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The position of European countries regarding opportunities for Industrial Symbiosis: A comparative analysis employing multi-criteria decision-making tools

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Abstract: The Circular Economy is recognized as a significant model of sustainable development that enables waste reduction, more efficient use of resources and climate neutrality. Considering that the estimates indicate that the planet Earth's resources and biodiversity are expiring, the European Union invests constant efforts to foster the transition towards regenerative business models and create opportunities for consumption within the planetary boundaries. Production industries are identified as particularly significant resource consumers. Therefore, special attention is directed to the feasibility of collaborative business models and the application of digital technologies to address resource depletion and negative environmental impacts. The concept of the Circular Economy has become crucial in global efforts to reduce the ecological footprint and transition to a green economy, especially through the concept of Industrial Symbiosis. Through Industrial Symbiosis,

companies from different sectors combine their waste and by-products, considering them as raw materials, thus optimizing energy consumption, decreasing primary resource consumption and reducing harmful gas emissions. Although the EU's efforts are evident and clear targets have been established through the European Green Deal, it is essential to monitor and analyze regional results for European countries to effectively develop their potential, define strategies, and implement plans that transform material consumption and environmental impact modalities. Therefore, understanding the material and value chains and processes is crucial to reaching the potential and establishing adequate frameworks to facilitate the implementation of Industrial Symbiosis. In this sense, this study aims to analyze the potential of Industrial Symbiosis in EU countries. Multi-criteria decision-making tools have been used for this purpose. The data used in the analysis were obtained from the Eurostat database. The results highlight a significant divide between EU member states in terms of opportunities and eagerness to implement Industrial Symbiosis. The results indicate the need to focus attention on targeted policies to strengthen institutions and companies to analyze the applicability of collaborative business models and integrate Industrial Symbiosis at local, regional, and global levels.

Keywords: Industrial Symbiosis; European countries; comparative analysis; multi-criteria decision-making

1   Introduction

Fifteen years after the European Commission released the First Circular Economy Action Plan, EU countries have been integrating environmental concerns into their policies and planning [1]. Special attention is paid to waste management through EU documents and recommendations. However, many countries have only recently integrated Industrial Symbiosis (IS) into their waste management plans. IS is a business model in which traditionally separate industries collaborate to optimise the use of materials and energy. Thus, the networks of cross-sector industries and companies have been created in order to achieve joint economic, ecological and technical benefits. This Circular Economy business model primarily aims to reduce waste by extending value chains for waste and by-products. The driving force is undoubtedly the economic benefit derived from extending the material cycle by sending waste to another industry and reducing waste disposal costs with an economic gain. Networks built through IS go beyond traditional supply chains in the sense of chains within one industry, sector or country and along those chains. Companies, industries and sectors are reassessing the quantities, types and streams of waste and by-products to assess whether there are opportunities for applying a new business IS model. The application of IS can significantly contribute to reducing the consumption of raw materials, increasing energy utilisation and minimising waste disposal [2].

The promotion of IS in the EU aligns with broader sustainability objectives such as climate change mitigation, improved resource efficiency,and the transition towards

a low-carbon economy. As countries seek innovative approaches to address environmental challenges, IS provides a practical and effective way to achieve multiple sustainability goals simultaneously. By establishing stronger connections between industries, IS fosters collaboration that can unlock new business opportunities, reduce reliance on virgin materials and improve waste valorisation. Moreover, IS is increasingly recognised as a key enabler for achieving the objectives set out in the European Green Deal, promoting circular value chains and decoupling economic growth from resource consumption.

Two literature gaps related to IS have been identified. First, it is generally accepted that IS business models must be highly adapted to the specific needs of the environment, therefore, a vast amount of literature deals with case studies related to specific products or companies (micro level), eco-parks (meso level) or regions, counties (macro level) [3-5]. However, comparative studies would help evaluate the potential of specific countries to implement IS within and across borders.

Second, a set of comparable indicators must be established to measure and monitor the potential and progress in IS implementation. Considering the scope and diversity of IS systems, a unique set of indicators, especially those related to entire countries, has not yet been found in the literature. Developing these indicators is essential for policymakers, industry stakeholders, and researchers to track IS progress, assess environmental and economic outcomes, and identify best practices that can be replicated across different regions. By creating consistent evaluation criteria, countries can better measure their progress in achieving IS goals and identify areas requiring further support or innovation.

The paper aims to analyze the potential of Industrial Symbiosis in EU countries. For this type of research, the need for uniformly collected and mutually comparable indicators is additionally expressed. Databases managed by certain international organizations can be a fruitful source for such research. In this sense, the data in this research were obtained from the Eurostat database and used to compare EU member states.

The methodology used in the paper is a hybrid CRITIC-TOPSIS, where CRITIC (CRiteria Importance Through Inter-criteria Correlation) was used to determine the objective weights of the criteria, while TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) was used to determine the order of EU countries based on their IS potential.

The importance of such a study is reflected in the analysis of the potential of neighbouring countries that have diversified production to establish IS networks, especially due to the fact that the EU market is viewed as a single one. The results of this study can be crucial for discovering the factors that can contribute to or hinder the successful implementation of IS in certain countries. The analysis of the results looks back at the comprehensive challenges that may arise, such as geographical and logistical challenges, specific industries and material needs, as well as levels of industry development.

2 Literature review

2.1 Identifying the methods for analyzing IS potentials

In the literature, one cannot find a large number of works that deal with Industrial Symbiosis (IS) using methods for comparison in an international context. Works connecting IS and MCDM (Multi-Criteria Decision-Making) deal with the assessment and selection of the optimal scenario in specific industries [6], eco-industrial parks [7], facilitating frameworks for specific countries [8,9].

Sonel et al. (2022) use MCDM to analyze and compare the factors that affect adopting IS using ANP (Analytic Network Process) by creating a network of groups of factors and sub-factors to evaluate environmental, economic, institutional and legal factors. The results indicate the greatest importance of the environmental factor, and the most significant sub-factor within it is environmental awareness [10]. Chrysikopoulos et al. (2024) analyzed critical factors for the success of IS implementation and, using the DEMATEL (Decision Making and Trial Evaluation Laboratory) method, determined that leadership and technology most significantly influence IS and are the driving forces behind all other factors [11].

In one of the more recent works, which is close to IS due to waste management, Sharma et al. (2025) assessed the potential for improving the sustainability of waste management practices. The authors used the IF-TOPSIS approach to deal with the issue of waste collection and segregation strategies as a way to foster a circular economy and achieve material savings [12].

A bit more research in terms of comparative research is found in works dealing with the Circular Economy [13]. Özkaya (2024) performed a comparative analysis of EU countries focusing on the Circular Economy, considering Sustainable Development Goals. He employed several hybrid methods, the CRITIC-Based MAUT (Multi-Attribute Utility Theory) and COPRAS (COmplex PRoportional ASsessment) [14]. Kaya et al. (2023) analyzed the circular economy in terms of social factors in EU countries. The conclusions of this paper indicate the clustering of EU countries and propose a reliable decision support system for the evaluation of EU countries. This complex analysis was performed using the integrated CRITIC and MEREC (MEthod based on the Removal Effects of Criteria) methods to determine the weights of the criteria, while the MARCOS (Measurement of Alternatives and Ranking according to the Compromise Solution) method was used for clustering [15]. Candan et al. (2024) assessed the social circular economy performance of EU countries using the perspective of sustainable development by evaluating the positions with the fuzzy VIKOR method [16].

2.2 Identifying the evaluation criteria for IS potentials

This research uses quantitative indicators, which allow comparisons of EU countries. Quantitative indicators that can illuminate the potential of IS can be found in the Eurostat database. One indicator of IS potential is the resource base, that is, the amount of waste of individual materials that could be available for IS. Quantitative measures can also express the amount of waste that is already recycled or used as raw material in other industrial processes, thus assessing the level reached by individual countries in this segment. Effective use of resources implies quantitative monitoring of the need for raw materials in order to see the consumption of primary and increase the use of secondary raw materials. Therefore, the material footprint is related to the pressure that the final consumption of the state causes on the environment [17].

It is also possible to estimate the economic value of recycled materials that can be used in new processes. In this way, it is possible to identify economically profitable opportunities for IS. Trade in materials that can be recycled and whose life cycle is extended in this way fosters economic growth while at the same time affecting the reduction of the environmental burden.

The quantification of greenhouse gas emissions indicators is crucial for the assessment of emission reduction and the evaluation of the effectiveness of policies and goals aimed at emission reduction.

Planetary boundaries represent limits that must not be crossed in order to preserve the stability of the Earth's ecosystem [18]. Their measurement is linked to the consumption footprint and measures the environmental impact of EU members. For each category, planetary boundaries represent the ratio of the absolute value divided by the planetary boundary per capita [19]. According to this, the set of indicators used to assess the potential of IS is presented in Table 1.

Label	Indicator	Measure
C1	Circular material use rate	Percentage
C2	Trade in recyclable raw materials -Imports intra-EU27	Thousand euro
C3	Trade in recyclable raw materials -Imports extra-EU27	Thousand euro
C4	Trade in recyclable raw materials -Exports extra-EU27	Thousand euro
C5	Waste generation per capita	Kilograms per capita
C6	Material footprint	Tonnes per capita
C7	Greenhouse gases emissions from production activities	Kilograms per capita
C8	Consumption footprint -Acidification	Planetary Boundary
C9	Consumption footprint -Climate change	Planetary Boundary
C10	Consumption footprint -Resource use, fossil	Planetary Boundary
C11	Consumption footprint - Resource use, minerals and metals	Planetary Boundary
C12	Consumption footprint -Water use	Planetary Boundary

Table 1

IS indicators (Eurostat)

3   Methodology

Given the large number of IS indicators and the fact that some of them have opposing effects, a simple assessment of IS potential is not possible. The selected indicators are used to monitor IS potential in different segments, and at the same time, a unique ranking list that provides insight into the positions of individual EU states must be obtained.

In order to effectively assess the potential of each country, a hybrid evaluation method combining CRITIC and TOPSIS was developed. In decision-making problems that contain many criteria and possible solutions, managers often struggle to determine the relative importance of specific criteria, and even if they can, the results are biased by their subjectivity and can lead to distorted results. However, there are ways to address the limitations of the subjective assessment of weighting coefficients. The CRITIC methodology was proposed by Diakoulaki et al. (1995) for the objective determination of the criteria weight, which is based on the study of the decision matrix and the expression of the conflict and the intensity of the contrast contained in it [20].

For the selection and ranking of alternatives, Hwang and Yoon developed TOPSIS [21]. This method is intensively used in research and has experienced many extensions and hybrid models. Mainly because it also includes criteria weights, it represents a basis for combining various objective and subjective methods for determining the importance of criteria in decision models [22,23]. In research on

the Circular Economy and waste management, TOPSIS was used to assess barriers to implementing waste management strategies [12] and analyze barriers in the Circular Economy [24].

The hybrid CRITIC-TOPSIS methodology can also be found in the literature in various segments. It was used, among other things, in the research of material selection [22], stakeholder assessment [25], financial performance assessment [26], and software reliability [27]. A methods flow chart was created to present the process of obtaining results and clarifying the methodology, presented in Figure 1. Detailed methodology with mathematical procedures used for the calculation can be found in the works of [20, 21,28,29].

Figure 1
Metods flow chart [29]

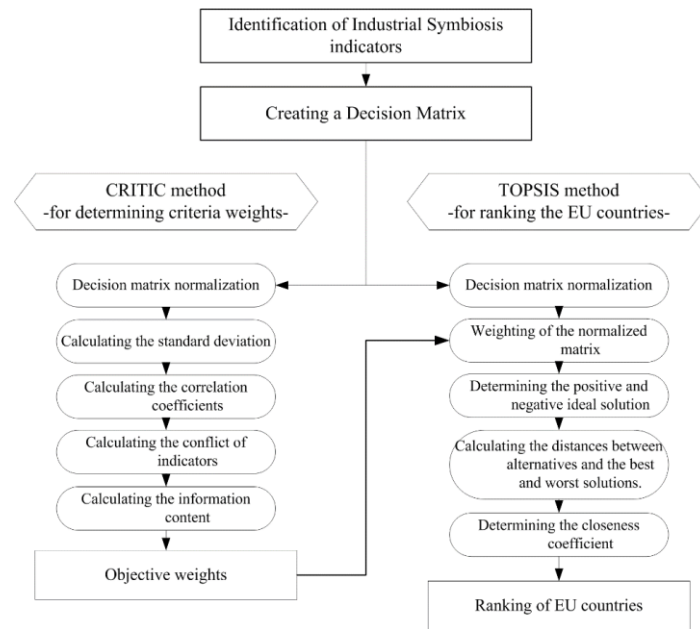# 4   Results

The initial decision matrix comprised 12 criteria outlined in Table 1 and 27 alternatives consisting of EU member states. Utilising the CRITIC method, indicator weights were determined using an objective approach based on the information contained in the collected data. The data was gathered by employing a representative year in which the data set is complete, as some indicators are

collected annually while others are gathered biennially. The results indicate that the biggest contribution to the ranking is the indicator of Circular material use rate. The TOPSIS approach was used to rank EU countries based on 12 proposed criteria, and the obtained results are presented in Table 2.

Rank	Country	Rank	Country	Rank	Country
1	Germany	10	Greece	19	Lithuania
2	Belgium	11	Denmark	20	Slovenia
3	Netherlands	12	Slovakia	21	Austria
4	Italy	13	Croatia	22	Sweden
5	Spain	14	Czechia	23	Estonia
6	France	15	Latvia	24	Romania
7	Malta	16	Hungary	25	Luxembourg
8	Poland	17	Ireland	26	Bulgaria
9	Portugal	18	Cyprus	27	Finland

Table 2

Rank of EU countries (own research)

Based on their distance from the ideal solution, the results indicate that Germany has been assessed as having the highest IS potential, followed by Belgium and the Netherlands.

