine-tuning of the generative AI models was used Cross-Entropy Loss.

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (3)$$

$$L = -\frac{1}{n} \sum_{i=1}^n \sum_{c=1}^C y_{i,c} \log \hat{y}_{i,c} \quad (4)$$

where:

- n is the number of samples,
- C is the number of classes,
- y_{ij} is the actual binary indicator (1 if the class label is correct, 0 otherwise) for sample i and class j ,
- $\hat{y}_{ij}$ is the predicted probability for class j for sample i ,
- The logarithm is taken element-wise.

This loss function is commonly used for classification tasks, particularly in neural networks, where it measures the difference between the predicted probability distribution and the true distribution. Lower cross-entropy loss values indicate better model performance.

Generative AI models, such as Llama-3.2-1B and GPT-2, are primarily designed for natural language processing tasks, where they predict sequences of text tokens. As such, they struggled to accurately predict continuous numerical values, like the EUR/USD exchange rates. The models did not grasp

the context of the financial data and produced the same predicted value regardless of the forecast horizon. In contrast, the LSTM model, which is specifically designed to capture temporal dependencies in sequential data, showed natural suitability for time-series forecasting, leading to better prediction outcomes.

To improve the predictive performance of both the LSTM model and the Generative AI models, a series of targeted optimizations were implemented. For the LSTM model, we utilized a Training Agent (as detailed in Subsection 1.2.3) to explore a range of hyperparameter configurations. These included adjustments to the number of training epochs, the number and size of hidden layers, and the application of various dropout rates to mitigate overfitting.

In parallel, we applied fine-tuning techniques to the Generative AI models. Given the eco-conscious design of our approach and constraints on computational resources, the fine-tuning process was deliberately limited to a maximum of 10 training epochs per model. This strategy was intended to balance performance gains with resource efficiency.

Following these optimization steps, we evaluated the forecasting results of the optimized LSTM model and the fine-tuned generative models—LLaMA-3.2-1B and GPT-2—using standard performance metrics. The results, summarized in Table 2, indicate that the optimized LSTM model achieved a marked improvement in prediction accuracy compared to its baseline configuration, thereby confirming the effectiveness of the hyperparameter tuning process. Conversely, the fine-tuned generative models exhibited only marginal performance gains, suggesting a more limited sensitivity to fine-tuning under the given constraints.

Table 2. Predictions of the EUR/USD rates by LSTM, Llama-3.2-1B and GPT-2 after optimization

Model	7 days		30 days		180 days		365 days	
	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE
LSTM	0.01133	0.01104	0.01268	0.01239	0.0114	0.01107	0.01041	0.01019
GPT-2	0.07512	0.07387	0.08156	0.08042	0.10589	0.10231	0.09745	0.09401
Llama-3.2-1B	0.07344	0.07205	0.07871	0.07012	0.10003	0.09021	0.09531	0.08873

Source: Authors' calculation

Based on these results, we conclude that for forecasting time-series data, such as the EUR/USD exchange rates, an optimized LSTM model is more effective than Generative AI models like Llama-3.2-1B and GPT-2. The LSTM model's ability to handle sequential data and learn from temporal dependencies makes it better suited for this task.

1.2.3. HYBRID ECO-MODEL ELABORATION

In the development of our model, we adopted an eco-approach aimed at creating a lightweight, efficient system that minimizes computational resource requirements, which in turn reduces carbon emissions associated with model training and execution. The broader goal of this eco-friendly approach was not only to optimize for energy consumption but also to make the model more accessible, enabling it to run on a wide range of devices and operate at higher speeds.

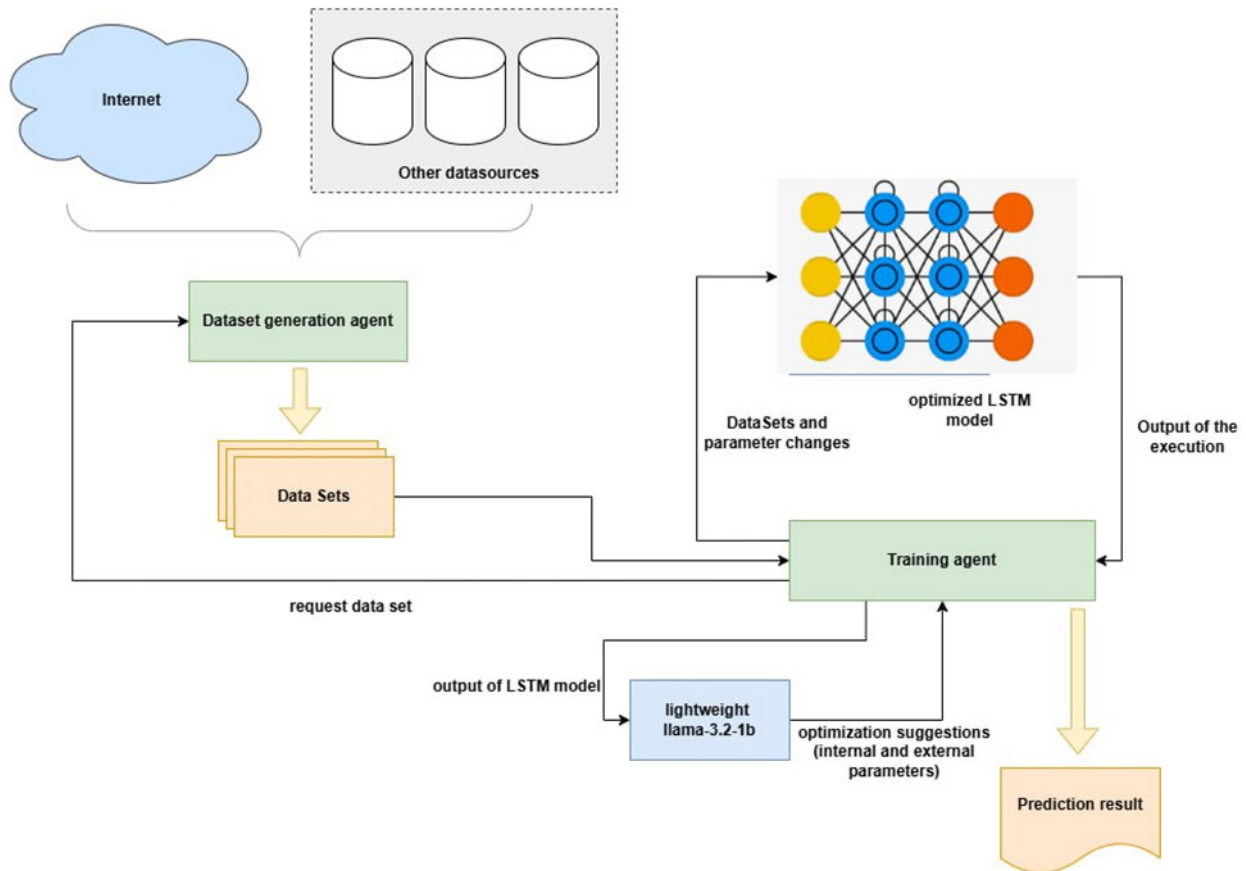
Our ECO-approach encompasses the following key strategies:

- **Use of Lightweight Models:** We prioritized the use of lightweight models for developing a hybrid prediction solution.
- **Data Set Optimization Based on Prediction Horizon:** The size and complexity of the datasets used for training were optimized based on the prediction horizon. For example, for short-term forecasting (7-day prediction), we utilized smaller datasets, which reduced both the time required for training and the computational power needed. For medium-term forecasts (30-day predictions), a medium-sized dataset was used, while for longer-term predictions (180 and 365 days), we employed larger datasets. This tiered approach ensures that only the necessary amount of data is processed at each stage, minimizing resource consumption without compromising the accuracy of the forecasts.

- **Use of Training Agent for Model Optimization:** A central component of our eco-approach is the Training Agent, which plays a crucial role in maintaining a minimal model size. The agent works by interacting with the generative AI model (Llama-3.2-1B) to select and optimize the hyperparameters. This allows us to focus on identifying and adjusting only those parameters that have the most significant impact on the model's performance.
- **Efficient Deployment Across Devices:** A key goal of our eco-approach is to ensure that the model is not only lightweight in terms of training but also optimized for inference. By focusing on computational efficiency, we aim to make the model deployable on a wide range of devices, from standard workstations to mobile devices.

To provide accurate and effective predictions of the EUR/USD exchange rate, we have developed a hybrid eco-model, combining various AI techniques to enhance the model's performance. The architecture of this hybrid model is illustrated in Figure 1.

Figure 1. Hybrid ECO-Model high-level architecture



Source: Authors' design

The system is composed of two primary agents and two AI models. The first agent is the Dataset Generation Agent (discussed in section 3.4.2), responsible for collecting and preparing the data needed for training. The second is the Training Agent (see section 3.4.1 for more details), which manages the overall training process. The AI models involved include an optimized Long Short-Term Memory (LSTM) model, designed to predict the EUR/USD rate, and a lightweight generative AI model (Llama-3.2-1B), which analyzes the outputs of the LSTM model and provides valuable feedback for refining both internal and external model parameters.

The **Training Agent** (TA) initiates the training process by requesting the LSTM model to predict exchange rates for a specific forecasting horizon. It then queries the Dataset Generation Agent for the necessary datasets, gathers this data, and trains the LSTM model with default parameters. The LSTM model's output is collected by the Training Agent and sent to the Llama model for further analysis.

The **Generative AI Model** (Llama-3.2-1B) processes the LSTM model's outputs, analyzing the results to identify potential improvements. These suggestions may include adjustments to internal

parameters such as the number of epochs, dropout rates, and the number of layers in the LSTM model. Additionally, the generative model may propose changes to the dataset, such as the inclusion or removal of specific training parameters.

TA plays a central role in the Hybrid ECO-Model, acting as the system's coordinator for model training and optimization. It operates iteratively, incorporating feedback from the generative AI component to refine the LSTM model's performance. Based on this feedback, the agent may modify the model's architecture or request new datasets as needed, re-running the training process to improve accuracy. This cycle repeats until the generative AI determines that the LSTM model is sufficiently optimized for the target prediction horizon.

Once the optimization process is complete, the Training Agent saves the finalized LSTM model for future deployment. It also documents and publishes the outcomes of both the training and testing phases, ensuring transparency and reproducibility of the results.

To better understand how this system functions, we now examine the key components of the Hybrid ECO-Model, starting with the Training Agent itself.

As a core component of the model TA is responsible not only for executing training scenarios but also for facilitating communication between different modules within the system. It ensures smooth data flow and model interaction through its integrated API interfaces. Specifically, the agent is equipped with a REST API that allows efficient communication with external systems and components.

One of its key responsibilities is triggering the Dataset Generation Agent, which handles the retrieval and preparation of training datasets. Once the dataset is available, the Training Agent initiates the execution of the Long Short-Term Memory (LSTM) model - an advanced type of recurrent neural network - by adjusting a range of hyperparameters to enhance model performance. These include:

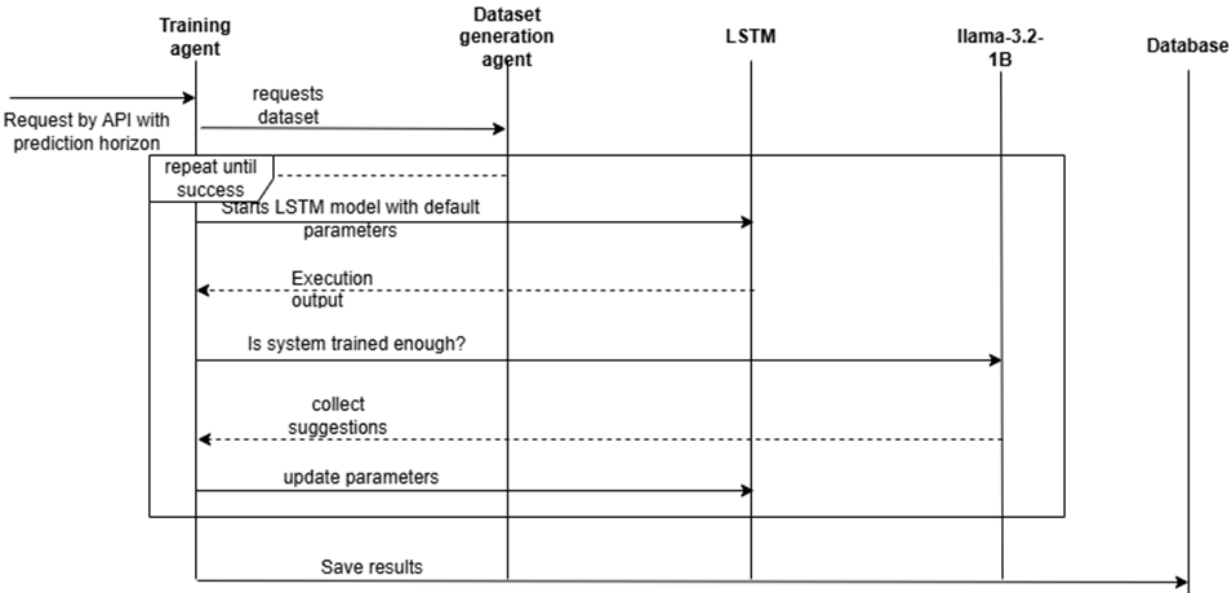
- Number of epochs: Defines how many times the training process iterates over the dataset.
- Dropout rate: Regulates the dropout layers in the LSTM to prevent overfitting.
- Loss function: Determines the metric used to optimize the model.
- Hidden layers and size: Specifies the architecture of the LSTM, including the number of hidden layers and their respective sizes.

TA executes the LSTM model using the specified parameters and collects the resulting outputs. To enhance the model's performance, it then engages in a feedback loop with the Generative AI model (LLaMA-3.2-1B), leveraging prompt engineering techniques. The generative model analyzes both the inputs and outputs of the LSTM and returns structured recommendations for improvement. These may involve changes to the model architecture, training configurations, or other hyperparameters that could boost predictive accuracy.

TA interprets these suggestions and applies the proposed adjustments to the LSTM model. Once the updates are made, it re-initiates the dataset retrieval and training process. This iterative cycle continues until the LLaMA-3.2-1B model confirms that the LSTM has been sufficiently optimized for the desired forecasting horizon.

After the optimization is complete, the final version of the LSTM model, along with its training results, is stored in a centralized database. This allows the model to be reused for future predictions or further analysis without requiring retraining—ensuring both efficiency and reproducibility. Figure 2 illustrates a sequence diagram depicting one of the training agent scenarios, showing the sequence of interactions between the agent and other system components during the model training process.

Figure 2. Sequence diagram of the training agent scenario



Source: Authors' design

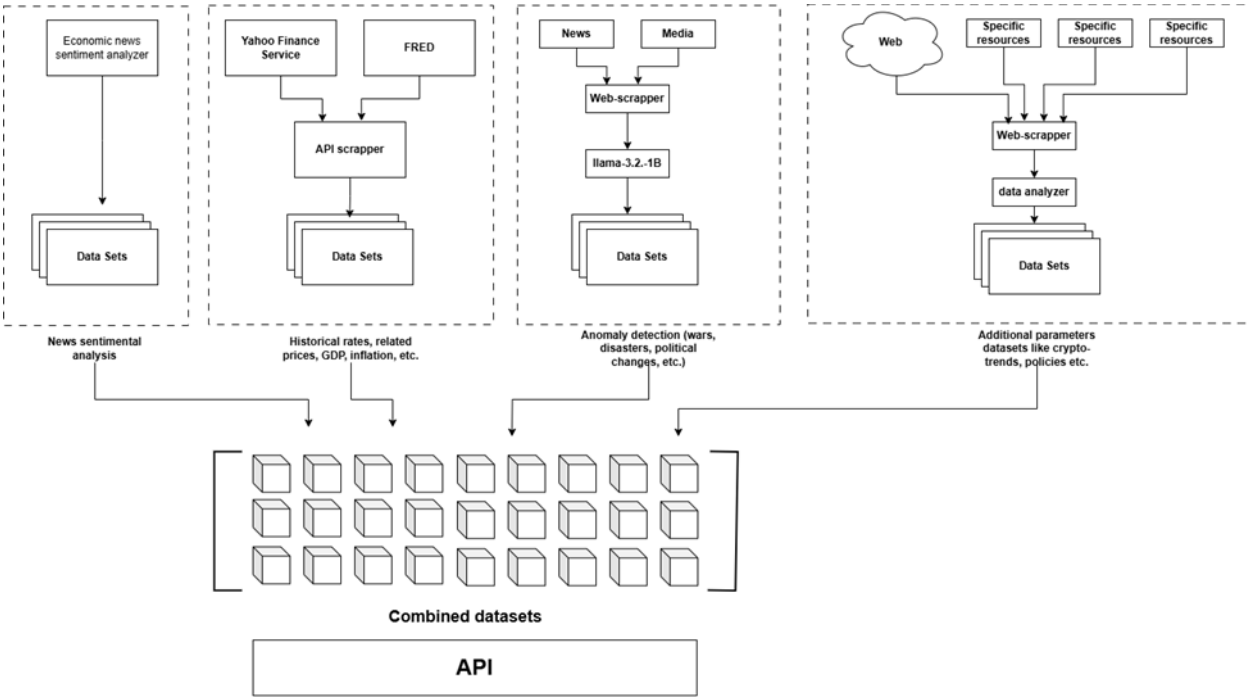
TA is also responsible for interaction with generative AI model to select the most optimal external input parameters that should be included in the final configuration (like price oil and gold).

Dataset Generation Agent is a critical component of the hybrid eco-model, responsible for collecting data and generating datasets. It consists of several micro-services, each dedicated to a specific task:

- News Sentiment Analyzer
- Financial and Economic Indicators Collector
- Anomaly Detection Analyzer
- Additional Parameters Collector

Figure 3 illustrates the architecture of the Dataset Generation agent.

Figure 3. Dataset Generation Agent architecture



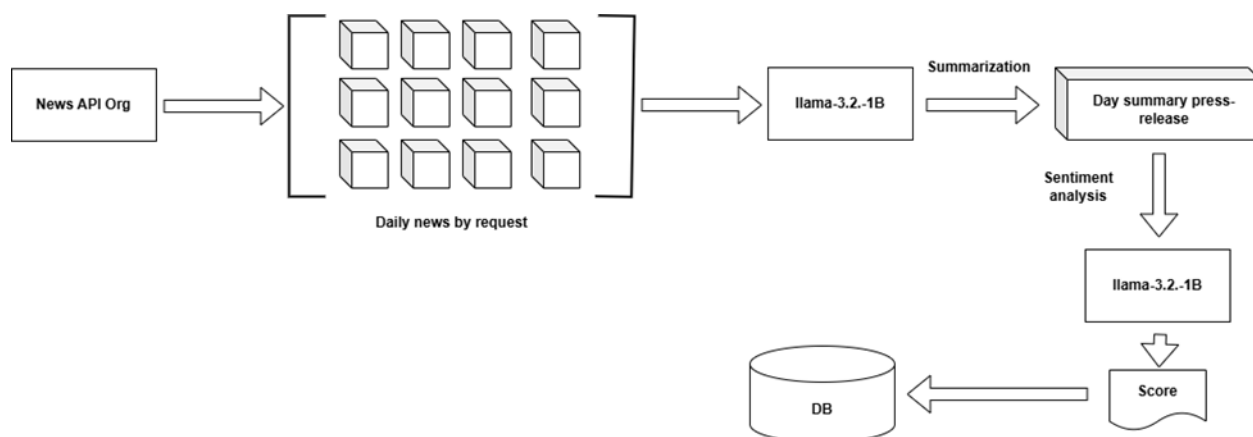
Source: Authors' design

The Dataset Generation agent provides a REST API to request the necessary datasets. It can trigger the execution of various analyzers either on-demand via API requests or based on a pre-defined schedule. The generated datasets are then stored in CSV format, either in file storage or a relational database.

Below is a more detailed description of each submodule:

The News Sentiment Analyzer is responsible for gathering daily financial news, generating daily press releases using the generative AI model (Llama-3.2-1B), and performing sentiment analysis on these press releases using the same model (see Figure 4).