Discussion and conclusion

Industrial Symbiosis (IS) is a business model focused on retaining the added value of products as long as possible and eliminating waste simultaneously. This is achieved by monitoring and analyzing business processes within but also beyond production processes. Many institutions and policies support IS through support for the Circular Economy. The IS business model is entirely in line with the Sustainable Development Goals (SDGs), especially SDG 12. SDG 12 aims to improve resource management by reducing waste, increasing recycling and promoting sustainable production practices. Planning operations following IS needs enables the identification of key areas in which it is possible to minimize waste generation, improve resource efficiency and implement sustainable business practices, which leads to numerous positive effects.

Nevertheless, the transformation of companies towards IS is complex and faces numerous challenges [24]. This work is based on the assumption that some EU countries are better prepared and have greater potential for IS implementation. The results indicate that the German economy has the greatest potential for IS implementation based on the analyzed criteria. Namely, when evaluating the current level of IS implementation, Denmark, as the cradle of this type of company integration, is still ahead of its counterparts. The Danish government, seeing the benefits that come from IS, has strongly supported initiatives in the circular economy [30]. Also, the Netherlands is stated as one of the leading countries in this

segment, particularly highlighting geographical positions and importance in global logistics as an advantage in IS implementation [31].

However, when it comes to potential, Germany has the greatest potential due to the fact that it has a developed industrial base and is one of the leading industries of the EU. Large industrial systems produce large amounts of waste and by-products that can be used in other industries. Also, developed infrastructure allows for easy trade and transport of these materials. The Netherlands is also at the top of the list, primarily because of its good geographical position and developed transport infrastructure, which contributes to the efficient distribution of resources [31,32].

The position of the last ranked country in this research, Finland, can not be overlooked. Although Finland is recognised as a leader in many environmental aspects, several shortcomings can be identified in the specific context indicators related to its contribution to IS. First of all, the Finnish industry has developed specific branches, such as paper and forestry, and technologies that do not create a wide range of by-products that have not already been recycled, so their capacities for synergy are limited. Secondly, in ranking results, countries with a favourable geographical appeal occupy a high rank, and for Finland, geographical and logistical challenges can be considered as a big drawback for IS.

Overall, the study's results indicate that there are differences between EU countries in terms of their potential for IS implementation. When looking at the results, one cannot see the traditional divisions of east and west or north and south, but rather the connection with the strength and extent of the industrial development of a country, as well as with the estimated institutional support. Therefore, further progress in IS implementation is closely tied to the economic level and the level of development of industrial sectors, as well as infrastructure. Incentives toward IS can additionally help improve economic conditions, create new jobs and improve the general environmental and social situation. The institutional and European support for waste reduction and resource efficiency that helps companies in IS endeavours should not be left out. In future research, it is necessary to examine the conditions in which IS is most fruitfully developed and to adapt the IS model for implementation in the lagging areas.

The most significant limitation of this research lies in the lack of consistent data for European countries that are not EU members. This gap is particularly important, given that certain conclusions suggest that in more advanced countries, particularly in industries, greater attention is devoted to IS. However, this does not imply that less is produced in less developed countries, as their potential for IS may be more pronounced.

Acknowledgement

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Case Studies of Cybersecurity Implementation in Leading Digital Payment Platforms

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Abstract: This study explores the impact of cybersecurity on digital payments, specifically examining how cyberattacks affect these systems. Using a case study approach and analyzing existing cybersecurity reports and academic research, the study reveals that while platforms like Alibaba and Revolut employ robust security measures like encryption and access control, they still struggle to effectively counter cyber threats. The research highlights the crucial role of both technological solutions and ongoing user education in strengthening digital payment security. These findings offer insights into digital payment platforms seeking to improve their cybersecurity strategies and user engagement to ensure transaction security and reliability. However, the reliance on publicly available data and literature may limit the study's scope, as it may not capture the full range of unpublished cybersecurity challenges faced by these platforms.

1 Introduction

Digital payments have become a crucial component of international economic activity in the current era of fast digitalization, considerably improving people's daily lives. The trend toward digitalization and the usage of the internet has resulted in significant changes to how the global economy runs. The introduction of a diverse set of financial technology (FinTech) applications allows users to go beyond the traditional cash-based payment method [1]. Digital payments are becoming increasingly common in people's daily lives. These rapid advancements in the financial sector resulted in the invention of numerous digital payment systems,

which enable payers and payees to send and receive money using digital apps. Thus, the payment system is rapidly transitioning from coin-based and paper-based money to digital forms of payments that are convenient, quick, and cost-effective [2].

However, worries about this payment method's security are growing along with its popularity. Cyber attackers constantly search for ways to breach the security defenses of digital payment systems in order to obtain, alter, or even destroy crucial data, posing a serious threat to personal privacy and property security. These tactics include malware, ransomware, phishing attacks, and more sophisticated persistent threats [3] These security risks can jeopardize the stability of the world economy in addition to undermining users' confidence in digital payment systems.

The majority of cyber-attacks are automated and aim to exploit common faults rather than specific websites or enterprises. It is a fallacy to assume that cyber attackers do not care about you. Every person who uses the internet needs cyber security. Ensuring secure payment is a crucial part of cyber security for any firm that accepts electronic payments or transactions [4].

Digital payments utilize a network of interconnected systems that ensure that transactions are executed swiftly. Cybersecurity is the core magnet holding all these systems together and ensuring that all these systems perform their duties without harm or malfunction. Figure 1 depicts how cyber security acts as the centerpiece connecting all the techniques used in the protection of digital payments.
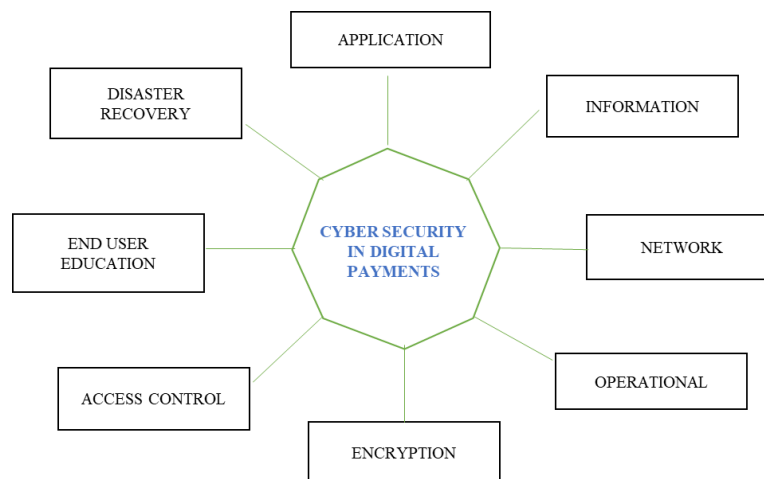
Figure 1.

A schematic diagram of the techniques employed by cyber security as protective tools to curb the surge of internal and external cybercrimes [5]

Cybersecurity is used to complete one or more successful transfers and prohibit undesired attacks that may or can happen. A few key figures in digital payments, their platforms, and the ways in which they have altered the overall landscape of retail will be focused on [6].

The purpose of this study is to explore the impact of cyber security incidents on the security of digital payment systems, user trust and willingness to use, as well as the effect of different cyber security measures on enhancing user trust and the stability of payment platforms. In order to determine the most effective cybersecurity strategies and measures in the current, constantly evolving cyber threat environment, the study focuses on analyzing which types of cybersecurity incidents have the greatest impact on digital payments and how different cybersecurity strategies shape users' trust in digital payment platforms.

The core research question posed in this study includes aims to understand what cybersecurity strategies and measures have been implemented by digital payment platforms. It looks at how effective these measures are in mitigating cyber threats and also understanding how cybersecurity incidents affected digital payment transaction volumes and user behavior. This study proposes the following research probe:

RP: Users with a high level of cybersecurity awareness are more likely to adopt digital payment methods, however they are still most likely to be the susceptible one to cyber-attacks [7].

Some of the most prevalent digital payments that are susceptible to cyber-attacks include, but are not limited to:

- Bank Transfer
- E-Wallet: Apple Pay
- Contactless payments: NFC
- Mobile POS
- QR codes
- Biometric authentication: Fingerprint,
- Wire Transfer
- P2P
- Direct Carrier Billing (DCB)
- Cryptocurrency Payments: Bitcoin

This study adopts a quantitative research methodology that relies heavily on secondary data sources such as publicly released cybersecurity news, reports and academic articles for systematic analysis. This approach not only helps to gain a deeper understanding of the multidimensional characteristics of the impact of cybersecurity incidents on digital payments but also provides a solid theoretical and practical foundation for making targeted security enhancement recommendations.

In summary, this research intends to improve user trust, protect the stability of the payment system, and support the robust growth of the digital economy by thoroughly examining cybersecurity events and their effects on digital payments. To conclude, it will offer actionable security strategy recommendations for digital payment which focus on Alibaba platforms.

This paper explores cybersecurity challenges in digital payments, focusing on the security measures of Alibaba and Revolut. First, the introduction section outlines the security threats facing digital payments and the research objectives; the literature review reviews the main types of cyberattacks and the strategies to counter them; the methodology describes the quantitative research methodology used and the data sources; the results section demonstrates the specific security measures of Alibaba and Revolut in terms of encryption, access control, and so on, and compares the security of the two; and the discussion analyses these measures and their impact on user trust; finally, the conclusion summarizes the findings, points out the limitations of the study and suggests directions for future research.

2   Literature Review

Previous research has revealed a broad understanding of cybersecurity challenges in the digital age, highlighting the escalation of sophisticated cyber threats such as malware, ransomware, phishing attacks, and advanced persistent threats (APTs) [8], [9]. The integration of AI and ML technologies is considered a revolutionary approach to combating these threats, enhancing anomaly detection, threat intelligence, predictive analytics, and behavioral analysis [10], [11].

Verma [12] highlights the accelerating pace of digital transformation, emphasizing that it brings with it both unparalleled efficiencies and extensive cybersecurity challenges. The digital age brings with it complex issues such as data breaches, ransomware and IoT vulnerabilities that need to be examined with vigilance [4]. Maurer & Nelson [13] noted that financial institutions play a key role in the economy, providing loans, savings, deposits, and ensuring that payments and settlements are conducted efficiently. Because of their critical role in the economy, these institutions face a significant risk from cyberattacks that could have a profound impact on the global economy.

While the convenience of digital payment systems is attracting more and more users, the corresponding lack of digital regulation and the absence of effective complaints and remedies have become a major pain point. This situation has emboldened cyber attackers, leading to more frequent security threats and financial losses for users [12].

The literature review highlights the dynamic and complex nature of cyber threats and the need for advanced and flexible defense mechanisms. Several studies have emphasized the critical role of artificial intelligence and machine learning in enhancing cybersecurity measures, and provided innovative strategies for threat detection, prediction, and incident response [8], [11], [12], [14], [15], [16]

The economy is moving toward digital transformation due to digital and business activities, and as technology advances, so do cyber threats and fraud. To achieve long-term revenue and cost optimization, some departments are able to optimize business operations independently thanks to big data, cloud computing, 3D printing, and cyber security [17]. Cyber threats escalated in the wake of COVID-19, highlighting the growing complexity and frequency of cybersecurity by discussing various attack channels such as social engineering and ransomware attacks [18] [19] alluded in the research, and elaborates on the security concerns of digital payment systems by highlighting consumer privacy and cybersecurity risks.

Gitau [20] hypothesized a significant relationship between cybersecurity awareness and e-market adoption, arguing that the higher the awareness, the higher the adoption rate. Trust in cybersecurity mechanisms is also expected to have a positive impact on adoption rates, as trust alleviates the fear of financial or data loss. The rapid growth in the field of digital payments can be traced back to a variety of factors, including the lack of user awareness of digital payment technologies and the inadequacy of digital payment infrastructure [12].

This viewpoint raises an important hypothesis that by gaining a deeper understanding of the specific causes of cyber-attacks during digital payments, the threats faced, and the possible strategies to address them, we can effectively improve our ability to prevent such cyber-attacks. The increase in cyber threats to financial institutions is being targeted by hackers both because of their increased digitization and their importance to the economy. The study argues that distributed ledger technology (DLT) can effectively defend against cyber-attacks because of its security. Maintaining global financial security requires governments, technology, and the financial sector to work together to develop a comprehensive strategy focused on developing effective measures to prevent, respond to, and mitigate cyber attacks [18]. While the consensus of these studies highlights the benefits of AI and machine learning in cybersecurity, they also note the challenges and ethical considerations of algorithmic bias, data privacy, and the adaptability of AI models to evolving threats. A limitation that recurs in these studies is that the rapid evolution of cyberthreats outpaces current defenses. The ethical implications and potential biases in AI-driven cybersecurity solutions also pose significant challenges that require a careful and ethical approach to technology implementation [11], [21]

3 Research Design and Research Methodology

This study aims to explore in depth the connectivity of cyber-attacks and their impact on digital payment systems, with a particular focus on how these attacks evolve into different types of threats. By analyzing emerging threats, technological advances, and user behavior in the digital attack environment, this study will identify potential vulnerabilities in digital systems and explore how financial institutions can enhance their resilience and security against attacks by implementing effective mitigation strategies.

The study employs an Okoli and Schabram inspired 8-step guideline for conducting a schematic review of information from secondary research into interpretable review that researchers could use (Figure 2).
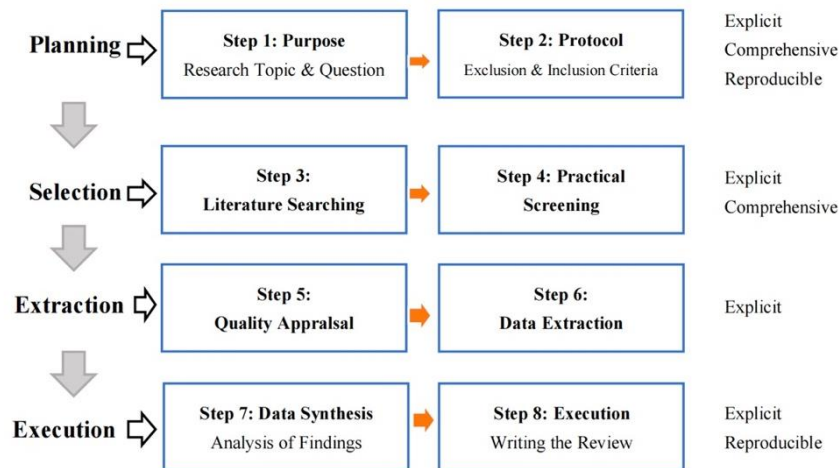
Figure 2.
Schematic 8-Step Review Process for analyzing secondary data [22], [23]

Figure 2 presents a schematic 8-step review process for analyzing secondary data. The process is divided into four major phases: Planning, Selection, Extraction, and Execution. The process is explicit, comprehensive, and reproducible, ensuring a transparent and systematic approach to secondary data analysis.

Step 1: *Purpose* – The goal of this study was to combine available empirical knowledge about the rise of cyber security in digital payments with a zoom in on Alibaba's web platform.

Step 2: *Protocol* – Predefined eligibility criteria were established prior to the initial 'search procedure' (step 3). The protocol comprises of 'inclusion and exclusion' criteria. The articles that meet the delimitation criteria are to be included for the

review (e.g., articles written in English, published journal articles and conference proceedings), while articles written in languages other than English, research in progress, or 'articles in press' are to be excluded based on the criteria set.

The study solely contains empirical studies, thus conceptual papers like literature reviews and book chapters will be eliminated. However, the insights gained from these papers are included in the study's theoretical framework.

Step 3: *Literature Search* – This phase depicts the search method and first selection of papers, including the keywords and databases utilized, the delimitation criteria specified above, and the number of articles discovered throughout the search process. The major database searched was 'Scopus' using the required keywords, download bibliographic data and author data from Scopus to be able to run analytics on Alibaba's critical cybersecurity issues. In the line diagram of the VOSviewer, the main Alibaba network safety is based around 'network security, 'cloud computing', 'security systems information management', 'virtual machine', 'electronic commerce' as the main important words to analyze. Only peer-reviewed scholarly articles from journals and conferences were considered, as specified in step 2 (protocol), with no date constraints. The search was not limited by date because, while the field of study is expanding and digital payment systems are fast evolving to meet new difficulties, there is a scarcity of relevant empirical studies on this overall topic.

Step 4: *Practical Screen* – After the practical from Scopus download everything together with bibliographic data and author data to be able to run an analysis by country.

Step 5: *Quality Screen* – The suitable articles chosen in the previous step were then vetted for quality by carefully reading the whole text of each item. Because only empirical papers were included in this study to assure the quality of the review, the quality screening focused on the methodological validity and reliability of the findings.

Step 6: *Data Extraction* – having completed the quality screening, data was extracted to specifically address the first research question. This then allowed for the second question to be answered.

Step 7: *Data Synthesis* – In this section, the extracted data is arranged and analyzed to compare Alibaba in an organized fashion to assist in defining the broad topic of the effects of cyber security in digital payments.

Step 8: *Writing the Review* – The last seven steps clearly document the review technique for easy replication. The authors cooperatively refined the report,

focusing on concise, clear descriptions to enhance readability and distribution potential.

Moreover, the present study is designed to be replicable. The data and research models are clearly presented so that other researchers can understand and replicate these methods and results. This contributes to the ongoing dialogue and development within the cybersecurity community regarding digital payments in VOSviewer.

4 Results

In the digital era, cybersecurity has become a key component of technological innovation. This research explores the performance of Alibaba and e-payment applications such as Revolut in some different areas through a comparative analysis in application security; disaster recovery; end-user education; assess control and network operation. This comparison aims to reveal the differences in strategy and effectiveness of different platforms in handing security challenges that provide insights into cybersecurity practices.

4.1 Alibaba VOSviewer analysis

In order to comprehensively analyse the progress of Alibaba's research on cybersecurity, relevant literature can be downloaded from the Scopus database.

Firstly, by filtering keywords such as 'Alibaba', 'cyber security', 'cloud computing' and 'data protection', we locate specific research papers. and 'data protection', etc., to locate specific research papers. Then, the results are further refined by using the two dimensions of authors and domains of the literature. Through this method, high-quality literature related to Alibaba cybersecurity can be obtained. Keyword network analysis of the downloaded literature can be performed using VOSviewer software. This analysis can help reveal the correlations and research trends between different research topics. As shown in Figure 3, the network connections between keywords and the size of the nodes can visualise which areas are the hotspots of research and how different topics are related to each other. For example, it can be seen that keywords such as 'cloud services', 'data security' and 'machine learning' occupy a central position in the network, indicating that these areas are the current research focuses of cybersecurity. In this way, researchers can effectively grasp Alibaba's research dynamics and core technologies in the field of cybersecurity, providing theoretical support and technical guidance for further research and application.
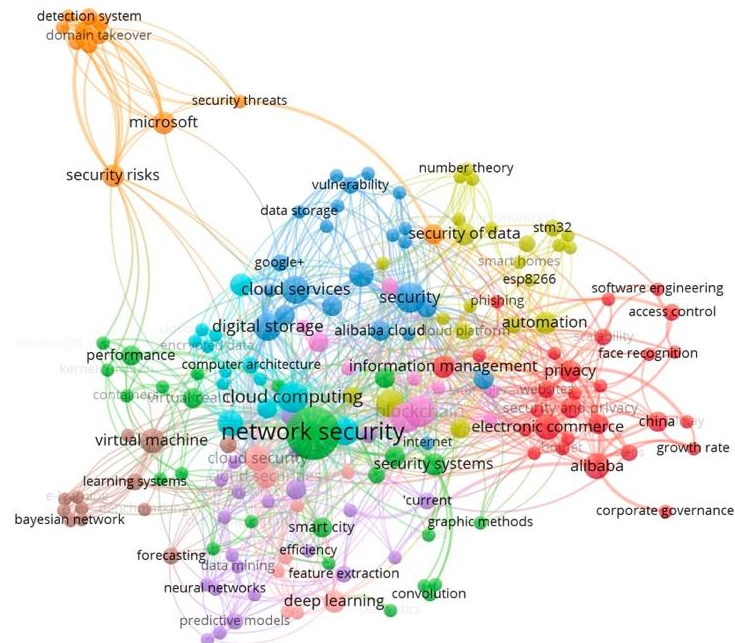
Figure 3.

Cybersecurity links to Alibaba's web platform, source: VOSviewer by sources from Scopus, 2024

Figure 3 shows that 'network security' is at the center of the knowledge graph and is closely linked to a number of technologies and concepts, such as 'cloud computing security' and 'block chain', demonstrating its position at the heart of protecting information systems. Cloud services such as 'Google+' and 'Alibaba Cloud Platform' are closely related to cybersecurity, reflecting the importance of infrastructure and platform support in modern cybersecurity. In addition, the linkage of 'data security' with concepts such as 'data storage' and 'privacy' underscores the importance of protecting data in the cyberenvironment, which is not only a technical issue, but is also closely related to regulatory compliance and user privacy protection [24]. Table 1 lists the most frequent keywords and their link strength.

Based on the analysis of keyword frequencies from Table 1, the important concerns about Alibaba in the field of cybersecurity. These high-frequency terms reflect Alibaba's multi-dimensional layout of security technologies and services, especially its investment in network cybersecurity, blockchain, cloud services, cryptography, digital storage, internet of things, alibaba, cloud security, cloud-computing, electronic commerce, cloud platforms and virtual machine.

Keyword	Occurrences	Total link strength
network security	29	172
blockchain	19	65
security	9	45
cloud service	8	67
cryptography	8	66
digital storage	8	41
Internet of things	8	60
alibaba	7	18
Cloud security	7	67
Cloud-computing	7	51
Electronic commerce	7	29
Cloud platforms	6	46
Virtual machine	6	49

Table 1.

Main keywords from VOSviewer

Firstly, 'network security' and 'security' show that Alibaba attaches great importance to overall network security and is closely linked to cloud computing, virtual machines and other related technologies, which lay the foundation for the security of the e-commerce platform . In addition, 'blockchain', as an emerging technology, plays an important role in Alibaba's ecosystem, and the decentralised and tamper-proof nature of blockchain effectively improves the security of data transmission and storage, especially in the field of digital payment [25]. Secondly, the keywords 'cloud service', 'cloud security' and 'cloud computing' show Alibaba's security and protection strategy in cloud storage and processing [26]. As one of the world's leading cloud computing platforms, Alibaba continues to strengthen its security protection mechanisms in the cloud environment. Combined with 'virtual machine' technology, Alibaba is able to provide users with highly isolated computing resources, reducing the risk of cross-tenant attacks . Finally, the frequency of 'e-commerce' and 'Alibaba' suggests that Alibaba has spared no effort in securing e-commerce platforms for transaction security and user data protection, especially in the application of emerging technologies such as the 'Internet of Things' and 'digital storage', which have further raised security standards within its ecosystem [27], [28].

Encryption is an integral part of network security, and its connection to 'performance' and 'digital storage' illustrates the dual role of encryption in performance optimization and security enhancement.' The connection to 'performance' and 'digital storage' illustrates the dual role of encryption in optimizing performance and increasing security. The mention of modern technologies such as 'Smart Home' and 'Face Recognition' shows that with technological advances, the security of the home and the individual is becoming more and more important and raises new issues of privacy and data protection.

Major technology companies such as "Alibaba," "Microsoft," and "Google" occupy prominent positions in the map, indicating their leadership roles in the global field of network security. These companies not only provide technical solutions but also play key roles in setting security standards and policies [28], [29], [30], [31]. Additionally, the special marking of "China" reflects the country's importance in the development of network security technology, policymaking, and market development, as well as its significant impact on the global network security ecosystem.

Terms like "phishing" and "domain takeover" in the map represent specific threats faced in network security, which require particular techniques and strategies to counter. The construction of 'security systems and the management of 'security risks' were highlighted as important components of cybersecurity that need to be maintained through continuous evaluation and updating.

The application of 'deep learning' and 'data mining' technologies in network security is mainly reflected in the use of big data analysis to predict and identify potential threats. The use of deep learning technology not only improves the automation level of threat detection, but also enhances the efficiency of security incident processing, reflecting the key role of artificial intelligence technology in modern network security.

4.2   Comparison of applications

4.2.1   Application security

Alibaba Group has taken comprehensive measures in maintaining the security of its multi-platform applications, which include Linux, MacOS, iOS, Android and AliOS. The company has not only developed technologies for code obfuscation, anti-reversal and anti-tampering, but has also successfully implemented these technologies in critical business activities [26]. For example, during the Double 11 mega shopping festival, these technologies provided solid security for the transaction chain. In addition, in order to deal with online scalping and other unlawful behaviors, Alibaba has developed special protection features for 12306 APP (China Railway Customer Service Platform), which effectively stops illegal ticket-snatching behaviors.

In addition, the company also excels in the field of IoT security. Through in-depth research on various types of sensors and IoT systems, including firmware and software levels, Alibaba aims to uncover and patch potential security vulnerabilities. In particular, in the research of 4G/5G communication protocols and

baseband security, the company combines IoT virtualization technology to enhance the security performance of devices [32].

For vulnerability mining technology, Alibaba adopts two main approaches: first, through in-depth dynamic and static analysis, recording and analyzing program running state and behavioral data, assisting security personnel to quickly understand the program's potential attack paths; and second, implementing large-scale vulnerability mining, which combines expert experience with scaled and data-driven analysis to improve the efficiency and vulnerability discovery ability of security experts when faced with a large number of analytical objects. The ability of the security experts to find vulnerabilities. In the future direction of cooperation, the company is particularly looking forward to further research and develop in the automated verification of vulnerabilities and the application of machine learning in vulnerability mining scenarios, in order to continue to enhance the cutting-edge and effectiveness of application security technology [33].

4.2.2   Disaster recovery

First, the appropriate device is selected for operation through a well-defined workflow. Next, a new cloud provider is added and the necessary storage space information is obtained, a process that requires proper entry of authentication information to ensure access. The configuration of storage pools details how to select the appropriate RAID (Redundant Array of Independent Disks) level based on the storage requirements and name and configure the pools to ensure data security and access speed. Also covered is how to optimize the data writing process by selecting specific storage policies, such as the choice of write-back and write-through policies. Finally, a detailed description of how to set up and manage data volumes in disaster recovery, including restoring data from a selected Bucket, is presented. These steps exemplify the complexity and importance of implementing disaster recovery in modern cloud computing environments, providing organizations with an effective way to protect critical data and ensure business continuity [34].

4.2.3   Access control

Alibaba's access control system employs multi-level and multi-dimensional security measures to protect data and resources. This includes physical access control, network access control, and application and data level access control. Alibaba utilizes the latest technologies and strategies, such as the Least Privilege Principle, Role-Based Access Control (RBAC), Multi-Factor Authentication and continuous security auditing. These measures help ensure that only authorized users have access to sensitive information and critical systems, thereby reducing the risk of data leakage or unauthorized access [35].

4.2.4   Encryption

Alipay's key generation relies on self-developed security technology, which consists of two main parts: encryption algorithms and signature algorithms. In terms of encryption, Alipay utilizes advanced AES and RSA algorithms to encrypt users' payment passwords, ensuring the confidentiality and integrity of password data. For signature verification, SHA1 and SHA256 algorithms, which combine timestamp and hash value technologies, are used to strengthen the security and reliability of authentication [36], [37].