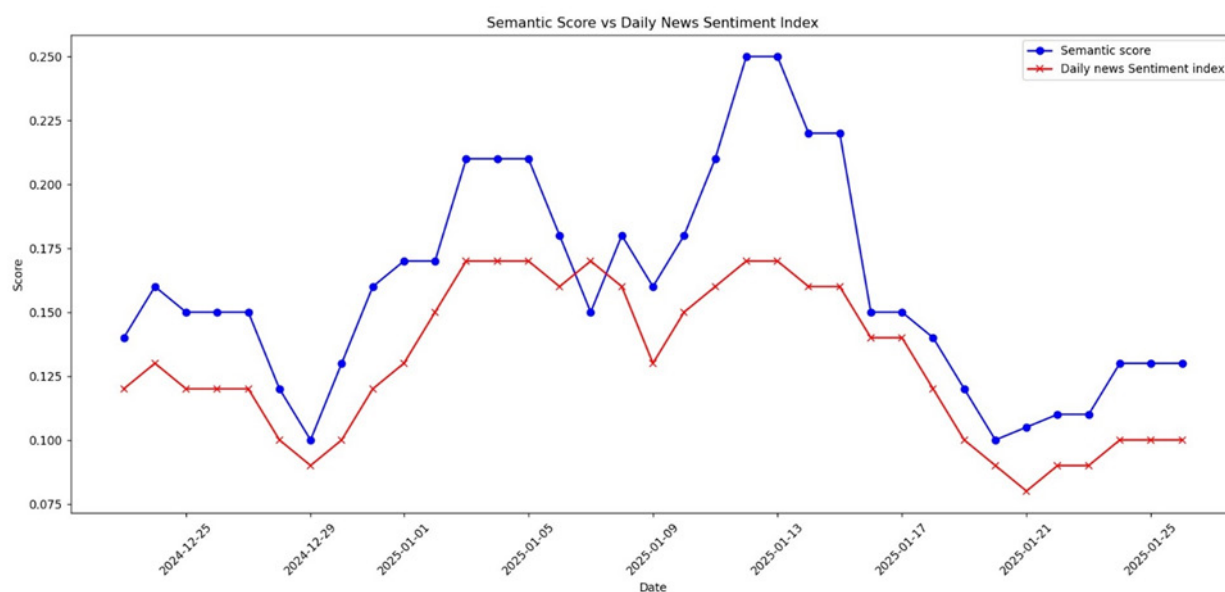
Figure 4. News Sentimental Analyzer architecture



Source: Authors' design

The results of the sentiment analysis are stored in the database. The analyzer collects historical news for a specified time period. We utilize the News API to gather data; however, this API, via a developer account, only allows access to 30 days of historical data. As a result, we were able to create datasets limited to a 30-day period. In the context of the hybrid eco-model, we require data spanning multiple years, ideally starting from 01/01/2010. To address this gap, we decided to use the Daily News Sentiment Index, as it closely correlates with the sentiment scores generated by the News Sentiment Analyzer (see Figure 5).

Figure 5. Correlation between Financial News Sentimental Score and 'Daily news sentiment index'



Source: Authors' calculations and graphing

Financial and economic indicators collector – The Financial and Economic Indicators Collector gathers relevant data from various sources, such as Yahoo Finance and the Federal Reserve Economic Data (FRED). The collector interacts with the REST APIs of these sources and saves the gathered data into CSV files for further use in the model.

The Anomaly Detection Analyzer is a promising yet currently unimplemented submodule. Its objective is to analyze various online sources to detect anomalies such as wars, natural disasters, pandemics, political changes, or other significant events that could influence financial and economic indicators. This component aims to incorporate such real-world events into the model for better accuracy and robustness.

The Additional Parameters Collector gathers supplementary minor economic parameters from open sources. It leverages both APIs and web scraping techniques to collect information, generating datasets that include these additional parameters to enhance the hybrid eco-model.

In summary, the Dataset Generation agent orchestrates the collection and preparation of diverse data sources, enabling the hybrid eco-model to train, predict, and simulate based on a wide range of financial and economic indicators.

Generative AI models play a crucial role in our hybrid ECO-model, driving decision-making processes based on the training outcomes of the LSTM model. Specifically, these models are responsible for adjusting the structure of the LSTM network, incorporating additional parameters into the dataset, modifying model coefficients, and other tasks that enhance the model's performance. Furthermore, they contribute significantly to the dataset generation process by providing capabilities such as text summarization and sentiment analysis.

Given that our objective is to minimize computational resource consumption in the hybrid ECO-model, we opted against fine-tuning the generative AI model. Instead, we employed prompt engineering to guide the model's behavior. While Retrieval-Augmented Generation (RAG) could be considered as an alternative, we found that prompt engineering alone was sufficient for the scope of our experiment.

In the overall system architecture, the generative AI model is tasked with several critical responsibilities:

- **Text Analysis and Suggestion Generation:** The model analyzes input data and generates recommendations for improving dataset quality or adjusting model parameters.
- **Model also responsible for selecting the strongest parameters to the final dataset.**
- **Input-Output Suggestion Based on Data:** The model offers insights and recommendations based on the relationships between the input data and output predictions.
- **Text Summarization:** It summarizes relevant news articles and reports to provide concise and relevant information for the model.
- **Sentiment Analysis of News:** It evaluates the sentiment of economic news to assess the market's potential impact on the EUR/USD exchange rate.

The operations of the generative AI model are orchestrated by the Training Agent and Dataset Generation Agent, ensuring that data preprocessing, model training, and decision-making are seamlessly integrated. Throughout our experiment, the generative AI module demonstrated high performance, effectively contributing to the accuracy and efficiency of the overall system.

2.RESULTS AND DISCUSSIONS

We implemented the Hybrid LSTM-Generative AI ECO-model and conducted an experiment to predict the EUR/USD exchange rates based on historical data and a specified prediction horizon. The model demonstrated the ability to effectively handle this task, providing fairly accurate predictions, making it suitable for use by a wide range of organizations in currency forecasting applications. Notably, the system's efficiency offers significant financial gains, particularly for financial institutions, investment firms, and currency traders who rely on precise exchange rate forecasts to inform their decision-making processes.

The system was trained and operated according to recommendations from the Generative AI module, which provided real-time guidance on LSTM model improvements. The results of the training process are summarized in Table 3, which presents the prediction accuracy achieved using various model configurations. Our analysis demonstrated that incorporating the "Inflation" parameter into the historical data resulted in reduced prediction accuracy compared to using the "GDP" parameter

alone. Furthermore, the inclusion of any of the “Inflation” and “GDP” parameters led to lower accuracy than adding the “Oil/Gold” parameters. This suggests that macroeconomic indicators may not have an immediate direct impact on the exchange rate, but they could exert a more significant influence over the long term.

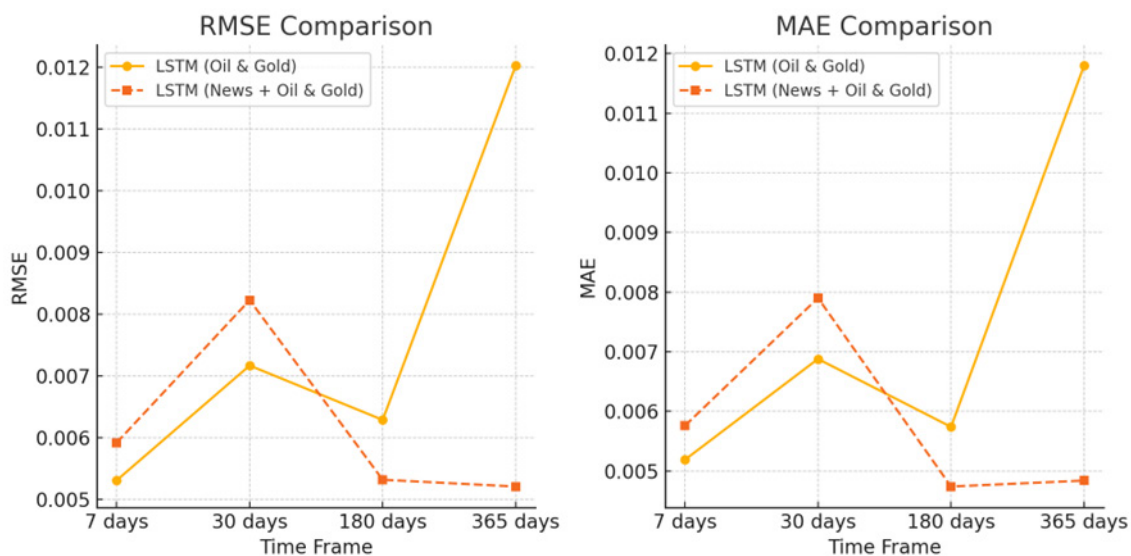
Table 3. Predictions of the EUR/USD rates by LSTM model with different parameters

Feature	7 days		30 days		180 days		365 days	
	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE
Inflation	0.05206	0.04842	0.0617	0.06054	0.0574	0.05711	0.05689	0.05677
GDP	0.05042	0.0463	0.05389	0.05283	0.05557	0.05535	0.05335	0.05323
Oil and gold	0.00531	0.00519	0.00717	0.00688	0.00629	0.00574	0.01203	0.0118
News semantic analysis	0.00959	0.00925	0.01363	0.013263	0.01024	0.00987	0.0118	0.0116
Oil/gold + semantic analysis	0.00592	0.00576	0.00823	0.007902	0.00532	0.00474	0.00521	0.00484

Source: Authors' calculation

One of the key suggestions from the Generative AI model was to incorporate a combined oil/gold parameter. The inclusion of this combined parameter led to a significant improvement in prediction accuracy (from 5 to 12 times depending on the prediction horizon). As part of our goal to develop an optimal model with minimal resource usage, the Generative AI module further recommended adding sentiment analysis of economic news to enhance model performance. By integrating this additional feature, the final model contained three extra parameters: oil/gold prices, historical EUR/USD exchange rates, and news sentiment analysis.

Figure 6. Comparison of prediction accuracy for Oil&Gold and combined Oil&Gold+News parameters:
a) Description of RMSE comparison is contained in the left part; b) Description of MAE Comparison is contained in the right part



Source: Authors' calculation and graphing

For short-term prediction horizons, the final model with the added sentiment analysis parameter showed slightly lower accuracy compared to the LSTM model (in about 11% for 7 days prediction) that only included the oil/gold parameter. However, for longer prediction horizons, the inclusion of the news sentiment analysis parameter resulted in a dramatic improvement, with prediction accuracy more than doubling the performance of the model that used only oil/gold data. This underscores the importance of incorporating sentiment analysis for long-term forecasting, where external factors such as geopolitical events or economic shifts have a more pronounced impact.

The study conducted advances the field by proposing a more integrated and balanced hybrid architecture—the Hybrid LSTM-Generative AI Prediction ECO-Model—which ensures that both model types contribute meaningfully to the forecasting task. By designing a system where the generative

model plays a more active role in both pre-processing and direct forecasting tasks, this research moves beyond the auxiliary use of generative AI and demonstrates how deeper synergy can lead to improved forecast accuracy, especially in long-term horizons.

Moreover, the emphasis on efficiency and practicality—a lightweight, resource-conscious design—directly addresses the increasing demand for scalable and deployable forecasting tools in real-world economic policy and industry settings. In doing so, this study not only refines the theoretical understanding of hybrid forecasting models but also offers a viable path toward more accessible, interpretable, and cost-effective forecasting solutions.

Thus, the findings contribute meaningfully to the macroeconomic forecasting literature by:

- Challenging the traditional asymmetric hybrid model design;
- Demonstrating the performance benefits of a more balanced integration of LSTM and generative AI;
- Introducing an eco-efficient framework that aligns with practical deployment needs;
- Setting the stage for future work on generalizable, modular hybrid forecasting systems.

While the system demonstrated exceptional performance in predicting the EUR/USD exchange rate, several limitations were noted, which should be considered for future improvements and real-world application:

- **Limited Fine-Tuning of the Generative AI Model:** Due to the constraints of our eco-approach, we were unable to significantly fine-tune the Generative AI model. Instead, we relied on prompt engineering and, as an optional strategy, Retrieval-Augmented Generation (RAG). The inability to fine-tune the model restricts its flexibility in adapting to highly specific market conditions.
- **Limited Access to Historical Financial News:** The sentiment analysis module relied on available financial news data, but due to limited access to comprehensive historical and more specific (for example, exchange rates) financial news, the model's sentiment analysis was not as robust as it could be. This limitation affected the model's ability to accurately predict sentiment scores for specific days, which, in turn, impacted its performance.
- **Restricted Access to Broader Media and Social Media:** The model lacked access to a wide range of historical media and social media resources that could be used for anomaly detection. The absence of these data sources may have limited the model's ability to detect sudden shifts in market sentiment driven by social or media events.
- **Minimalist Approach to Parameter Inclusion:** In keeping with our goal of developing a minimalist LSTM model with the fewest parameters necessary, we did not include all potential weak parameters in the model. While this approach optimized resource consumption, it may have excluded some parameters that could have further enhanced the model's predictive capability.

3.CONCLUSION

The Hybrid LSTM-Generative AI ECO-Model presents a transformative approach to forecasting and economic indicator analysis, offering significant benefits to financial organizations and the broader economy. By integrating the predictive capabilities of Long Short-Term Memory (LSTM) networks with the creative adaptability of Generative AI, this model enhances the accuracy, adaptability, and efficiency of economic forecasts. Financial institutions, including banks, investment firms, and policy-making bodies, can leverage this model for more precise risk assessment, portfolio optimization, and macroeconomic planning.

Furthermore, the model's ability to generate synthetic economic scenarios enables stress testing and strategic decision-making, allowing businesses and governments to anticipate and mitigate potential financial disruptions. The increased forecasting accuracy enhances market stability, improves investment strategies, and fosters data-driven policymaking, ultimately leading to more resilient economic systems.

In this study, we demonstrated the feasibility of developing an efficient predictive model using an eco-approach, leveraging lightweight models and carefully selected parameters. The results indicate that, despite the advancements in generative AI models, they are not yet optimal for direct time-series forecasting. However, when integrated into hybrid systems alongside models such as LSTM, generative models can provide valuable insights and optimization strategies, contributing to improved overall predictive performance.

Our findings confirm that LSTM models, when optimized, outperform generative AI models in forecasting financial time-series data, such as the EUR/USD exchange rate. The results highlight the significance of incorporating domain-specific features, such as oil/gold prices and economic sentiment analysis, to enhance forecasting accuracy. The hybrid ECO-model, which integrates LSTM with Generative AI model proved effective in refining model predictions while maintaining minimal computational resource consumption.

Despite the success of our approach, certain limitations remain. The reliance on predefined hyperparameters, the limited fine-tuning of generative AI models, and the restricted access to historical financial news and broader social media data suggest avenues for further exploration.

Several potential directions for **future research and development** include:

- Anomaly Detection Module – Implementing an anomaly detection system to identify unusual patterns and external market shocks (e.g., political events, economic crises, or natural disasters) that could impact exchange rate predictions.
- Expansion of Data Sources – Enhancing dataset diversity by incorporating social media sentiment, broader financial news sources, and alternative economic indicators to improve model accuracy and robustness.
- Hybrid Model Enhancements – Exploring the potential of combining multiple weak parameters, which individually contribute little predictive power but may collectively enhance model performance.
- Adaptive Learning Strategies – Developing self-improving models that can dynamically adjust hyperparameters, input features, and prediction strategies based on real-time market changes.

By addressing these research directions, future iterations of the hybrid ECO-model can achieve even greater predictive accuracy, broader applicability, and enhanced adaptability to real-world financial forecasting challenges.

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INNOVATIVE MANAGEMENT METHODS IN CONTEMPORARY BUSINESS ORGANIZATIONS

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ABSTRACT

The discovery and application of innovative management methods for strategic decision-making in all global business organizations is becoming a comprehensive process for achieving sustainability in all spheres. Given the great popularity and importance of the topic, both in practice and in theory, the number of publications on it is increasing rapidly. The search for innovative forms and methods for managing organizations is the reason for writing this report, the whole issue is to create a research framework for innovation in management. Its application will help scientists and managers to understand, analyze and guide organizational processes when introducing innovations in management. The framework outlines the key variables, the relationships between them and the analysis system, giving guidelines on how to collect, analyze and interpret data, in accordance with current strategic and/or current tasks and problems. An in-depth review of specialized literary sources was conducted, based on which findings were drawn about the most used innovations in the management of all different organizations. A methodological tool was created and a survey was conducted among managers in Bulgarian business organizations. Based on the results of the empirical study, a synthesized review of the current state and their requirements for innovation in the context of the modern dynamic market environment is made.

Keywords: *innovation in management, strategic and current management, managerial decision-making, research framework for innovation, management effectiveness, innovative methods in management, growth and sustainable future*

1. INTRODUCTION

This report aims to lay the foundation for developing a universal research framework for generating innovations in management, applicable to all management processes and activities. It is based on the results of theoretical and empirical research on existing innovative theories and practices related to management, which have proven their usefulness. For this purpose, an empirical tool has been created to further establish the extent and type of innovations introduced in the management of Bulgarian business organizations.

The article is structured in six sections: introduction; description of the methodology for the overall study; presentation of the results of the literature review of studies conducted in the field of management innovations, the existing types of such and the most applied of them; discussion and analysis of the results of the empirical study; formulation of conclusions and description of the process for designing innovations in management with structuring a conceptual framework for creating innovations in management; conclusion, including notes, limitations and opportunities for future research.

The relevance of the topic under consideration is dictated by the need for modern management to respond adequately to everyday challenges in business, with a view to sustainable existence of companies despite the many unpredictable circumstances of the market environment. This is a prerequisite for their constant search for new solutions for change towards a new stability achieved through dynamics. In our time, it is known that the success of any such organization based on knowledge depends on the innovations, creative resourcefulness and ingenuity of its creators and employees (Martins, E.C., Terblanche, F., 2003). As a result, innovations as a factor that affects the overall organizational performance have become the main goal of most business organizations oriented towards sustainability over time. More precisely, this statement applies not only to technological innovations, but also to the so-called non-technological – organizational, marketing and management innovations (Manual, O., 2005; Hamel, 2006), the latter being the subject of this study. Referred to the development and implementation of new management processes, models or systems, management innovation (MI) has its own characteristics that distinguish it from other innovations. Unlike the familiar technological ones, those in management (MI) encompass more collective “social” aspects than the physical technologies themselves (Krasnicka, T., Głód, W. & Wronka-Pośpiech, M., 2018; Nelson & Sampat, 2001).

It turns out that the statement established after a 2006 study that “despite their importance, innovations in management remain poorly managed and poorly understood” (Birkinshaw J., Mol, M., 2006) is still relevant. Quite a few articles on MI have been published in recent years and the topic still maintains great interest in business, where the need to improve management activities is palpably felt. At the same time, there are few scientific studies that could explain and frame the mechanisms for creating MI, and could confirm their importance and impact on technological innovations and economic results of business organizations. It is necessary for these future studies to emphasize the important role of top and middle management, which in itself does not directly influence technological innovations (Elenkov, D. S., Manev, I. M., 2005), influences strategically and tactically through its way of management and development of non-standard business solutions.

Changing the organizational format from accepted practices, structures and approaches in the company in a way that is new for it and/or the business sector is a key characteristic of MI and an indicator of its innovativeness, productivity and competitiveness (Volberda, Van Den Bosch & Heij, 2013). In this regard, the question of the significance, connection with the strategic concept and the mechanisms of creation and implementation of MI remains open, with many unknown answers and unfinished discussions.

From a comprehensive review of the literature on this topic, it is evident that many reasons stimulate research on MI and, more specifically, encourage attempts to operationalize them in a conceptual framework, as a kind of tool for generating innovative management practices. The present study aims to contribute to filling this gap in the existing innovation theories for the management of organizations, by providing a broad-spectrum approach and at the same time specific recommendations for the creation and implementation of innovations in this area. The aim is to achieve the development of a management tool in the form of a conceptual framework, with the help of which it is possible to implement MI. This effort will provide an opportunity to get to know their nature and impact on the final results, as well as on the overall performance of organizations.

2. RESEARCH METHODOLOGY

To find a solution to this problem, the present study was initiated, with the aim of better understanding how innovations in management occur and how they can be introduced into all management processes. The methodology of secondary research includes an initial examination of some known cases of innovations in management, and then their study is expanded to other literary and electronic sources, where data for a number of studies in many areas are stored. The studied information is analyzed and systematized in several more important directions, so as to serve as a basis for formulating conclusions and recommendations necessary for the conceptual framework. For this purpose, a combination of data from case studies in business and the results of the survey were used, which testify to the experience of a large sample of managers in Bulgaria. Attention is focused on understanding the conditions and stages in the process of the emergence of innovation in management and discovering the roles that *leading individuals* have in the *formation and stimulation* of MI.

2.1. METHODOLOGY OF SECONDARY RESEARCH AND DATA ANALYSIS

(conducted research of sources by Bulgarian and foreign authors on the use of innovations in the management of organizations)

The methodology for secondary research on innovations in management encompasses a systematic review of published data on them regarding their understanding, research and implementation. The aim is to access old and new information that demonstrates the significance of this type of innovation and the effectiveness of their implementation in real management processes. The methodology supports finding data on the types of innovations and those of them that are most used in modern management, as well as the discovery of patterns and trends in the processes of their initiation, creation and implementation.

The purpose of the secondary research is to obtain up-to-date information, which can be collected and processed so that it can serve as a basis and form a research framework for creating future MI. The chosen research method has a number of advantages, some of which are speed and low cost, providing an additional opportunity to present the information descriptively and systematized by direction.