Alipay's key management process includes three links: key generation, storage and use. In the generation session, keys are generated under strict control through a secure certification authority to meet high security standards. In the storage segment, the keys are securely stored in a professional data center under the strict supervision of professional security managers to prevent any unauthorized access or leakage. In the use segment, Alipay closely verifies the payment passwords entered by users to ensure the security of each payment behavior [36], [38]

In addition, Alipay implements multiple security measures, including encrypted processing of keys and double authentication technology, as well as backup and encrypted processing of data, to protect the security of user data in all aspects. Through these comprehensive measures, Alipay has demonstrated a high degree of responsibility and technical expertise in protecting user payment security, ensuring a safe and secure payment environment [39].

4.2.5   Privacy Information Protection

Alipay's Privacy Policy details how user information is handled, ensuring that collection and use are based on the principles of lawfulness, necessity and propriety. The policy includes detailed provisions on the collection, use, storage and sharing of information, and highlights users' rights to access and manage information, such as updating and managing privacy settings and account cancellation. It is specifically mentioned that if information needs to be shared with a third party, the legality and security measures of the third party will be strictly assessed. In addition, for minors' information, Alipay takes additional protection measures and makes it clear that users can change the scope of authorization or directly cancel their accounts through specific settings to ensure that they can effectively manage their personal information [40]

4.2.6   Network and Operational Issues

Alibaba's Chief Risk Officer [28] revealed the extensive measures Alibaba has taken to secure its vast network, which serves 670 million domestic shoppers and

130 million international customers. Zheng highlighted that Alibaba's systems fend off five billion cyberattacks a day, help 40 per cent of China's websites and patch 8.33 million vulnerabilities throughout the year. The company provides basic security defenses for more than one million businesses and handles more than half of the country's large-scale DDoS attacks.

Based on its 20 years of experience, Alibaba has developed a comprehensive 'end-to-end network security protection' system that can withstand terabyte-level attacks, with the largest attack being 776.8 GB. In addition, Alibaba ensures content security through an algorithmic recognition system that analyses text, images, videos and live broadcasts to eliminate harmful online information. information online. The 'Technology Brain for Intellectual Property Protection' has accumulated years of experience in developing from combating online infringement to protecting original designs [29].

5   Research Findings and Discussion

Fintech businesses are becoming more and more crucial in today's globalized economy by providing creative services and solutions to consumers varied financial demands. An overview of some of the most well-known fintech platforms and their featured services is provided below. These services range from online payments to money exchange, international remittances, and more, demonstrating how effective technology integration can further optimize and transform the financial services experience.

Both Alibaba and Revolut prioritize strong security to protect their users. Alibaba uses advanced encryption methods and a centralized key management system to secure transactions across its vast network. On the other hand, Revolut emphasizes end-to-end encryption, multi-factor authentication and real-time fraud detection, focusing on protecting user accounts and international transactions.

Aspect	Alibaba	Revolut
Focus	Online payments; Wealth management; Credit; Insurance.	Currency exchange; Online payment; International transfer;
Key Security Features	Advanced encryption; Centralized key management.	End-to-end encryption; single-use virtual card; real time fraud
Integration	Shopping payments; public service.	Mobile-first approach; innovative financial products
Technology	Incorporates advanced encryption methods; user-centric financial ecosystem.	Utilizes GPS for transaction verification; virtual cards; real-time fraud detection.
Unique Offerings	Focus on Chinese market; e-commerce	Cryptocurrency transactions
Innovation	To improve user experience, financial services are continuously integrated into their environment.	Consistent innovation with new financial products and data-driven personalized services
Preventing Fraud	focuses on transaction security and encryption	Sherlock anti-fraud system with real-time monitoring; alerts based on location and transaction behavior

Table 2.
Comparison between Alibaba and Revolut

Alibaba provides a comprehensive suite of financial services, including online payment, wealth management, credit services, and insurance [25], [41], [42]. It has seamlessly integrated into the daily lives of users, encompassing a wide range of activities from shopping payments to public service fee transactions, thereby constructing an extensive ecosystem. This strategic incorporation of advanced technological solutions not only reinforces Alipay's position in the financial services sector but also contributes to the evolution of a more sophisticated and user-centric financial ecosystem [27], [43]

Revolut delivers an expansive range of financial services, encompassing currency exchange, international transfers, debit card provisions, cryptocurrency transactions, and stock trading. Through ongoing innovation and the introduction of novel financial products, the platform caters to the diversified demands of its users. Additionally, Revolut employs sophisticated data analytics and personalized services to enhance the user experience and fulfill individualized requirements.

Revolut's mobile apps offer multiple authentication methods, including password protection and fingerprint recognition. These measures effectively prevent unauthorized access and ensure the security of user accounts, and Revolut's 'Sherlock' anti-fraud system monitors and detects suspicious activity in real time, enabling the security team to respond quickly to potential threats and protect user funds. To further enhance the security of online payments, Revolut offers a single-use virtual card. Users can destroy the card after completing an online transaction, avoiding the risk of secondary use of the card number. The Revolut app utilizes

GPS technology to track a user's geographic location in order to prevent suspicious transactions that are not made at commonly used locations. For example, if a user's mobile phone is located in the UK, but their Revolut card is being used in Spain, the system may refuse to perform the transaction [44], [45], [45], [46], [47].

Conclusion

This study systematically explores the dynamic and multifaceted impact of cybersecurity on digital payment systems, revealing vulnerabilities and robust defense mechanisms used to mitigate these risks. Through detailed analyses, primarily of the Alibaba platform, we identify key security measures such as encryption, access control, and disaster recovery as essential to protecting digital transactions. However, despite these advances, the ongoing evolution of cyberthreats continues to pose significant challenges that require continuous adaptation and improvement of security frameworks.

The main limitation of this study is its reliance on secondary data, which may not fully capture the rapidly changing cybersecurity threat and innovation landscape. In addition, the focus on specific digital payment platforms may not generalize to the wider fintech sector. Future research should aim to combine primary data collection and case studies to provide deeper insights into specific cybersecurity challenges and solutions.

Exploring the potential of emerging technologies such as artificial intelligence and machine learning for predictive threat detection is a promising direction. Further development may involve the creation of real-time security systems that can dynamically adapt to new threats as they emerge. Collaboration between financial institutions, technology providers and regulators are essential to create a resilient digital economy that can withstand the complex cyber threats of the future.

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Technical risks and social trust in the adoption of self-driving vehicles: an analysis of safety challenges and cyber threats

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Abstract: The technological development of self-driving vehicles opens up new horizons in transport, but also reveals complex technical and societal risks. This study investigates the relationship between accident risks, cyber threats and technological distrust based on empirical research (n = 1840). The results show that high levels of technical anxiety - in particular uncertainty around cyber security, system failure and autonomous decision-making - significantly reduce users' subjective sense of safety. Social acceptance of technology is thus determined not only by engineering performance but also by public attitudes. The study highlights the importance of safety-oriented engineering, transparent regulation and user education for the future successful integration of autonomous vehicles.
Keywords cybersecurity, self-driving vehicles, technical concerns, social trust, road safety, road safety

1 Introduction

The proliferation of self-driving vehicles is bringing about a major technological and societal transformation, affecting not only the automotive industry but also people's daily lives. The aim of this paper is to explore the opportunities and challenges associated with self-driving technologies, with a particular focus on ethical, safety and technological issues. Although semi-autonomous vehicles are becoming more widespread, social acceptance is still low, mainly due to fears about safety, especially among women. Trust in self-driving systems is affected by factors such as fear of hacking attacks or loss of control. In contrast, supporters stress the reduction of traffic accidents and the environmental benefits. The findings of this paper can provide important guidance to technology developers and policy makers for the successful integration of self-driving vehicles into future transport systems [4, 11, 14, 15, 18].

Technological progress, in particular the emergence of self-driving cars, has a mixed reception in society. One of the reasons for resistance to technological innovation is technostress, which can manifest itself as psychosocial strain resulting

from the use of digital technologies, especially in the workplace. Although clear data on the effects on mental health are not yet available, research suggests that well-organised digital work can increase flexibility, worker control and autonomy, and thus may even have positive effects. Digital work can therefore have a double effect: it can be both an opportunity and a risk. To understand the social acceptance of these technologies, it is essential to analyse user attitudes and to clarify ethical and legal issues so that these innovations can be safely integrated into everyday life [13, 16, 19].

The technology for self-driving vehicles is already available, but there are still a number of challenges that hinder their widespread uptake. Lack of confidence, high prices, legal and ethical issues are slowing down uptake. Of the six levels of autonomy, only the lower levels are widespread, while full self-driving (level 5) is still under development. In the US, progress is faster, while in the EU legal barriers such as the Vienna Convention need to be modified. Fears about technology, especially about the transfer of control, are putting many people off. Demographic factors, such as age and education, also influence adoption. Most people are not in favour of fully autonomous vehicles, but would prefer partial automation. Car manufacturers and developers should therefore take user concerns into account and increase social acceptance by developing transparent, safe systems [15, 18, 24, 25].

Research shows that although self-driving car technology is now available, the majority of people still have a lack of confidence in it. Key concerns include high cost, reliability and fear of losing control. However, many people are positive about the convenience and enjoyable driving experience, especially if they do not have to pay more for it. The use of technology in public transport is more widely accepted, as there is less emphasis on personal control. Research highlights that trust is a key factor in the uptake of self-driving cars and its lack is a barrier to social acceptance. The sense of vulnerability of users and the fear of losing control over technological decisions also raises ethical and social questions. Developers must therefore take human factors into account if they want to increase the acceptance of autonomous vehicles [4, 14, 15, 18, 19].

The development of self-driving cars raises serious ethical and safety challenges. One of the key dilemmas is how cars make decisions in inevitable accident situations - for example, when the lives of passengers may be at stake versus those of pedestrians. Research shows that people prefer to minimise casualties, but this view often changes when they imagine themselves in the car. Ethical decision-making and continuous updating are essential when developing software. In addition, cybersecurity is a key issue: self-driving systems can be hacked, which poses serious risks. Technology adoption depends largely on trust in security and transparent communication. People tend to reject technology if they do not understand how it works or feel threatened. Therefore, manufacturers need to focus not only on technical improvements, but also on educating users and increasing their sense of security [2, 3, 9, 10, 23, 26, 30].

1.1   Sensors and central unit for self-driving vehicles

In the development of self-driving vehicles, sensors that enable accurate sensing of the environment and autonomous decision-making are a key element. One of the most important sensors is LiDAR, which uses laser pulses to create a three-dimensional map of the vehicle's environment, providing highly accurate and detailed information. Although extremely useful, LiDAR is sensitive to weather conditions such as fog or rain and comes at a high cost. Radar measures the reflection of radio waves, allowing distance and speed to be determined even in adverse weather conditions. However, it has a lower resolution and therefore provides less detailed information on the shape of objects. The cameras capture visual data, which are processed by image recognition algorithms to enable object recognition and banding, but their performance is highly dependent on lighting conditions. Ultrasonic sensors measure distance over short ranges using sound waves and are mainly used for parking assistance, but their accuracy can be affected by surfaces due to their short range [1, 5, 6, 7].

The vehicle's central unit plays a key role in ensuring autonomous driving by processing the data provided by sensors and building up a comprehensive picture of the environment. The central unit fuses the incoming data and then interprets the environment, identifies objects and determines their position, speed and direction of movement. Based on this information, it makes decisions about the vehicle's behaviour, such as turning, speed, lane change, acceleration or braking[5, 6, 28].

The central unit converts the decisions into control signals that are sent to the vehicle's various actuators, such as the steering, brake and accelerator, to perform the desired manoeuvres. The system continuously monitors the environment and can activate emergency protocols if necessary, for example in the event of sudden obstacles to avoid accidents [1, 5, 7, 28].

The central unit could also be responsible for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, which can contribute to increasing the safety and efficiency of transport. The central unit of a self-driving vehicle is therefore responsible not only for sensing but also for control and communication functions, and the complexity of the system requires the cooperation of several computing units, such as CPU, GPU and FPGA, to perform these tasks efficiently [1, 6, 7, 12, 21, 31].

Sensor type	Operating principle	Benefits	Disadvantages	Typical application
LiDAR	3D imaging of laser pulses	High accuracy, detailed 3D information	High cost, sensitivity to weather conditions (e.g. fog, rain)	Environmental sensing, object detection, mapping
Radar	Measuring the reflection of radio waves	Works well in bad weather conditions, distance and speed measurement	Lower resolution, less detailed object shape information	Distance measurement, speed measurement, obstacle detection
Camera	Capturing and processing visual information	Rich information content, cheaper than other sensors	Performance depends on lighting conditions, complex image processing required	Object recognition, lane keeping, traffic sign recognition
UH sensor	Measuring the reflection of sound waves (short distance)	Cheap, simple implementation	Short range, accuracy may be affected by surfaces	Parking assistance, proximity obstacle detection

Table 1

Comparison of Sensors Used in Autonomous Vehicles by Operating Principle, Advantages, Disadvantages, and Typical Applications

1.2 Dangers of self-driving cars

The rise of autonomous vehicles offers many opportunities to improve transport safety, but also poses serious challenges, in particular with regard to accidents and terrorism. The use of self-driving technology can significantly reduce the number of accidents caused by human error, but it also brings new types of threats, such as cyber security risks or the possibility of terrorist acts.

In terms of accidents, self-driving vehicles offer a significant improvement through advanced detection and response systems. The technology can reduce human error caused by factors such as inattention, fatigue or drink-driving. However, system failures, weather conditions, data security and testing challenges can still be a barrier. Research in recent years has shown that accidents involving self-driving cars are often caused by the limitations of the technology and unexpected traffic situations [16, 22]. Such incidents have a negative impact on public perception, which is a key factor in the uptake of autonomous vehicles [22]. According to the US Department of Transportation, continued development of safety protocols and proper testing of autonomous systems is essential for widespread adoption of the technology. In addition, a comprehensive analysis of accidents involving self-driving cars is key to determining the direction of future developments [5].

Self-driving vehicles could be a new threat for terrorism. Modern technology allows autonomous systems to become tools for attacks that can be controlled remotely.

The risk of cyberterrorism is also a prominent concern in the context of self-driving vehicles, as malicious hackers may be able to take control of some vehicles, causing accidents or targeted attacks [20, 23, 29]. Former FBI Director Keith Lourdeau has also pointed to the growing role of autonomous systems as a tool for cyberterrorism, which could destabilise society. According to a 2021 NATO report, autonomous technologies could pose security risks not only in transport but also in military and strategic infrastructures. Furthermore, an international report suggests that the increase in cybersecurity threats suggests that autonomous vehicles could be potential targets for future terrorist attacks [17, 23].

As technology evolves, it is crucial to develop appropriate regulation and security measures. According to the principle of Manful Human Control (MHC), developers and programmers must also take responsibility for the security of the autonomous systems they create [2]. This includes continuous monitoring, anticipating potential threats and adhering to ethical development practices. There is also a need to strengthen international regulation to reduce the risk of cyberterrorism and inappropriate use of self-driving cars [2, 10, 26, 23].

The European Union Agency for Cybersecurity also stresses that the protection of autonomous systems should be a top priority in the coming years [29]. In conclusion, the risks of self-driving cars, both accidental and terrorism-related, deserve attention. While the technology has the potential to improve road safety, it can also pose serious risks in the absence of appropriate regulation and security measures. The responsibility of programmers, strengthening cybersecurity measures and public awareness are key steps to ensure that autonomous vehicles can be deployed safely and widely. Future research and technological developments should focus on minimising the safety challenges of self-driving vehicles and contribute to a more stable and sustainable transport system [3, 8, 27, 2, 17].

2 Data and methodology

Data was collected through an anonymous online questionnaire, which allowed respondents to express their opinions honestly, thus increasing statistical reliability. The online questionnaire format provided a quick and convenient way to collect and analyse the data. While the voluntary nature of the respondents and the convenience sampling method do not guarantee a fully representative sample, the large number of respondents (1 840) already provides a strong basis for the reliability of the survey results and helps to ensure that the conclusions are valid for a wider audience.
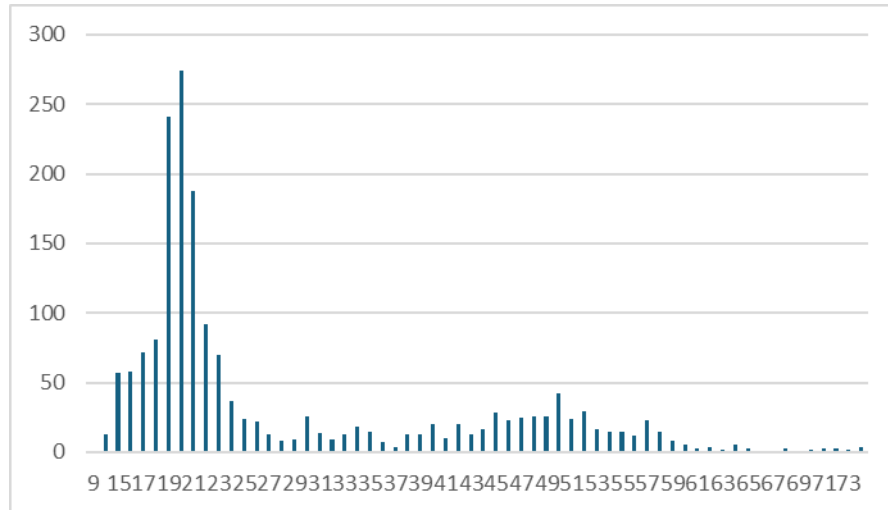
Figure 1

Age distribution of respondents (n=1840)

The aim of the research was to investigate the social acceptance of self-driving cars in particular. The results will contribute to a better understanding of the topic and may provide useful guidance for future research. The age of the respondents ranges from 9 to 75 years, with a mean age of 28.49 years and a median of 21 years, and a standard deviation of 13.819. The mean age is higher than the median, suggesting that more respondents were younger, but the wide age distribution shows that the questionnaire addressed several age groups, allowing a detailed analysis of different aspects of social acceptance.

The results of the survey, although not representative, can provide important insights into the evolution of public opinion and contribute to a better understanding of the social acceptance of future self-driving vehicles.

The research explored attitudes towards self-driving technologies along eight targeted questions covering perceived challenges, risks and potential uses of autonomous vehicles. The dimensions surveyed provide a comprehensive picture of respondents' views on both civilian and military applications. The following variables formed the basis of the analysis:

- Biggest technological challenge: The question aims to find out what respondents consider to be the biggest technological challenge in the development and deployment of self-driving vehicles. The responses will help identify the main barriers limiting technological adoption.

- Cybersecurity of self-driving cars: This question explores concerns about the cybersecurity risks of self-driving vehicles. The answers provide an

indication of the extent to which respondents feel vulnerable to hacking and unauthorised access.

- Communication between drivers and pedestrians: This question measures the importance respondents attach to the establishment of effective communication between self-driving vehicles and human road users. This issue is particularly relevant in the context of urban transport, where implicit human interaction is common.
- The need for regulation: This question addresses the need for a regulatory framework for autonomous vehicles. Respondents express their views on the importance for them of regulating responsibility, ethics and safety at the level of legislation.
- Most challenging traffic environment: This question asks respondents which traffic environment (e.g. city, motorway, extreme weather) they consider most challenging for self-driving systems. The results highlight socially perceived technological barriers.
- Combat use of self-driving military vehicles: This question explores societal attitudes towards the use of autonomous vehicles for combat purposes in the military. It focuses on the acceptability of military decision-making without human intervention.
- Most suitable military tasks for self-driving vehicles: This question explores which military tasks (e.g. logistics, reconnaissance, surveillance, combat) respondents consider most suitable for autonomous vehicles. The results contribute to the societal perception of autonomous military technology developments.
- Likelihood of terrorist use: This question assesses the extent to which respondents fear that self-driving vehicles could be used for malicious purposes, such as terrorist attacks. The answers reflect societal perceptions of the technological threat.

4   Results and discussion

For the analysis, two composite indicators (indices) were first developed: the technical concern index and the security perception index. The technical concern index was composed of four variables representing different dimensions of technological risk perception: (1) fear of cybersecurity threats, (2) likelihood of failure of self-driving vehicles, (3) lack of possibility of human intervention, and (4) concerns about the security of personal data. By averaging these variables, an aggregate variable was created that reflects the extent of an individual's lack of

confidence in technology. The perception of safety index was composed of perceptions of safety for different levels of automation (from full human control to full autonomy) of self-driving vehicles, also averaged.

		Levene's Test for Equality of Variances		t-test for Equality of Means						95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference		Lower	Upper
biztonsag index	Equal variances assumed	1,453	0,230	0,243	188	0,809	0,02544	0,104 82		-0,18134	0,23222
	Equal variances not assumed			0,225	77,97 8	0,823	0,02544	0,11306		-0,19965	0,25052

Figure 4

Independent sample t-test to examine differences between perceptions of safety and technical concern

The first step in the statistical analysis was an independent samples t-test, which examined differences in perceptions of safety between two groups (low and high technical concern). Three categories were then created based on the level of technical concern (low, medium, high), and a one-factor analysis of variance (ANOVA) was used to test whether there was a statistically significant difference in mean safety perceptions between them.

ANOVA

security_index

	Sum of Squares	df	Mean square	F	Sig.
Between Groups	9,423	2	4,712	8,784	0,000
Within Groups	985,317	1837	0,536		
Total	994,740	1839			

Table 2

Comparison of means of the safety perception index between different levels of technical concern using one-way analysis of variance (ANOVA)

Since the condition of homogeneity of variance was not met (Levene's test: $p < 0.05$), the Tamhane post hoc test was used to interpret the differences between pairs of groups. The analyses aimed to determine the extent to which attitudes towards technological risks influence the social acceptance of self-driving technologies, in particular the development of the perception of safety.

Multiple Comparisons

Dependent variable:

Tamhane

(I) concern_group		Mean Difference (I-J)	Std. Error	Sig.	95% confidence interval	
					Lower Bound	Upper Bound
1,00	2,00	-0,04536	0,04242	0,635	-0,1468	0,0561
	3,00	,12224*	0,04380	0,016	0,0175	0,2270
2,00	1,00	0,04536	0,04242	0,635	-0,0561	0,1468
	3,00	,16760*	0,03928	0,000	0,0737	0,2615
3,00	1,00	-,12224*	0,04380	0,016	-0,2270	-0,0175
	2,00	-,16760*	0,03928	0,000	-0,2615	-0,0737

*. The mean difference is significant at the 0.05 level.

Table 3

Pair-wise comparison of the safety perception index using the Tamhane post hoc test between different levels of technical concern

The results of the statistical analyses supported the initial hypothesis that the level of technical concerns affects the subjective perception of the safety of self-driving vehicles. The analysis first used an independent samples t-test to compare two groups of respondents with low and high technical concerns. However, the t-test did not show any significant difference in the perception of safety between the two groups, and the hypothesis was not confirmed in this form. For a more detailed analysis , after categorising the respondents into three groups based on their level of technical anxiety, a one-factor analysis of variance (ANOVA) was performed. The ANOVA results indicated a significant difference between the means of the three groups in terms of safety perception. The inequality of variance revealed by the Levene test necessitated the application of the Tamhane post hoc procedure, which revealed that members of the high anxiety group reported significantly lower feelings of safety than members of the medium or low anxiety groups. In contrast, there was no significant difference between the low and medium groups. Overall, the results show that perceptions of technological risks, in particular cyber security, system failure and uncertainty related to autonomous decision-making processes, have a negative impact on subjective attitudes towards the safety of self-driving vehicles. This finding highlights the role of technological confidence and technical risk perception in the social acceptance of autonomous systems

Conclusions

The rise of self-driving vehicles is both a technological breakthrough and a new type of risk to road safety. The aim of this study is to examine societal perceptions of technical concerns and safety perceptions related to self-driving technology, with a particular focus on the challenges posed by accidents and cyberterrorism. The quantitative research is based on an online questionnaire survey of 1840 respondents covering a wide age range (average age: 28.5 years).

Among respondents, ambivalence about trust in technology was particularly high, with a significant proportion of respondents sensitive to the idea of system failure, cyber threats and lack of human control. Two composite indicators - the technical anxiety index and the security perception index - were constructed and the relationship between them was examined using statistical analysis. Although the first t-test did not confirm a significant difference between the low and high concern groups, ANOVA and Tamhane's post hoc test showed that the high concern group had significantly lower perceptions of security.

The results suggest that the subjective perception of technical risks has a direct impact on the social acceptance of self-driving vehicles. The perception of safety is not only a technological issue, but also a social and psychological construct. The study stresses that strengthening technical reliability, user education and a transparent regulatory and safety framework are essential for the development of autonomous transport in the future.

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Globalization of European Union countries in the context of global turbulence and geopolitical shift in the 2020s

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Abstract: Globalization of EU countries in the context of global instability and shift was studied. Analysis with the use of KOF globalization index confirmed hypothesis assuming that EU countries represent a relatively high level of globalization, but there are still large differences between new and old EU members. Globalization does not solve world economy's problems, and may even induce new global challenges and threats. Turbulence in the 2020s raises questions about further development of international relations and globalization. Disrupted international cooperation and disturbed geopolitical balance, may limit, inhibit or change globalization. Exacerbation of tensions between global powers may lead to the division of the world into competing platforms. Geopolitical shift becomes particularly important. Hypothesis assuming that instability in the global economy in the 2020s influence prospects of globalization, including globalization of EU countries was positively verified.

Keywords: Globalization, Geopolitics, Europan Union

1 Introduction

Intensive processes of internationalization, regional integration, and globalization were characteristic for the last decade of the 20th century and for the beginnning of the 21st century. However, the 21st century turned out to be a period of many global challenges and threats, as well as related instability, uncertainty and turbulence for the globalized world economy, resulting from both economic and non-economic factors.

The main objective of the conducted research was to identify changes in the level of globalization of the European Union countries from 2010 to 2024. The parallel objective was to identify the prospects for further development of globalization in the context of global turbulence and geopolitical shift in the 2020s. The following hypotheses were verified during the research:

– H1: The European Union countries are characterized by a relatively high level of globalization, but there are still large differences between the degree of globalization of the new and old EU countries;

– H2: Instability and uncertainty in the world economy in the 2020s affect prospects of globalization, including globalization of European Union countries.

The research was conducted with the use of the following research methods: critical literature study, analysis and logical construction, descriptive analysis, descriptive statistics and synthesis. KOF globalization index (KOF GI) was used for the comparative analysis of the level of globalization of the EU countries. The study concerned the 27 countries that operating in the EU structures in 2025[1].

Possible scenarios for further development of globalization were examined, taking into account the phenomena and processes that have become visible in the world economy by the end of April 2025, including the COVID-19 pandemic, a full-scale war in Ukraine, the armed conflict in the Middle East, US foreign policy change in 2025.