The methodology used for the secondary research includes the following *five stages*:

- *The first stage* is to define the objectives and research questions of the study. It involves formulating and refining them so that they are directed towards the specific search without implying ambiguous answers.
- *The second stage* includes: selecting and collecting sources by relevant keywords, finding them in international and national databases (Scopus, ResearchGate, Google Scholar, specialized journals, national libraries, etc.) and selecting appropriate publications and materials on the topic.
- In *the third stage*, different criteria are applied for inclusion and exclusion of certain publications (filtering the results found) according to their relevance to management innovations.
- *The fourth stage* covers the review and analysis of the content from the selected sources, with the aim of extracting important information on the supporting points of the research framework, which is intended to be structured as a result of this study. The stage also includes conducting a comparative analysis between the selected data in the context of the study, synthesizing them to form a more comprehensive picture by extracting the essential moments and identifying trends and gaps in the literature.
- In *the Fifth Stage*, the collected data are interpreted and interpreted, the most important results of the analysis are summarized in order to formulate conclusions about how MI is implemented in management processes and affects organizations. The findings are used to compile and offer useful recommendations and guidelines in the form of a systematized research framework for practical application.

These steps ensure a structured and clear conduct of the secondary research, which allows for a systematic, consistent summary and analysis of the literature on the topic of management innovations. Thus, the secondary research can cover the necessary amount of data for a proper understanding of the meaning of the MI, as well as a sufficient amount for an objective analysis of the trends affecting business processes in modern management. In this way, the generated data provide the necessary information to gain a real idea of their significance and influence on the business climate and the results of organizations.

2.2. METHODOLOGY OF EMPIRICAL SURVEY AMONG MANAGERS

(survey among managers from Bulgarian business organizations on the most used innovations in management by them, as well as on the need for specific innovations, according to their most pressing problems, taking into account the effects of the innovations in management used so far)

The empirical study among managers of Bulgarian companies is necessary to comprehensively examine MI in the context of the overall study in order to establish how business organizations in Bulgaria can create better business results by incorporating innovations at all levels of their management.

The sample in the study includes a group of different managers in Bulgarian business organizations, selected randomly, regardless of their field of activity and the industry they represent.

Access to the participants who completed the survey was achieved online through the mediation of various associations of managers of Bulgarian companies established in the country, such as: Bulgarian Industrial Chamber (BIC), Bulgarian Chamber of Commerce and Industry (BCCI), Association of Women Entrepreneurs in Bulgaria „Selena“, Union of Business Initiative (UBI), Confederation of Employers and Industrialists in Bulgaria (CBI), Bulgarian Executive Search Association (BESA), National Association of Small and Medium-sized Businesses in Bulgaria (NSMBB), Club 9000 Association, United Business Clubs (UBK), etc.

The answers to the questions included in the questionnaire will supplement the information on the implementation of MI in business organizations in our country, will provide guidance on the used, preferred and necessary innovations that optimize activities and processes when solving real business problems identified by the respondents.

The analysis of the results is based on data obtained from current company managers, which implies that their answers are based on information they personally use in practice, are professional and have a full understanding of the innovative practices that are applied in their organization. Subjective answers are not excluded, due to the lack of such understanding, but expectedly in a much smaller percentage, insufficient to affect the objectivity of the answers in the sample.

The results are processed using statistical methods and presented graphically. The combination of research methods aims to complement each other, minimize the shortcomings of their separate application, and increase the reliability of the results obtained.

The theoretical model of the study is built from four thematic blocks, each of which includes a different number of questions with the following content:

- I. Innovations in management practices..
- II. Needs for new methods for initiating innovations.
- III. Strategic management and problems in the organization.
- IV. Innovative management solutions and future prospects.

The survey was conducted using the Google forms application, and the respondents reached received an active link to it. It guarantees anonymity and confidentiality to encourage openness in responses. Each questionnaire was completed remotely within about 5 to 7 minutes.

The sample is random, as the answers were obtained based on the responding managers from Bulgarian business organizations.

The collection, analysis of data from the completed surveys and their organization is in electronic format. A quantitative analysis (statistical processing of closed questions) and a qualitative analysis (content analysis of open questions) were conducted.

The results are interpreted in relation to the research questions to draw conclusions about the most popular MI and the need for specific new actions necessary to outline a framework of recommendations necessary for their creation.

This structure provides a clear approach to conducting the empirical study through a survey, with each task in it being specifically defined and aimed at identifying current management innovations and the needs for innovations in the management of contemporary Bulgarian organizations.

3. SECONDARY SURVEY RESULTS

Management innovations, in their essence, involve changing the overall organizational form in business companies, in their processes and practices in a way that is previously unknown to the given company or the industry. In themselves, they lead to new technologies and processes in organizations that change their appearance in terms of productivity, innovation and competitiveness. The latest research studies indicate that innovations in management largely explain the overall innovative performance and achievements of companies. Increased stimulation of MI and, accordingly, their impact on new technologies, products or services, as a result, would be crucial for increasing com-

pany competitiveness and sustainability. Therefore, more in-depth research is needed that would clarify what is important in different types of MI and how they can be generated. Their development and promotion also require constant study of their key elements for success, as is the case with technological innovations. Similarly, a systematic development and research work on AI is needed (Volberda, H.W., Van Den Bosch, F. A.J. & Heij, C.V., 2013). The framework that is the aim of this study should cover precisely these common points between technological and non-technological innovations, as well as the conditions that need to be created in order to be successfully managed. In this regard, measurements are needed in the process of creating MI, the determining factors and the results. The collected and verified data are systematized in this framework, which represents a kind of program for MI research in the future.

3.1. RESULTS OF THE ANALYSIS OF SECONDARY SOURCES

Determining the exact number of publications related to MI in Bulgaria has proven to be a challenge due to the lack of a centralized database that would cover all scientific and practical research in this area. However, the presence of specialized publications and studies shows that the topic is a subject of significant interest among Bulgarian practitioners and scholars. For example, the periodical of the Department of Administration and Management at the New Bulgarian University publishes articles focused on effective management models and approaches, including MI in institutions and in the business environment. In addition, in 2013, an association for innovative management was established in our country, namely the STOOS “Network Bulgaria”, which aims to discover, share and promote the use of innovative management approaches to build an effective and balanced organizational environment (www.stoos.bg).

Although it is not possible to provide a specific number of publications on the topic, the presence of, albeit a few, specialized studies and initiatives in Bulgaria testifies to the emerging interest and progressive development in the field of MI. This is also observed in the information from foreign sources, where again it was impossible to establish their exact number. Additional search in them is hampered by the frequent confusion of the concepts of “innovation in management” and “innovation management”, whereby publications on the two topics were mixed up in the result lists of various online search engines. This necessitated the consideration of only the frequently cited publications and those of them that are positioned in leading positions in the samples.

From the selected sources, it was interesting to find that some MI in pioneering companies are indeed their main and lasting competitive advantage (Mol, M., Birkinshaw, J., 2009). While in others, for example, such as analyzing the investment portfolio and introducing environmental requirements for production materials, create more benefits for society. Taken as a whole, both types of innovations, aimed as a result at organizations and at society, are equally important for social and economic progress. But most of the unknowns come out in MI, where far less research has been done on the effects of their introduction into management processes. Based on these findings, the question arose: “Do organizations invest enough in MI?”.

Despite the high importance given to them in the researched sources, MI remain categorically poorly managed and not well understood. It was found that most of the organizations do not have an established internal process for promoting them. Most often, experience shows that innovations in management activities are left to happen in an intuitive way, for which successful innovators in management have repeatedly noted that they created their innovative discoveries in this area “despite the system”, and not with its help (Vaccaro, I. G., Jansen, J. P., Van Den Bosch, F. & Volberda, H. W., 2010). In addition, academic circles have also proven to provide little help in this direction, which is surprising. They discuss studies related to the dissemination of already created MI, for which literature can be found. But there is very little when it comes to their origins and the generative processes that give rise to them in the first place (Birkinshaw, J., Mol, M., 2006). The current search in various databases proved this, as thousands of peer-reviewed articles were found that examine technological innovations, but only hundreds focused on MI. A small but important part of the recent findings are summarized below, but overall they also provide businesses with scarce essential tools for engaging with MI and more specifically for their creation, development or improvement in the management of organizations.

Relatively few studies were found in Bulgaria devoted to innovation in the management of organizations.

These studies cover different aspects of the topic and provide some insights into the integration of innovations into business processes. One of them, which stood out as more significant, is the monograph “Integrated Management of Innovations in the Business Organization” (Yordanova, Z., 2020), which examines the possibilities for integrating their management among other business functions through the use of information systems. It introduces the concept of the “innovation mix”, which encompasses 16 elements of innovation in the organization and 32 management activities for innovations. The author makes a reference precisely from “innovation management” to “innovation in management”.

Another important study is the article “Innovations and their role in the anti-crisis management of organizations” (Ivanova, R.), which analyzes how innovations can be used in the development of anti-crisis measures that correspond to the market situation, the goal being that they be provided to organizations and used by their management in extreme situations.

In the first part of Volume 24 of the Almanac “Scientific Research”, a study entitled “Innovative Management Practices for Good Governance” was published, which presents innovative practices in business organizations and emphasizes that “organizational innovation is a key factor for sustainable management of the modern business organization” (Assenov, A., Aleksieva, D., Stoyanova, S. & Roussenov, G., 2017). The focus is on the need to successfully combine the applied management tools and experience to achieve the set goals.

Last but not least is the treatment of innovations in management in the article “Information Systems in Business Organization Management” (Slavova, P., 2015), offered by information systems in the management and design of business processes through them. The author defines this MI as one of the criteria for successful and sustainable development of business organizations.

The reviewed studies and publications by Bulgarian authors provide important guidelines and examples of good practices in implementing innovations in the management of business organizations, which the authors determine to be of significant importance for increasing their competitiveness (Ivanova, D., 2009) and adaptability in the dynamic business environment (Alexandrova, M., 2015).

3.1.1. STUDY AND ANALYSIS OF RESEARCH CONDUCTED BY FOREIGN AUTHORS ON THE USE OF INNOVATIONS IN THE MANAGEMENT OF ORGANIZATIONS

From the studied foreign sources, several more significant studies emerged that discuss various innovative processes leading to innovations in the management of business organizations. These studies target practical steps for creating new management tools for business that lead to better results and strong competitiveness.