2 Globalization of European Union countries in the light of KOF Globalization Index

KOF Globalization Index (KOF GI) 2010-2024 for EU27 countries is presented in table 1. In 2010 KOF GI ranged from 71.51 in Romania to 92.95 in Belgium. It should be noted here that Belgium was the most globalized country in the world in 2010, while Romania took the 39th position in the KOF globalization ranking. Globalization of Austria and the Netherlands was also extremely high in 2010 (they formed the top three most globalized countries together with Belgium). Having in mind the fact that the average value of KOF GI for EU27 amounted to 83.19, while it was only 56.8 for the world, one has to perceive all EU27 countries as relatively highly globalized countries in 2010. The following years brought only slight changes for some EU27 countries, while others did experience more dynamic situation:

- Germany improved its position in the KOF ranking by 13 places thanks to increase in KOF GI by 3.53 (it was the 5th most globalized country in 2024, while in 2010 it took the 18th position in 2010);

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[1] For example, Croatia was included, even though it only joined the European Union in 2013, whereas the study did not cover the United Kingdom of Great Britain and Northern Ireland, which joined the European Community in 1973 and operated within the EU's institutional structures until the end of January 2020.

- Greece's position in the KOF ranking improved by as much as 17 places (it was 31st in 2010 and 14th in 2024), and its globalization index increased by as much as 8.04;

- Romania improved its position in the KOF ranking by 6 places (from the 39th position in 2010 to the 33rd one in 2024) and its KOF GI increased by 7.27;

- Cyprus has dropped by 13 positions in the KOF ranking from 2010 to 2024 (21st position in 2010 and 34th one in 2024);

- KOF GI for Hungary was reduced by 3.82 in the analyzed period of time, which resulted in a drop of 8 places in the KOF ranking (10th position in 2010 and 18th in 2024);

- KOF GI for Portugal was reduced by 3.99 in the analyzed period of time, which resulted in a drop of 8 places in the KOF ranking (8th and 16th places respectively);

- Czechia's position in the KOF ranking worsened by 8 places (it took the 19th position in 2024, while in 2010 it was classified on the 12th place), due to the drop in the KOF GI by 3.79;

- Poland's position deteriorated by 7 places (23rd position in 2010 and 30th place in 2024), which was related to the drop in the index by 1.73.

It should be pointed out that despite the persisting differences among the EU27 countries in regard to globalization, the disparities of the level of globalization in the studied group of 27 EU countries decreased significantly in the analyzed period of time. This is evidenced by the reduction of the KOF GI range by over 8.2 percentage points from 2010 to 2024.

Economy	KOF Globalization Index overall								KOF GI change	Position		Position change
	2010	2012	2014	2016	2018	2020	2022	2024	2010 /2024	2010	2024	2010 /2024
Austria	92,51	90,55	90,48	89,83	87,91	88,56	88,36	87,6	-4,91	2	7	-5
Belgium	**92,95**	**92,76**	91,61	90,51	**90,47**	90,46	90,09	88,9	-4,05	1	3	-2
Bulgaria	75,41	72,50	71,38	77,16	79,52	79,77	79,04	77,52	2,11	32	36	-4
Cyprus	82,45	86,59	85,27	84,07	*75,60*	83,06	79,54	78,4	-4,05	21	34	-13
Czechia	86,87	85,76	83,97	86,60	83,41	84,88	84,85	83,08	-3,79	12	19	-7
Germany	84,16	81,53	79,47	78,24	86,89	88,83	88,44	87,69	3,53	18	5	13
Denmark	89,68	88,11	87,43	86,44	87,85	87,96	87,86	86,48	-3,2	6	9	-3
Spain	85,71	84,36	84,66	83,73	83,31	83,81	85,18	84,52	-1,19	16	12	4
Estonia	79,49	79,34	79,38	78,46	81,97	82,91	82,21	81,81	2,32	26	23	3
Finland	87,31	84,34	85,87	85,47	85,98	87,7	87,22	86,16	-1,15	9	10	-1
France	86,18	84,12	82,76	82,61	87,34	87,69	86,94	86,72	0,54	13	8	5
Greece	75,83	81,30	80,29	80,4	80,31	82,89	83,25	83,87	8,04	31	14	17
Croatia	76,85	75,88	74,92	75,59	79,04	81,19	81,04	80,63	3,78	29	25	4

Hungary	87,00	87,38	85,91	85,78	84,20	83,83	83,84	83,18	-3,82	10	18	-8
Ireland	86,92	91,95	**92,17**	91,64	83,53	85,54	85,82	84,36	-2,56	11	13	-2
Italy	82,26	81,02	80,37	79,59	82,15	82,82	82,56	83,04	0,78	22	20	2
Lithuania	74,73	66,56	73,27	77,26	78,78	81,15	81,28	79,77	5,04	33	28	5
Luxembourg	85,84	86,02	84,57	83,55	82,00	82,82	85,37	84,65	-1,19	14	11	-3
Latvia	71,61	*66,27*	*70,17*	*70,97*	*75,42*	79,77	*76,79*	*76,54*	4,93	37	38	-1
Malta	76,42	76,39	75,95	75,04	77,51	*77,28*	80,76	79,47	3,05	30	31	-1
Netherlands	91,90	90,94	91,33	**91,7**	90,24	**90,68**	**90,48**	**89,72**	-2,18	3	1	2
Poland	81,26	80,81	79,52	79,9	78,72	79,67	80,83	79,53	-1,73	23	30	-7
Portugal	87,54	86,73	87,01	85,08	82,21	84,88	84,79	83,55	-3,99	8	16	-8
Romania	*71,51*	74,94	72,24	75,09	77,88	*79,29*	79,4	78,78	7,27	39	33	6
Slovakia	85,07	83,83	83,55	83,62	80,74	82,66	83,2	81,96	-3,11	16	22	-6
Slovenia	78,78	77,67	76,86	76,24	79,76	81,21	79,7	80,36	1,58	28	26	2
Sweden	89,95	88,23	87,39	85,92	88,05	89,44	89,2	87,63	-2,32	5	6	-1
KOF GI Arithmetic mean for EU27	83,19	82,44	82,14	82,24	82,62	84,10	84,00	83,18	-0.01	–	–	–
KOF GI Arithmetic mean for the world	56,8	57,3	58,17	58,93	59,32	60,24	59,93	60,42	3.62	–	–	–
KOF GI Maximum for EU27	92,95	92,76	92,17	92,30	90,47	90,68	90,48	89,72	-3.23	–	–	–
KOF GI Minimum for EU27	71,51	66,27	70,17	69,00	75,42	77,28	76,79	76,54	5.03	–	–	–
KOF GI range for EU27	21,44	26,49	22,00	23,30	15,05	13,40	13,69	13,18	-8.26	–	–	–
KOF GI Standard Deviation for EU27	6,30	7,03	6,39	5,55	4,30	3,72	3,75	3,66	-2.64	–	–	–
Raw data for year	2007	2009	2011	2013	2015	2018	2020	2022	–	–	–	–

Table 1.

KOF Globalization Index 2010-2024 for EU27 countries

Source: (KOF, 2010, 2012, 2014, 2016, 2018, 2020, 2022, 2024) and own calculations.

The analysis of the KOF ranking 2022 (created with the use of raw data for the pandemic 2020 year) confirmed a negative impact of the outbreak of COVID-19 pandemic and lockdowns which were introduced practically worldwide on globalization for both the EU27 and in global terms. The same conclusion can be drawn from the analysis of the KOF ranking 2024 (reflecting the situation in 2022, i.e. the year of the outbreak of a full-scale war in Ukraine – raw data for 2022 were used in this case). Here, too, the globalization index for the EU27 has slightly decreased.

3 Globalization at Crossroads

In the first decade of the 21st century the emergence of terrorism as a new global problem and the outbreak of the global financial crisis initiated the debate on globalization. Many experts began to emphasize that globalization does not solve the most important problems of the contemporary world economy, and may even induce new global challenges and threats. The process of reshuffling the main economic, political and military powers, as well as the growing income and wealth inequalites should be mentioned here (Kleer, 2008). The third decade of the 21st century has brought a series of accumulating global problems, challenges and threats. Geopolitical, economic and demographic shocks (Thompson, 2022) have been superimposed on global problems that had been identified much earlier, such as international debt, the ongoing degradation of the natural environment and climate change, demographic problems, the problem of hunger, international terrorism, and which had not been solved or even mitigated. The increasing instability and uncertainty in the world economy of the third decade of the 21st century as a result of the COVID-19 pandemic, the war in Ukraine, the new edition of the conflict between Israel and Hamas, as well as a change of the US foreign policy in 2025 raise questions about further development of international relations, including the future of globalization. Tensions between global superpowers, as well as fragility of international geopolitics destabilized the global environment already before the COVID-19 pandemic (Altman, 2020; Yip, 2021). Russia's armed aggression against Ukraine in February 2022, which initiated a full-scale war, overlapped with the ongoing COVID-19 pandemic. The consequences of the still ongoing war between Russia and Ukraine have been shaking not only the two countries, their societies and economies, but also the whole Europe and, more broadly, the global economy. They clearly showed the importance of the global security network (Kammer et al., 2022). The fragile international geopolitical balance was disturbed. The awareness of strategic external dependencies of regional and global nature increased (Gutmann, Pitlik & Fronaschutz, 2023). The consequences of the war in Ukraine for globalization were also pointed out by Erasmus (2022), Jenkins (2023), UN experts (United Nations, 2023). The attitude to globalization changed considerably also in the US (despite the very many gains from globalization for the US) (Wen, 2024). Trade and foreign policy of the US under D. Trump's presidency in 2025 became unpredictable: it has already created numerous threats for international business, disrupted international trade and ruined global geopolitical architecture (Fields, 2025; Islam, 2025). Fields (2025) indicated that the US decision to escalate trade war in 2025 "is designed not just to reshape America, and trade, but the way the world itself has been run". International Monetary Fund pointed to damages to the global economy resulting from Trump's tariff policy (Stewart, 2025).

It seems that due to such a high level of advancement of globalization, it is impossible to completely reverse the process of globalization. However,

unfavorable phenomena and processes that take place in the world economy in the third decade of the 21st century, disrupting international cooperation and disturbing the so far international geopolitical balance, may limit or inhibit globalization, as well as change its shape. The political divisions between the major powers are deepening. This could lead to the division of the global economy into competing platforms and a shift from the logic of cost optimization to the logic of risk reduction (Płóciennik, 2022). Many points to the end of globalization in its current form, not the end of globalization as such (Sofuł, 2022). Undoubtedly, globalization 1.0 has ended (Atkinson & Ezell, 2025). Geopolitical shift becomes particularly important. The world faces four fundamental and existential challenges: increasing inequality, climate change, demographic change, and the weakening of democracy. Far-reaching international cooperation will be needed to solve them. However, for this to be possible, it is necessary to rebuild global institutions and regain their credibility. Structural reforms are necessary for the creation of a more resilient economic, financial, and geopolitical system. Solving the basic threats facing the global economy in the 21st century is a necessary condition for moving towards a safer and more sustainable world (Acemoglu et al., 2022). It can therefore be stated that the hypothesis assuming that instability in the global economy in the 2020s influence prospects of globalization, including globalization of EU countries has been positively verified.

Conclusions

The EU27 economies are characterized by relatively high level of globalization. Comparative analysis with the the use of KOF Globalization Index indicated the existence of significant differences in the studied group of countries from 2010 to 2024.

In 2024 the highest level of globalization was characteristic for the Netherlands, Belgium, Germany, Sweden, Austria, France, Denmark and Finland – they were positioned in the top ten of the KOF Globalization Ranking (with KOF GI overall ranging from 86.16 in Finland to 89.72 in the Netherlands – the number one most globalized country in the world). The lowest level of globalization was noted in the following EU27 countries: Latvia, Bulgaria, Cyprus and Romania. They were classified in the 4th ten of the the KOF Globalization Ranking 2024 (and the value of KOF GI in their case was less than 80). Even these EU countries must be considered highly globalized entities if we look globally and analyze them against the background of all the countries of the world.

The third decade of the 21st century brought an end to the hitherto shape of globalization. We have passed the turning point of globalization. We do experience dynamic creation of a new shape of the world economy system. There is no come back to the pre-pandemic shape of globalization. International conflicts, geopolitical tensions, economic competition, technological innovation, and climate change will determine the future of the world economy. Instability and uncertainty

in the world economy and in the global politics do affect the directions and prospects of further development of globalization, including globalization of the EU countries. Rules-based multilateral agreements are shifting away. Reorganization of the global economy in order to reduce global risks (catastrophic climate change, the danger of further pandemics, bioterrorism, rising inequalities, the growing problem of exclusion, regional and world military conflicts) is of vital importance. This requires a sort of historical change/leap. On the one hand, it seems extremely difficult, even impossible, but on the other hand, it is precisely the major crises that create political space for radical reforms. The questions are: Is there a chance for international / global action resulting in a better / fairer model of globalization? Is de-globalization more likely?

Acknowledgement

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Literature Review on Access to Finance and Support Networks in the Development of Women's Entrepreneurship in Kosovo

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Abstract: Women's entrepreneurship plays a crucial role in economic development and social empowerment; however, female entrepreneurs often face significant challenges in securing financial resources and building support networks. This paper provides a literature review on the impact of access to finance and support networks on the development of women's entrepreneurship in Kosovo. Through an analysis of studies from countries with varying levels of economic development and Kosovo's specific context, key challenges and best practices are identified to help female entrepreneurs overcome financial barriers and establish effective support structures. The study highlights that dedicated financing schemes for women entrepreneurs, mentoring programs, and professional networking platforms are key factors for their success. However, the literature suggests that these mechanisms are often fragmented and limited by the absence of comprehensive approaches addressing gender and structural challenges. Additionally, the lack of data on the long-term effectiveness of these initiatives poses a barrier to the development of well-structured policies in Kosovo. This paper contributes to the existing literature by analyzing the key factors influencing access to finance and the establishment of support networks for female entrepreneurs in Kosovo. Furthermore, it offers recommendations for improving financial access and strengthening support networks, thereby fostering a more enabling environment for the development of women's entrepreneurship in Kosovo.

Keywords: Women's entrepreneurship, access to finance, support networks, mentoring, economic development, gender equality.

1 Introduction

In recent years, women-led enterprises have gained significant importance in economic development and social empowerment, contributing to innovation, job

creation, and economic sustainability. The number of women-owned businesses in Kosovo has increased considerably; however, they remain underrepresented in the entrepreneurial landscape (GAP Institute, 2023).

This indicates that despite progress, women entrepreneurs still face substantial challenges that hinder the growth and success of their businesses.

One of the primary barriers is limited access to finance. Recent studies suggest that women entrepreneurs often encounter structural constraints and gender biases that negatively affect their ability to secure start-up capital and funding for business expansion (Brush et al., 2019; Carter et al., 2020). Women have significantly lower access to bank loans due to a lack of collateral and higher interest rates, which, in turn, restricts their capacity to grow their businesses (World Bank, 2021).

Further research confirms that women face greater difficulties in obtaining credit and investment compared to men (Coleman & Robb, 2020). In addition to financial constraints, the development of support networks plays a crucial role in the success of women-led enterprises. Professional networks and mentorship programmes can help female entrepreneurs overcome challenges by providing opportunities for experience-sharing, information exchange, and the formation of strategic partnerships (Goyal & Yadav, 2019). However, literature suggests that many of these networks are fragmented and fail to comprehensively address the specific needs of women entrepreneurs (Verheul et al., 2020). Women entrepreneurs in developing countries, including Kosovo, have limited access to support networks and mentorship, which hinders the growth of their businesses (OECD, 2022).

Several international and local organizations have launched initiatives to support female entrepreneurs in Kosovo. For instance, the Kosovo Women's Network (2021) has provided grants to various organizations through the Kosovo Women's Fund, aiming to promote economic empowerment and gender equality. Similarly, the United

Nations in Kosovo (2021) has organized campaigns and activities to raise awareness and support women in business.

These initiatives are crucial in creating a more enabling environment for women's entrepreneurship; however, further efforts are needed to address the existing challenges and ensure sustainable and inclusive support.

Research Aim: This study aims to analyse the impact of access to finance and the significance of support networks in the development of women-led enterprises.

Drawing on existing literature, the research will examine the key challenges women entrepreneurs face in securing funding and building support networks. According to Noguera et al. (2020), these challenges include gender discrimination and a lack of institutional support. Furthermore, the literature suggests that best practices and strategic approaches, as identified by Goyal and Yadav (2019), can help improve access to finance and strengthen professional networks.

Research Question: What are the main challenges that women entrepreneurs face in securing financing for their businesses, and how can these challenges be overcome?

Supporting Questions:

How does the development of support networks influence the growth of women-led enterprises?

What are the most effective strategies for improving access to finance for women entrepreneurs?

This study contributes to the existing literature by examining the key factors influencing the success of women's entrepreneurship and offering recommendations for improving access to financial resources and strengthening support networks. In doing so, it aims to foster a more favourable environment for women entrepreneurs and the growth of their businesses.

2 Literature Review

2.1 Access to Finance for Women Entrepreneurs

One of the most significant challenges faced by women entrepreneurs in the United States and Europe is the lack of equal access to finance. Studies indicate that the gender gap in lending and investment is not merely a matter of funding availability but also a result of risk perception by financial institutions (OECD, 2022; EIB, 2020).

According to the World Bank (2021), the global financing gap for women-owned businesses amounts to $1.7 trillion, with women frequently receiving loans under less favourable conditions, including higher interest rates and stricter collateral requirements (IFC, 2023). A study by the European Investment Bank (EIB, 2020) highlights that women are significantly underrepresented in the venture capital sector, with only 2% of venture capital funding in Europe allocated to women-led companies. The OECD (2022) suggests that the creation of state-guaranteed funds for female entrepreneurs has proven effective in increasing access to start-up capital.

In the United States, the National Women's Business Council (2022) reports that women are 50% less likely than men to secure financing from traditional banks and often rely on alternative funding sources such as grants and microfinance. The World Economic Forum (2023) notes that the expansion of targeted financing schemes for women has led to increased participation in entrepreneurship, particularly in the technology and innovation sectors.

A key obstacle for women entrepreneurs in Kosovo is limited access to finance, which has been identified as one of the critical factors affecting business growth and sustainability (Brush et al., 2020). According to a report by the European Bank for Reconstruction and Development (EBRD, 2023), women entrepreneurs in Kosovo have fewer opportunities to secure financing compared to men, primarily due to a lack of collateral and gender biases within the banking system.

To address this issue, the EBRD (2023) has allocated €4 million in funding for the microfinance institution KEP Trust, with €1 million specifically dedicated to women-led businesses. This programme aims to improve financial access and increase women's participation in the business sector.In addition to the EBRD, the International Finance Corporation (IFC) has undertaken initiatives to support female entrepreneurs in Kosovo.

A recent IFC (2023) report emphasises that limited funding and restricted access to credit remain among the primary challenges faced by women in business.In October 2023, the IFC provided a €5 million loan **to** Raiffeisen Leasing Kosovo LLC to expand access to finance for micro, small, and medium-sized enterprises, with a particular focus on women-owned businesses (IFC, 2023). These initiatives aim to foster competition and create new employment opportunities for female entrepreneurs by facilitating easier access to capital.

2.2   Support Networks and the Importance of Mentorship

Professional networks and mentorship programmes have a direct impact on the success of female entrepreneurs. A study by Eddleston et al. (2021) reveals that women who participate in mentorship networks have a higher likelihood of securing funding and expanding their businesses.

An analysis by the Cherie Blair Foundation (2020) shows that mentorship programmes for women entrepreneurs have contributed to a 45% increase in business revenues within two years. However, women's participation in professional networks remains low, particularly in male-dominated industries (GEM, 2021).

In Europe, the OECD and the European Commission (2021) suggest that the establishment of national networks for women entrepreneurs has been successful in countries such as Germany, the Netherlands, and Sweden, where mentoring platforms are funded by both government and the private sector. The Rose Review (UK, 2021) highlights that women who receive mentorship are 20% more likely to secure external investment than those who are not part of support networks.

In the United States, the National Association of Women Business Owners (2022) states that women involved in business networks have a higher capacity to secure government and private contracts, underlining the importance of strategic partnerships. Beyond financial challenges, the development of support networks

remains a crucial factor in the success of women-led enterprises. Research suggests that women entrepreneurs who engage in professional networks and mentorship programmes have a significantly higher probability of securing funding and expanding their businesses (Eddleston et al., 2021).A report by the Organisation for Economic Co-operation and Development (OECD, 2022) indicates that women entrepreneurs who are part of mentorship and collaboration networks have better access to information, financial resources, and new business opportunities.

In Kosovo, the lack of support networks poses a significant challenge for female entrepreneurs (Kosovar Foundation for Open Society [KFOS], 2023). According to a report by KFOS (2023), there is an urgent need for mentorship programmes and professional networks to assist women in establishing connections with investors and expanding their businesses.Another study highlights that many women entrepreneurs lack sufficient information on available financing opportunities, and the absence of training and professional connections limits their ability to develop their businesses effectively (Minniti, 2021).

In this context, the experiences of other countries could serve as a model for Kosovo. In Albania, for instance, the Albanian Women's Chamber of Commerce (2022) has organised initiatives aimed at increasing women's access to financing and strengthening their professional networks. A similar programme in Kosovo could support women entrepreneurs in establishing stronger ties with financial institutions and expanding their market reach.

2.3 Policies and Institutional Support for Women Entrepreneurs

Public policies play a crucial role in eliminating structural barriers and creating a more enabling environment for women entrepreneurs. The OECD (2022) and the European Commission (2021) suggest that countries with specific policies supporting women in business have a higher level of female representation in economic sectors.In the United States, the Small Business Administration (SBA, 2022) has implemented various initiatives, including the Women-Owned Small Business Federal Contracting Programme, which facilitates women's access to government tenders. The EU Gender Equality Report (2022) highlights that countries with integrated policies for female entrepreneurship have witnessed a significant increase in women's participation in business sectors.

A study by the European Institute for Gender Equality (EIGE, 2021) notes that governments that have established dedicated funds for women entrepreneurs, **such as** France, Denmark, and Finland, have achieved a 30% increase in female-owned businesses over a decade.

In the United States, the Women's Business Enterprise National Council (WBENC, 2022) stresses that supportive policies for women in business include greater

transparency in lending practices and the elimination of gender-based discrimination in the financial sector. The OECD (2022) suggests that the establishment of monitoring mechanisms and impact assessments is essential to ensure the sustainability of support for women entrepreneurs.Government policies and institutional support are key factors in creating a more conducive environment for female entrepreneurship (Ramadani et al., 2020).

Several initiatives have been undertaken to support women in business, including trade fairs, training programmes, and grant allocations (Agency for Gender Equality in Kosovo [AGEK], 2023).

However, reports indicate that the lack of accurate data on allocated budgets for women entrepreneurs and the impact of these measures makes it difficult to assess their effectiveness (AGEK, 2023).

To overcome these challenges, some researchers argue that more targeted and sustainable policies should be implemented to support female entrepreneurs in Kosovo (Noguera et al., 2021). This includes the creation of dedicated funds for women-led businesses, mandatory mentorship programmes for grant recipients, and stronger government involvement in building support networks.

3   Findings and Discussions

3.1   Findings

This study highlights that women entrepreneurs in Kosovo face multiple barriers in accessing finance and establishing support networks. While various initiatives exist to support them, these efforts are often fragmented and fail to address the long‑term needs of women in business.International best practices indicate that targeted policies, dedicated funding, and structured mentorship programmes can significantly improve the business environment for female entrepreneurs in Kosovo.

Challenges in Access to Finance	Lack of Collateral, High Interest Rates, Gender Discrimination, Lack of Dedicated Funds
The Role of Support Networks	The Impact of Mentorship, Limited Professional Networks, Support from International Organisations
Best International Practices	Dedicated Financing Schemes, Mentorship Platforms, Supportive Government Policies
The Need for Integrated Policies	Enhancing Transparency in Lending, Establishing Dedicated Funds, Developing National Mentorship Networks, Involving the Private Sector

Table 1.

Challenges, Support Networks, and Policies for Women's Entrepreneurship Financing

Source: Compiled by the authors, based on data from OECD (2022), World Bank (2021), GEM (2021).

In this section, a critical analysis of the data presented in Table 1 is conducted, comparing it with previous studies on access to finance for women entrepreneurs in Kosovo.

Challenges in Access to Finance**:** The literature indicates that women entrepreneurs in Kosovo face significant barriers in securing financing. According to a GAP Institute report**,** women often struggle to provide collateral and face higher interest rates, which limits their financing opportunities.

The Role of Support Networks**:** While mentorship and professional networks are crucial for entrepreneurial development, studies show that women in Kosovo have limited access to such networks. A study by the GAP Institute highlights that businesses owned by women and ethnic minorities have restricted opportunities to engage in professional networks, primarily due to high membership costs and a lack of awareness regarding potential benefits.

Best International Practices**:** The implementation of dedicated financing schemes and mentorship platforms has shown positive outcomes in other countries. However, adapting these practices to the Kosovan context requires a careful analysis of cultural and economic factors**.**

The Need for Integrated Policies: To address existing challenges, it is essential to develop comprehensive policies that promote transparency in lending processes and establish dedicated funds for women entrepreneurs. Active involvement of the private sector and the development of national mentorship networks could contribute significantly to the empowerment of women in business.

Graph: Key Challenges in Access to Finance for Women Entrepreneurs in Kosovo

This graph presents the relative percentages of various factors that hinder access to finance for women entrepreneurs in Kosovo.

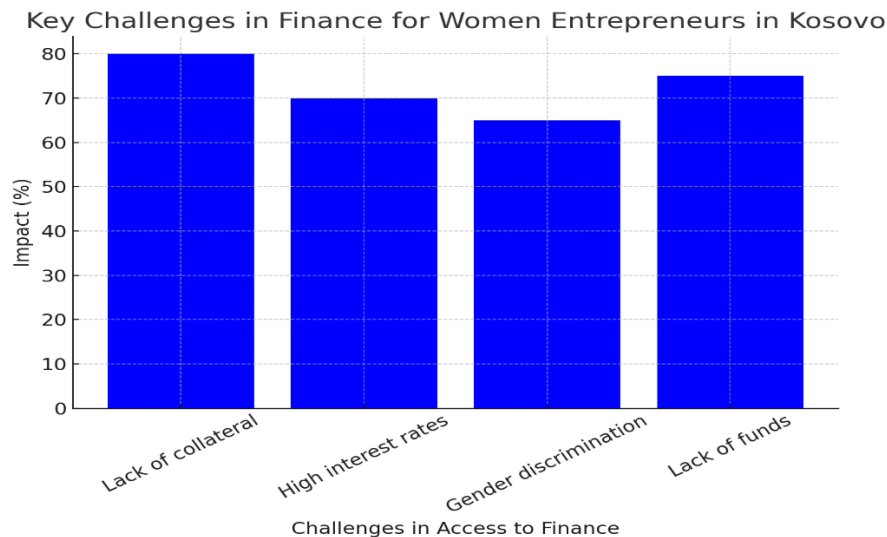**Key Challenges in Finance for Women Entrepreneurs in Kosovo**

Figure 1
Key Challenges in Access to Finance for Women Entrepreneurs in Kosovo
Source: Compiled by the authors, based on data from OECD (2022); World Bank (2021); EBRD (2023); IFC (2023).

The graph presents an analysis of the most significant challenges faced by women entrepreneurs in Kosovo in accessing finance.

The key identified factors include lack of collateral, high interest rates, gender discrimination, and the absence of dedicated funds**.** These challenges reflect a complex environment that affects women's ability to secure financial resources for the development and growth of their businesses.