The report “Global Innovation 1000: How the Best Innovators Keep Winning”, published by Strategy&Business, analyzes innovation practices in 1,000 of the world’s largest companies and provides insight into the strategies that leading innovators use to achieve success. Based on the results of the study, the relationship between innovation management strategy and its impact on corporate financial performance is better understood (Jaruzelski, B., Schwartz, K. & Staack, V., 2015). The findings contributed to the selection of strategic guidelines necessary to compile a conceptual framework for stimulating and introducing innovation management in various organizations.

Separately, Gary Hamel’s article “Why, What and How of Innovation in Management” (Hamel, G., 2006), published in Harvard Business Review, discusses management innovations and more specifically how they can provide long-term competitive advantages to business organizations. Each of the cases described in it provided useful information for the purposes of this study, as did the book “The DNA of the Innovator”, which analyzes the behavior of successful innovators and leaders (Dyer, J.H., Gregersen, H.B. & Christensen, C.M., 2011). The five main key skills identified in it, which they possess and increase the innovativeness of their companies, showed another element for the targeted conceptual framework with which to stimulate the process of creating innovations.

A contribution to this search is also made by the book “The Future of Management” by Gary Hamel, which discusses how traditional management practices can be transformed through innovation to meet the challenges of the modern business world (Hamel, G., 2007). A significant part of its content

is useful information about new management techniques that can be used in the management of organizations of different types.

Another interesting source related to MI is the book “How Today’s Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses” by Eric Ries (Ries, E., 2011), in which he presents an approach to managing organizations that encourages continuous innovation and adaptation. His arguments are based on the experience of start-ups and established companies, which he studied in depth, similar to James Moore in his book “The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems”. There, the author explores how companies can use innovation to create and manage business ecosystems that stimulate growth and competitiveness (Moore, J.F., 1996). Thus, he provides valuable conclusions for practice that can serve as guidelines for future research in the field.

Another author who has made a significant contribution to management science and whose insights also provided guidance for this study is Clayton Christensen, known for his concept of “disruptive innovations”. His book “The Innovator’s Dilemma” examines how successful companies can lose their leadership position if they do not adopt radical innovations in their management (Christensen, C.M., 1997). The concept of radical innovations is expanded in the book “Lean Startup: How Today’s Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses” by Eric Ries, who presents the “lean startup” approach, which encourages rapid testing and adaptation of ideas to achieve sustainable innovations in management and product management (Ries, E., 2011). For their part, Michael Tushman and Charles O’Reilly, in „Lead and Disrupt: How to Solve the Innovator’s Dilemma,“ explore how organizations can simultaneously manage their current business and adapt to the changing business environment by introducing radical innovations into the management of their companies (O’Reilly, Ch.A., Tushman, M., 2016).

Another innovator in management science is Henry Chesbrough, who introduced the term “open innovation” in his book “Open Innovation: The New Imperative for Creating and Profiting from Technology”, where he discusses how company managers can use external ideas and technologies to accelerate the innovation processes in their businesses (Chesbrough, H., 2003). Similarly, the book with a collection of essays “Open Innovation: Exploring a New Paradigm” (Chesbrough, H., Vanhaverbeke, W. & West, J., 2006) provides an in-depth analysis of the concept of open innovation and how it is applied in different industries and organizations. For this purpose, they are also included in the questions to the respondents in our empirical study.

In summary, these sources provide valuable information on important starting points in MI design that help to understand this process so that it is actually applicable in practice for different organizational contexts. An in-depth look at different aspects of innovation in management helps to understand how they can be applied in real business conditions by managers, regardless of the type of organization they lead.

3.2. KEY INNOVATIONS IN ORGANIZATIONAL MANAGEMENT

For the purposes of this study and more specifically to formulate the questions in the empirical survey, it was necessary to identify the most frequently applied MI used by managers in making management decisions and their other activities. The sample showed that the innovations in management processes preferred by modern management have the potential to truly contribute to more effective and adaptive management in a much more dynamic business environment, as well as to shape the future shape of business. Here are the more important MI that have emerged as key in the management of modern organizations:

- *Group decision-making.* Modern approaches encourage collective participation in making management decisions. This includes the use of methods and techniques that support effective interaction between team members, combining different perspectives and expertise. Some of them that are applied are design thinking, Collective Intelligence Platforms, game techniques for decision-making (Gamification), Holacracy Decision-Making, artificial intelligence as a co-decision partner in group sessions (Decision-Making via AI Co-Creation), etc.

- *Change Management.* The introduction of this management approach in today's dynamic business environment is becoming a critical factor for success. Structured approaches for transitioning to the desired future state help organizations adapt quickly and effectively to new business conditions, technologies, and market requirements.
- *Organizational culture that encourages innovation.* Creating a culture that supports and stimulates innovative thinking is essential for the creation and adoption of innovations in organizations. Such a culture motivates employees to propose new ideas and solutions, which gradually leads to sustainable development and increased competitiveness of companies.
- *Open innovation.* Organizations are increasingly seeking collaboration with external partners to jointly develop innovations. This approach allows for the pooling of resources and expertise, which speeds up the process and increases the quality of new products and services. It represents co-creation with sharing of knowledge, resources and risks in innovative products, services or technologies, from the perspective of management and business processes, management strategies, monitoring and control.
- *Integrated decision-making models:* Common models are being developed that unify different stages and methodologies in the decision-making process. These models facilitate the understanding and implementation of management decisions, especially in the operational activities of organizations (Lean startup/Agile", VISE Model, Scenario Planning/Real Options, etc.).
- *Information systems for supporting management decisions* (Decision Support Systems - DSS, Management Information Systems - MIS, Executive Information Systems - EIS, Expert Support Systems - ESS, Business Intelligence - BI Systems, Enterprise Resource Planning - ERP, Group Support Systems - GSS, etc.): These systems provide managers with the necessary data and analytical tools for making informed decisions. They integrate internal and external sources of information, which facilitates the analysis and assessment of different scenarios (Lazarov, M., Rashidov, A., 2014).
- *Digital transformation and artificial intelligence (AI).* Technological innovations, especially in the field of artificial intelligence, are significantly changing human resource management. AI is used to automate processes, analyze data, and improve decision-making, leading to more effective personnel management and more. Examples of such intelligent systems and platforms supported by AI and used in the work of managers are: AI-Powered Predictive Analytics (for predicting future events - sales, customer market behavior, etc.), Intelligent Process Automation (robotic automation with AI for managing complex business processes), Digital Twin (a virtual copy of a process, product or system for analysis and optimization using AI and sensor data), Augmented Decision-Making (AI providing recommendations, analyses and simulations), AI-Driven KPI Monitoring (AI monitoring for anomalies and suggesting actions to fix problems), Natural Language Processing (AI analyzes data from surveys, emails and chats), AI-Based Strategic Scenario Simulation (AI simulates various business scenarios, market crises, price changes or regulations and predicts what the consequences will be), etc. (Westerman, G., Bonnet, D., & McAfee, A., 2014)

The conclusion that must be drawn is that all these management innovations demonstrate the importance of technology and a collective team approach in making management decisions. They emphasize the need for adaptability and proactivity of modern management in order to meet the challenges of the new business and market environment.

3.3. ANALYSIS OF THE RESULTS OF THE EMPIRICAL STUDY

Management innovations need to be part of the culture of companies and a generator of their competitiveness. They must constantly add new elements to their creation system in order to maintain their relevance and adequacy to the changing business processes and activities in organizations in relation to the dynamics of the environment inside and outside them.

The conducted literature study showed that IE are sought after by every successful business organization in the world that strives to be at the forefront of the market. In recent years, business companies have been tracking trends in the return on their investments from every innovative activity they undertake. This provoked the present specialized in its nature empirical study among managers

from various companies in Bulgaria, which included 68 respondents. The qualitative and quantitative analysis of the data obtained from the survey gave the results described below.

There is a trend towards a clear orientation towards “Lean management” (25.2%), “Agile methodologies” (20.7%) and “Design thinking” (15.5%), which indicates a desire for flexibility, efficiency and user-oriented thinking of Bulgarian managers (Fig. 1). Increased attention is paid to open and innovative management with cooperation, confirmed by the significant share of those who indicated “open innovations”. Underestimating goal setting may be a signal of the need to develop the analytical culture and strategic approach in organizations. Predominant in the choice of managers are methods that are easily applicable in practice and with proven quick results, which suggests that Bulgarian organizations are looking for rational, not conceptual-theoretical solutions.

92% of respondents assess the effect of the innovations introduced in their organizations as positive, and only 31% define it as “extremely positive” (Fig. 2). This may mean that managers’ expectations for transformation through innovation have not always been fully met and they do not have enough confidence in them. 6% of respondents cannot assess their impact, and 2% do not see their effect.

Figure 1. Question 1 from a survey on the management innovations used by managers in Bulgarian business organizations



Figure 2. Question 2 from a survey on the management innovations used by managers in Bulgarian business organizations



This may be due to several reasons: lack of clarity in the indicators of innovation success; a short implementation period that has not yet allowed for reporting on results; and poor internal communication or monitoring, which obscures the effect of MI on organizational performance. The reason may be existing internal barriers (such as lack of resources, organizational culture, resistance to change) that limit their maximum impact. A good sign is that no one indicated the answer “rather negative” effect, which is a strong indicator that MI is perceived as a valuable effort, even when it does not lead to remarkable results. From the answers to the second question of the survey, it can be summarized that MI is perceived almost unanimously as a positive phenomenon in management. Most organizations have not yet achieved the full potential of the effect of innovations, which may be a signal of the need for: strengthening leadership or other internal mentoring and capacities in innovation; clearer metrics for innovation impact and better strategic positioning of the MI with more targeted support of all innovation processes from management.

The results of the third question (Fig. 3) in the survey „In which areas do you notice the greatest improvement after the implementation of innovations?“ show that after their introduction, the efficiency of processes improves the most significantly (63%). This emphasizes the role of innovations as a driver for the automation of activities, their optimization and for reducing costs. In second place, respondents indicated decision-making (57%), which indicates that the introduced new management methods have probably led to better transparency and an analytical basis that facilitates the managers of business organizations. A significant improvement is also noted in the competitiveness of the company in the market (45%), which is a clear indicator that innovations not only improve processes within them, but also positively affect their external position vis-à-vis the competition. Significant, but more moderate, are the results in customer relations (35%) and risk management (26%), which is a sign that organizations are truly aware of the indirect impact of innovation on relationships with external stakeholders, as well as business sustainability. The percentage that employee satisfaction received - 23% is the lowest, which may mean that innovations are not yet

connected to employee well-being or have not yet been implemented by the managers participating in the survey in this way - with a focus on motivation and internal culture.

In the question in Fig.4, related to the choice of new methods by managers to stimulate innovation in their organizations, the highest share is given to collecting ideas from employees or external partners (61%), which is an indicator of a strongly expressed attitude towards open idea generation. It can be seen that organizations have increasingly begun to rely on the team intelligence of their employees and partners to strengthen innovation processes. There is a clear indicator of a transition to more democratic and horizontal models for managing innovation in Bulgarian business organizations. The next most preferred innovative management methods with 44% each are partnerships with startups or scientific institutions and digital platforms for managing the innovations themselves, indicators of the importance of external knowledge and fresh ideas, and of the pursuit of traceability, structuring and digitalization of innovative business processes. In the preferences of managers, internal entrepreneurial programs follow with 37%, which is an indicator of increasing attention within organizations to creating an entrepreneurial spirit. It is a resource for sustainable innovation with high value, but the percentage generated shows that it still needs understanding or stronger internal support. There is relatively low interest in innovation workshops and hackathons (16%), although they are creative and interactive formats, they may be perceived as one-off events with limited strategic scope, especially when they are not related to a long-term innovation process.

Figure 3. Question 3 from a survey on the management innovations used by managers in Bulgarian business organizations



Figure 4. Question 4 from a survey on the management innovations used by managers in Bulgarian business organizations



Figure 5 shows that the most frequently cited barrier is lack of time or low team capacity (63%). This result highlights one of the most common barriers to innovation initiatives – operational workload, which prevents employees from participating in innovation. This problem creates conditions for short-term operational tasks to be prioritized over long-term strategic outcomes.

The problem that respondents have identified as the second main one is the lack of a clear innovation strategy (51%) (Fig.5). This signals a vacuum in strategic planning, despite the fact that organizations are willing to introduce innovations. Of course, they do not have structured goals and a vision with the support of which to focus their efforts in this direction. This discrepancy leads to inefficiency, fragmentation and lack of coordination between activities. At the same time, employee resistance to change (44%) is also a serious factor that introduces imbalance into the system. It indicates the need for a change in the organization's culture, improved communication and the need to include people in the organization in innovation initiatives. For the successful implementation of innovations, the crucial component is change management. In this regard, it is interesting to note that financial resources rank fourth with 35% of the respondents' votes, which is a sign that the problems are not so much related to strategic and organizational challenges as to the problems. It is noticeable from the lower percentage (14%) that managers attach relatively little importance to limited access to technology. This may mean that in terms of technology, most organizations are already prepared and this is not the problem why they fail to stimulate innovation processes, but rather they lack the capacity and willingness to fully utilize this resource.

In the business of organizations, the most frequently mentioned challenges according to respondents are ineffective communication between departments and attracting and retaining talent, both of which reached 51% of all responses (Fig.6). It is known that these two factors are also key to

achieving innovation goals in management, because talents are an indispensable generator of ideas, new experiments and initiatives for the implementation of innovative technologies. If organizations are not able to retain them, they would have difficulty sustainably creating competitive innovations. Separately, good communication from the right people, as a connecting element between the individual work units within the company, is critically important for the successful coordination of efforts to preserve innovative potential.

In many organizations, innovation is not integrated into the behavior and thinking of teams. It is not routine, but rather implemented as separate, distinct projects. This is reflected in the third most frequently cited challenge by respondents, namely the lack of an innovation culture (39%). This culture, which is a necessary foundation for innovation, adaptability and sustainability.

Figure 5. Question 5 from a survey on the management innovations used by managers in Bulgarian business organizations



Figure 6. Question 6 from a survey on the management innovations used by managers in Bulgarian business organizations



Insufficient digitalization (35%) and slow adaptation to market changes (37%) also hinder the technological maturity and flexibility of organizations, which indicate the need for bolder investment in digital management solutions and faster strategic planning in response to market dynamics.

The results of Fig. 7 clearly show that the managers of the organizations see the greatest potential for the introduction and development of MI to optimize operational processes (65%), which includes lean practices, digitalization, automation and others that save time and resources. This also confirms that efficiency remains a top priority in Bulgarian organizations. Followed by the importance of employee engagement and motivation with 58%, which is a sign that the human factor is recognized as a key resource source of innovation. From this we judge that probably many managers of organizations in our country realize that the success of innovation efforts is not possible without engaged and motivated teams.

Significant weight is also given to flexible strategic planning with 39% of managers' votes, indicating the need for a more adaptive approach in today's changing environment, especially in risky or unexpected shocks related to market instability or technological changes.

Also important, but with lower support, are the results related to innovations in management, such as: data analysis (33%), innovation culture (32%) and sustainable development and corporate responsibility (25%). These percentages show that there are still organizations in the stage of fully implementing traditional data-driven approaches (analysis and interpretation of real data), that not everyone sees cultural transformation as a problem of paramount importance and that corporate responsibility and sustainable development remain in the background, which indicates their low immediate prioritization in Bulgarian organizations, despite global ESG trends (Environmental Social Governance).

The results of question 8 (Fig. 8) regarding the use of digital tools and innovative technologies that managers are considering introducing into their organizations for better management show that artificial intelligence (AI) is the most preferred choice. 37% of respondents indicate it as a technology that is applicable in their business. This result demonstrates strong confidence in artificial intelligence, which they perceive as a tool for optimizing management activities and for better business decisions. AI's capabilities for forecasting, analyzing large volumes of data and automating various processes are probably the reason for this. Here, the second position is occupied by Cloud systems for collaboration (32%), which indicates the need for remote management of teams with the possi-

bility of more flexible operational processes. The desire to increase operational efficiency and digitize these processes is the reason for the increased interest in them. And survey participants focused on freeing up time for more strategic management activities and eliminating routine tasks preferred the automation of their work processes through RPA (Robotic Process Automation) (26%). Analytical platforms and Big Data were mentioned by 18% of respondents, which shows a small share, given the potential they have to support informed management decisions. This may be an indicator of a lack of readiness or skills to work with this type of technology. The same may be the reason for VR/AR technologies for training and simulations, which have the lowest share – 12%, due to their limited use in a management context, as well as the higher costs of their implementation.

Figure 7. Question 7 from a survey on the management innovations used by managers in Bulgarian business organizations



Figure 8. Question 8 from a survey on the management innovations used by managers in Bulgarian business organizations



From the qualitative analysis of the ninth question (Fig. 9) it is understood that 30% of the participants conduct internal audits and analyses once a year in order to improve their management practices. Although it is relatively rare, this shows that most organizations have an established process for self-analysis and review of their management activities. From the point of view of innovation, this is moderate systematicity, but also potential for better adaptability. The respondents who conduct these internal analyses every month are 22%. This indicates the presence of a high organizational culture oriented towards continuous improvement, which is a good basis for integrating MI, since frequent audits allow for timely and more flexible solutions early, due to the timely detection of problems. This is an indicator of truly proactive and innovative management. Audits of internal activities with analysis are conducted quarterly by 20% of the surveyed managers. This is a balanced approach that shows regular cyclicity without feeling administrative burden or pressure. Business organizations with a similar rhythm are assumed to combine periodic renewal of management processes with standard regular control. Only when a serious problem arises do 20% of the organizations surveyed conduct internal inspections. This can be interpreted as worrying when the discussion is within the framework of innovation management. To some extent, it can be assumed that this is reactive behavior, which indicates the lack of strategic control and places the organizations in a vulnerable position to external changes and risks. The lack of management mechanisms for regulatory improvements and the likely lag in implementing innovations is noticeable in 8% of the responses that managers do not conduct internal inspections at all and analysis for subsequent measures to improve management practices. This shows that MI is largely perceived not as a culture, but as a reaction.

The latter statement is supported by the results of the qualitative analysis of the tenth question (Fig. 10), related to the managers' readiness to experiment with new and non-standard management approaches. The following conclusions were established for each of the questions:

- „Yes, we are actively looking for new solutions“ - 46% of respondents. A very positive result in the context of MI, which indicates an extremely good environment for introducing innovative technologies and practices, as almost half of the organizations demonstrate a proactive attitude towards innovations.
- “Only if there is a proven positive effect in other organizations” – 40%. This share is also high and shows a cautious, but still accepting approach to new ideas, as there is interest in innovative methods, albeit after waiting to verify their effectiveness. This provides a safer and

less risky transformation, but limits the possibility of innovations having a leadership position in management.

- „Rather not, we prefer proven methods“ – 10%. This reveals a certain conservatism and inertia in organizations, where they probably do not want to part with established business processes, but do not realize to what extent this limits their adaptability in a rapidly changing market environment.
- „No, our organization is conservative towards change“ – 5%. This share is small, but important because it is an indicator of the existence of environments in which innovations are perceived not as an opportunity, but as a risk.

Figure 9. Question 9 from a survey on the management innovations used by managers in Bulgarian business organizations



Figure 10. Question 10 from a survey on the management innovations used by managers in Bulgarian business organizations



In summary, as many as 86% of managers, respondents in this empirical study, are open to innovations, regardless of whether they apply them conditionally or actively seek them themselves. This is a solid basis for deploying innovative management in Bulgarian business organizations and an unambiguous request for the creation of a framework for MI, adapted to our market reality and business environment, as well as to the specifics of Bulgarian management. The results show that the majority of organizations have the potential to adopt innovative approaches, if they are well argued and proven. The formed group of 15% is not small, which shows a tendency towards traditionalism in management and which should be taken into account in future planning of innovative steps.

4. CONCLUSIONS FOR PRACTICE

As a result of the empirical study conducted and the data collected, some trends have been identified that are of interest for the formulation of a conceptual framework for the creation of an MI. They are the following:

- A clearly expressed trend towards automation and digitalization of business processes as a necessary tool for improving management.
- Focusing on people as capital for innovation and a decisive factor – the need for talent retention, motivation and an innovative organizational culture.
- There has been a growing acceptance of experimentation with new ideas, but with a moderate approach to implementing previously untested innovations.

Some contradictions were also identified, as follows:

- A large majority of organizations do not have a clearly formulated strategy or separate resource for innovation, despite the expressed desire to do so.
- A discrepancy was found between the problems identified by respondents (e.g. need for flexibility) and the systems for regular evaluation and monitoring actually implemented.
- Digital solutions are perceived positively, but at this time there is a lack of organizational readiness for their full integration (lack of capacity and time cited).

Table 1 shows the relationships that emerged between the individual questions and the answers to them. In a comment, it can be said that:

- 86% of organizations are willing to experiment with new approaches, but the main obstacles are lack of time and strategy, and only 22% perform monthly internal controls (questions 5,

10 and 9), which is necessary for active implementation of new ideas. There is **a discrepancy** between the innovation that is declared and what is done in practice for real self-assessment and adaptation, that is, there is high readiness, but there is a lack of systemic support.

- The most worrying challenges are ineffective communication and employee engagement (question 6) and the most desirable is the implementation of innovations in employee motivation - 33% and operational processes - 37% (question 7). There is a coherence between innovation priorities and existing problems, which indicates a high level of awareness of management needs

Table 1. Relationships between the individual questions in the survey (Koleva, G., [here](#))

Element	Related to	What it shows?
Readiness for innovation (v.10)	Resource and cultural barriers (v.5, v.9)	Desire without stable support
Management issues (v.6)	Innovative goals (v.7)	Agreed vision for change
Technology selection (v.8)	Strategic priorities (v.7)	Practical innovation focus
Resistance to change (v.5, v.6)	Lack of checks (v.9)	Management inertia
Challenges (v.6)	Barriers to innovation (v.5)	Self-perpetuating cycle

- The technologies with the highest interest are AI (36%), cloud (31%) and RPA (25%) with a clear focus on automation and optimization (question 8) and this coincides with a focus on data analytics, agile planning and operational efficiency (question 7). There is a direct link between specific goals and technologies for improvement, indicating that innovations are functionally grounded, not abstract.
- From questions 5 and 6, obstacles to innovation in organizations are resistance to change (25%) and the lack of an innovation culture (22%), where more often they do not conduct regular internal audits, but only when a problem arises – 20%, or not at all – 8% (question 9). This shows the direct dependence that a conservative culture leads to a lack of mechanisms for learning and improvement, which limits opportunities for innovation.
- There is a closed cycle of management difficulties (bureaucracy, slow implementation of changes – question 6) leading to a lack of resources for innovation (lack of time and capacity, unclear strategy, resistance from employees – question 5), which in turn exacerbates existing problems. An innovative breakthrough in management approach is needed to break this cycle.

The findings made on the basis of an empirical study have the potential to contribute to progress in the study of innovations in general and specifically to the knowledge related to innovations in management. As a starting point, the generated new data on managerial behavior towards them, especially in the Bulgarian market validity, can serve to structure a conceptual framework for the creation and integration of managed innovations in our country. All presented results lead the study to specific practical-applied conclusions and recommend valuable utility for management practice.

4.1. ARESEARCHFRAMEWORKFORSTIMULATINGANDINTRODUCINGINNOVATIONS IN THE MANAGEMENT OF DIFFERENT TYPES OF BUSINESS ORGANIZATIONS

The data and conclusions obtained in this study provide a basis for building an author's research framework for stimulating and introducing innovations in management according to criteria specified by the surveyed managers, with the help of which it would be possible to initiate and implement MI in organizations in our country.

The most important management approaches for implementing the innovation prerequisites from the elements in the current framework, inspired by the empirical results and suitable for it, are three, namely: dynamic management - flexible and rapid reorganization of teams according to changing business priorities, instead of permanently fixed departments; decentralized structure, distributed roles in a flat structure, instead of the traditional hierarchical system; the ability of the organization to combine and optimize current processes and at the same time experiment with new approaches, as well as to combine activities that are opposite in nature, but are equally important for its stability.

The research framework for stimulating and implementing innovations in management (Fig.11) can be adapted to different types of business organizations, regardless of their size, structure or indus-

try. It covers the full cycle of innovation in management - from determining the need to implementing the innovation and sustainable development of the created new management practices. Created as a result of this research, it is structured with eight key elements, interconnected into a necessary whole, interdependence and logical sequence. The absence of any of these building blocks is a prerequisite for the failure of innovative initiatives in management:

1. **Leadership and vision** – building a clear organizational strategy and proactive leadership that supports change, new ideas and experiments. Formulating a long-term vision for creating, stimulating and implementing innovations, integrated into the company's management mission and goals. Creating flexible and adaptive planning of activities. Appointing an “innovation leader” to lead the innovation processes and culture in the organization.
2. **Organizational culture and people** – stimulating commitment, initiative, motivation in people and tolerance for change. Building a company culture that tolerates risks and changes, learning from failures and encouraging entrepreneurship within the organization. Creating an innovation culture and attitudes towards experiments. Attracting and retaining talents using innovative approaches in their work. Investing in training, developing an innovation culture and creating internal company programs for commitment and motivation.
3. **Processes and structures** – optimization and coordination of management practices and operational processes through innovation. Regulation of coordination between departments and clear structuring of innovation teams. Planning and management of change with a focus on people – training, active communication, and support in adapting to new management models and creating the opportunity to correct them in real time. Implementation and management of change in three steps: drawing up a plan for introducing the change: a phased approach to reduce risk by dividing the process into successive phases; training and communication: conducting training for employees and managers related to the new management practices being introduced and developing a communication strategy; adaptation to change and support, creating crowdsourcing open idea platforms within the organization for consultations and group decision-making.
4. **Evaluation and adaptation** – systematization of internal processes for conducting regular internal audits, analyses, monitoring the effect of innovations and feedback to track innovation efforts. Evaluation and prioritization of management innovative ideas with preliminary determination of criteria for selecting the most appropriate innovations and use of so-called „innovation portfolios“, in order to balance long-term and short-term management experiments. Creation of a cycle for continuous improvement by collecting feedback and adapting innovations to changing market conditions. Diagnosing challenges: analysis of strengths and weaknesses, and collecting feedback through interviews, surveys or focus groups with employees and managers.

Figure 11. Infographic of an author's framework for stimulating and introducing innovations in the management of Bulgarian business organizations (Koleva, G., [here](#)).



5. **Technologies and tools** – process automation and technological support for innovation, with the implementation of AI, cloud and analytical systems for decision-making. Experiment-

ing with new management models and pilot testing. Promoting digital change and access to new technologies through partnerships and training.

6. Partnerships – flexible collaboration with startups and scientific institutions. Generating and collecting business ideas from internal and external sources. Using innovative techniques to discover new management models through partnerships and information exchange. Expanding internal capacity with external knowledge through collaboration on successful methods with external experts or startups to generate innovative ideas.

7. Training and development – building internal capacity for innovation, skills and innovative thinking by introducing training in innovative methodologies (Agile, Design Thinking, Lean, etc.). Developing digital and analytical skills in employees to help them in innovation activities. Providing support for internal entrepreneurship and creativity to achieve the necessary competence and confidence in teams. Defining key indicators for the success of the introduced management innovations in organizations (team engagement and satisfaction, continuous improvement of feedback collection mechanisms, decision-making time, regular reviews of the effect of innovations, etc.).

8. Resources and funding – budget, time, people and access to external support, without which innovations remain declarative. Use of supporting innovation processes and tools, such as digital platforms for collaboration and data transparency. Providing with these resources and the necessary organizational capacity to develop innovation activity in companies. Ensuring targeted budgeting for innovation projects using external sources (e.g. programs, funds, partnerships). Maintaining time and human resources for designing, testing and implementing business innovations (Alexandrova, M, 2015). Showing flexibility in reallocating these resources to innovations with proven innovation value.

The proposed flexible and adaptable innovation framework is designed to be applicable to organizations of different sizes and industries. It combines strategic planning with practical tools for creating, testing, and implementing MI. Through a culture of continuous learning and a systematic approach, organizations can maintain their competitiveness, easily adapt to changes in the business environment, and manage to attract and retain talent with the help of modern and up-to-date management practices.

In compiling the research framework for stimulating and implementing innovations in the management of business organizations in our country, the generally accepted practices and methods in the field of MI used by Bulgarian managers, established in the empirical study, served as the basis. Although no specific sources were used for its creation, many of its elements correspond to known approaches described in specialized studies and publications. For example, in “Integrated Innovation Management in the Business Organization” (Yordanova, Z., 2020) basic methods and business processes for introducing innovations are considered. These practices are in line with the proposed steps in the author’s framework, such as strategic vision, assessment of the current state, implementation and measurement of results. Also, initiatives such as the procedure “Implementation of Innovations in Enterprises” (Procedure BG16RFPR001-1.003, 2025) and the Operational Program “Innovation and Competitiveness” (Operational Program, 2014-2020), which support enterprises in the process of introducing innovations, also offer steps to achieve them, which are also in line with the research framework proposed here.

4.2. STRATEGIC RECOMMENDATIONS TO ORGANIZATIONS

The presented author’s framework for stimulating and introducing innovations in management is applied in combination with the following specific recommendations to managers, aimed at Bulgarian business organizations and based entirely on the results and conclusions of the conducted empirical study:

- Start with small experiments with a positive return on investment to convince skeptical teams and managers to adopt them (40% of survey participants stated that „We will only implement innovations if there is a proven positive effect“);

- Следва разширяване използването на crowdsourcing отворени идейни платформи (*най-предпочитания метод, избран от респондентите с 35% е за „Генериране на идеи от служители и партньори“*);
- Next is the expansion of the use of crowdsourcing open idea platforms (*the most preferred method chosen by respondents with 35% is for „Generating ideas from employees and partners“*);
- Creating internal innovation centers or idea incubators with the right people to maintain a constant flow of innovations
- Building and maintaining sustainable beneficial partnerships with startups and external experts from scientific institutions that will contribute know-how and fresh creative solutions to the organization.

The specific recommendations for managers are of a practical nature for introducing innovations in management, combining proven steps with the active participation of employees and partners. They focus on the areas with the greatest impact when implementing MI - strategic planning, operational efficiency and motivation, while offering a solid foundation for them with internal innovation structures and external partnerships.

5. CONCLUSION

Innovations in management are an interesting and attractive topic not only for researchers and practitioners in real business conditions, due to their positive impact on work efficiency and organizational renewal. They refer to new management practices, organizational structures and administrative systems, which are a key indicator of competitive advantage for many organizations. In reality, research on innovations in management significantly lags behind that of technological and product innovations. This study has largely identified the challenges that contributed to this and shows the reasons for the conceptual ambiguity, methodological shortcomings and obstacles that have hindered research on innovations in management. On this basis, the author's conceptual framework has been developed, which offers a systematic approach to stimulating and introducing innovations in management, consistent with the specific needs identified by the managers themselves in our empirical study. This framework combines strategic vision, technological support, resource provision, organizational culture and human capital as interrelated elements for achieving sustainable innovative development in business organizations. Complemented with recommendations for gradual implementation of innovations, encouraging ideation and building partnerships, the framework is a practical tool for rapid adaptation to modern business reality. It can help any organization not only improve the engagement and effectiveness of its teams, but also build an internal culture of flexibility, systematic learning and entrepreneurship - the basis for long-term competitiveness and innovation maturity.

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