Lack of Collateral (80%)**:** This percentage indicates that the majority of women entrepreneurs are unable to provide the required collateral to obtain bank loans. In Kosovo, land and asset ownership is predominantly held by men**,** which restricts women's ability to use real estate as loan guarantees. This is a significant structural barrier that requires policy-level interventions to improve women's access to property ownership and financing.

High Interest Rates (70%)**:** Another major challenge is lending under less favourable conditions for women entrepreneurs. Banks and financial institutions often offer loans with higher interest rates, making it more difficult to obtain affordable financing. According to international studies (e.g., OECD, 2022), this is

linked to the perception of higher risk for women-owned businesses, an attitude that is not necessarily supported by data on their financial performance.

Gender Discrimination (65%): Discrimination in the financial sector is another factor that negatively impacts women's opportunities to secure financing. Selective access to financial institutions, gender stereotypes, and a lack of trust in women's ability to manage a successful business create additional barriers. These obstacles are also associated with the underrepresentation of women in the finance and investment sectors, highlighting the need for programmes that enhance awareness and financial education for women entrepreneurs.

Lack of Dedicated Funds (75%): Women entrepreneurs often do not have access to specific financing programmes, which could facilitate obtaining loans or investments. While some international funds and grants are designed to support women in business, these initiatives are often fragmented and unsustainable. The lack of supportive government policies **and** sustainable financing mechanisms emphasises the need for the creation of a dedicated guarantee fund for women entrepreneurs, as well as the development of preferential lending schemes.

The data in the graph show that women entrepreneurs in Kosovo face multiple challenges in accessing finance.

Graph on the Impact of Support Networks on the Success of Women-Led Enterprises

This graph illustrates the percentage impact of various elements within support networks on the success of women-led enterprises in Kosovo.
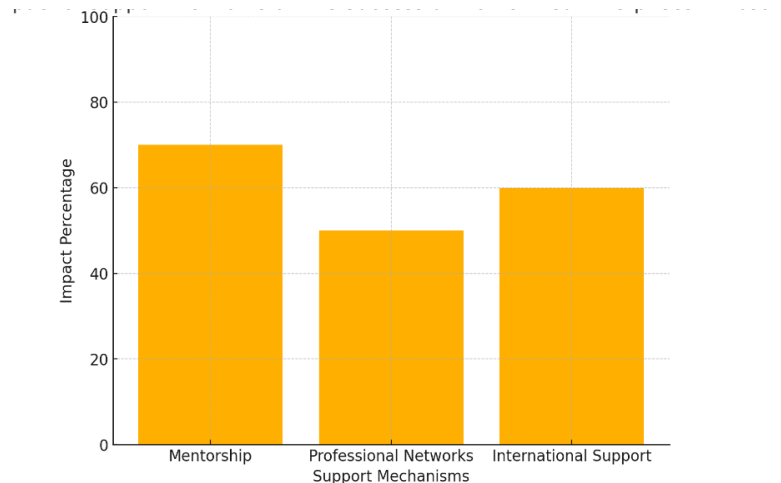

Figure 2

The Impact of Support Networks on the Success of Women-Led Enterprises

Source: Compiled by the authors, based on data from OECD (2022), Eddleston et al. (2021), Cherie Blair Foundation (2020), GEM (2021).

The graph illustrates the impact of mentorship, professional networks, and international support on the success of women-led enterprises in Kosovo.

The data suggest that social and institutional factors play a crucial role in creating opportunities for women entrepreneurs while also highlighting certain barriers to participation and the effectiveness of these support networks.

Mentorship (70%): One of the most influential factors in the success of women-led enterprises is mentorship. The data indicate that women participating in mentorship programmes develop better managerial, strategic, and financial skills, making their businesses more competitive. Mentorship also helps increase self-confidence and improve access to financial resources and new partnerships. However, the main challenge remains access to structured and continuous mentorship. Many mentorship programmes are temporary and linked to specific projects, failing to provide long-term support for women entrepreneurs. This highlights the need for the creation of continuous mentorship platforms, which could be connected to universities, chambers of commerce, and entrepreneurship organisations.

Professional Networks (50%): Women's participation in professional networks is relatively low, despite their considerable benefits. Professional networks facilitate experience-sharing, partnership-building, and access to new markets, making them an important tool for the success of women-led enterprises.A significant challenge remains the lack of structured networks for women entrepreneurs at the national level. Many of the existing networks are either fragmented or limited to a small group of entrepreneurs. Moreover, cultural challenges and a lack of self-confidence often prevent women from actively engaging in these networks.

International Support (60%): Support from international organisations such as the EBRD, IFC, and the EU has played an important role in providing financing and training for women entrepreneurs in Kosovo. These organisations often implement grants, mentorship programmes, and technical assistance for women in business.However, a major issue is the lack of a national strategy to absorb and utilise these funds in the long term. Many programmes focus on short-term periods and do not provide a sustainable mechanism to continue assistance once international funding ends.

3.2   Discussions

This study has examined the challenges and opportunities of women entrepreneurs in Kosovo, focusing on access to finance and the impact of support networks.Through a comparative analysis with international studies, it has been identified that women entrepreneurs in Kosovo face similar barriers to those in other countries, but to a greater extent due to institutional and socio-economic factors. Access to finance remains one of the main challenges. Lack of collateral, high

interest rates, and gender discrimination in lending processes are the primary obstacles for women entrepreneurs.

This aligns with the findings of the World Bank (2021) and OECD (2022), which indicate that women worldwide face restricted access to financial resources. While EU countries have established credit guarantee schemes for women entrepreneurs, Kosovo lacks similar government-backed support measures.The impact of support networks and mentorship is limited. While international literature suggests that mentorship contributes to managerial skill development and improves access to financing (Eddleston et al., 2021), in Kosovo, these networks remain fragmented and have low participation rates.

International programmes, such as those initiated by the OECD and the EU, have established platforms for mentoring women entrepreneurs, whereas in Kosovo, there is no national strategy for developing support networks.Institutional policies for women entrepreneurs are fragmented and have limited impact. In the EU and the US, clear policies exist for women's economic empowerment, including their inclusion in public contracts and dedicated funding schemes (SBA, 2022; WBENC, 2022). In Kosovo, although some initiatives exist, such as the Kosovo Women's Fund (KWF, 2021), there is no integrated approach that supports women at all stages of their business development.

Conclusions

Women entrepreneurs in Kosovo face significant barriers in accessing finance. Banks and financial institutions impose stricter requirements on women, affecting the growth of their businesses. Compared to the EU and the US, Kosovo lacks guaranteed funds and dedicated financial support schemes for women.

The development of support networks and mentorship programmes remains a challenge in Kosovo. While in developed countries, women entrepreneurs benefit from mentorship and strong business networks, in Kosovo, these initiatives are fragmented and lack sustainable impact.Supportive policies for women entrepreneurs in Kosovo are limited and dispersed.

The absence of integrated strategies for women's economic empowerment highlights the need for coordinated interventions between government institutions and the private sector. Best international practices indicate that targeted measures for women entrepreneurs are effective.

Studies from the EU and the US suggest that specific policies for women, including dedicated funds and well-structured support networks, have a significant impact on women's empowerment in business. Kosovo could learn from these models and implement similar strategies.

The Need for Continuous Research and Monitoring

Given the lack of detailed data on the long-term impact of policies for women entrepreneurs in Kosovo, it is essential to conduct further studies to evaluate the effectiveness of the measures implemented so far and to propose new strategies.

Recommendations

Based on the findings and conclusions of this study, several concrete steps are suggested to improve access to finance and strengthen support networks for women entrepreneurs in Kosovo:

Establishing government-guaranteed funds to support women entrepreneurs in obtaining loans under more favourable conditions.

Developing structured mentorship programmes to assist women in building managerial and strategic skills.

Strengthening professional networks and support organisations, including the creation of dedicated platforms for women entrepreneurs.

Enhancing transparency in lending processes, eliminating gender discrimination in the financial sector.

Monitoring and evaluating existing policies to ensure their effectiveness and relevance in improving the business environment for women entrepreneurs.

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Developing a Model for an Integrated Tourism Product: A Critical Analysis of Approaches and Territorial Perspectives

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Abstract This study represents an attempt to analyze the scientific approaches used in tourism sciences concerning the integrated tourism product. Both international and domestic scientific studies on the concept of the integrated tourism product to date demonstrate a gap in research. Current works focus primarily on discussions about the evolution of the terminology of the tourism product and its structure, which are addressed similarly by various disciplines and in the theoretical framework. This raises the question of whether the integrated tourism product is a pure expression of the diversification of mixed forms of tourism or represents the development of the tourism product of the territory as a comprehensive offer. For this reason, the objective of this paper is to continue with the analysis and proposal of an integrated tourism product model that combines the diversification of forms of tourist mobility with a territorial approach, aiming at sustainable development and increased destination attractiveness. The methodology used in this paper involves critical literature analysis, logical operations, and heuristics. The outcome of the study is the creation of a structured model for an integrated tourism product. Although the work is theoretical in nature, the issues discussed are of a practical nature.

Keywords: Integrated tourism product, territorial tourism product, integrated tourism product model.

1 Introduction

The concept of the tourism product has long been the subject of theoretical and methodological debate in international literature, owing to its complex,

multidisciplinary, and constantly evolving nature (Panasiuk, 2017; Smith, 1994). In particular, the development of the integrated tourism product has been challenged by the lack of a unified theoretical framework, even as industry practice has advanced in offering increasingly sophisticated solutions to the needs of the contemporary tourist (Steven & Dimitriadis, 2004). While product development in industrial sectors generally follows clear paradigms of innovation and design, in the service sector—especially in tourism—this process remains fragmented and is often driven by intuition and individual experience (Menor et al., 2002).

According to the United Nations World Tourism Organization (UNWTO, 2022), tourism products are defined as combinations of tangible and intangible elements—such as natural and cultural resources, hospitality infrastructure, and related activities—that together create a coherent offer centered around a specific travel purpose. However, in many cases, the design and delivery of these products occur in a fragmented and uncoordinated manner, particularly at the regional level, where multiple public and private actors operate independently (Benur & Bramwell, 2015; Grigorova & Shopova, 2013). This presents a significant challenge for the integration of various components of the tourism offer and the creation of a consistent and coherent experience for the visitor.

The absence of a structured theoretical framework for the integrated tourism product has been emphasized by several scholars who have called for the development of new models that go beyond the traditional supply-side components (Panasiuk, 2017; Grigorova & Shopova, 2013). On the other hand, the concept of *integrated tourism* has been used to describe efforts to link tourism development with broader socio-economic and environmental contexts, with the aim of fostering sustainable and inclusive development (Benur & Bramwell, 2015; Bousset et al., 2010).

This paper aims to analyze and synthesize contemporary literature concerning the conceptualization, structure, and design of the integrated tourism product. Through a critical review of scholarly contributions from the past five years, the paper will examine current gaps in the literature, the challenges associated with practical implementation, and the role of institutional and commercial actors in creating a competitive and integrated tourism offering. In this context, the study seeks to address key questions, such as how the integrated tourism product is conceptualized in academic discourse, what its core and interactive components are, and what best practices exist for its successful implementation at the destination level.

To achieve these objectives, the paper will be structured into several main sections: first, it will explore theoretical approaches to the nature and definition of the tourism product; second, it will examine the concept of integration in the tourism context; and third, it will review models and components of the integrated tourism product. Finally, the study will present international case studies and best practices that may serve as reference points for the sustainable and effective development of this type of product across different destinations.

2 Literature Review

The concept of the tourism product remains a subject of considerable debate in international literature, due to its interdisciplinary nature and continuous evolution in both theoretical and practical dimensions (Panasiuk, 2017). This semantic ambiguity arises from the broad usage of the term across various academic disciplines, including economics, marketing, management, and geography—each offering distinct perspectives on the structure and substance of a tourism product.

While product development in the manufacturing industry is well-established and extensively researched, the services sector, including tourism, lags significantly behind. Steven and Dimitriadis (2005) argue that this research gap is unjustifiable, particularly given the growing importance of the service sector in advanced economies. One of the core challenges lies in the conceptualization and development of new services. According to Menor et al. (2002), unlike tangible goods, services are often perceived as spontaneous creations—emerging from intuition, talent, or sheer luck—rather than outcomes of structured development processes. This approach leads to a lack of standardization, weak preparatory phases, and limited customer involvement in the product development lifecycle.

In the tourism sector, product development is frequently influenced by independent, market-based decisions made by various actors, rather than by coordinated policies or destination-level strategies (Benur, 2015). This fragmentation often results in disjointed offerings that may not align with tourists' expectations, thereby hindering innovation in designing new tourism products. Earlier studies have shown that most existing tourism product development models date back to the 1980s and tend to complement each other rather than introduce novel approaches.

To address this gap, Debadyuti and colleagues propose a model that integrates two strategic analytical frameworks: the **Analytic Hierarchy Process (AHP)** and **Quality Function Deployment (QFD)**. The aim is to establish a standardized, objective framework for the development of intangible tourism products by actively involving industry experts in the identification and prioritization of tourist needs. AHP facilitates the hierarchical comparison of factors using both quantitative data and expert judgments, while QFD translates these needs into actionable operational strategies.

The integration of these tools offers significant advantages by improving the alignment between development strategies and tourist needs, enabling decision-making that is based on structured analysis rather than solely on intuition or isolated experience. Furthermore, this model helps identify synergistic or conflicting relationships among strategies, thereby building a logical decision-making structure for integrated tourism planning. In conclusion, the literature points to a clear need for a shift from fragmented and intuition-based approaches toward systematic and scientifically grounded models in tourism product development. The application of

AHP and QFD provides an innovative and integrated approach capable of addressing the complexity and dynamism of the modern tourism sector.

3   Methodology

To ensure a rigorous and comprehensive literature review, a structured search protocol was adopted using reputable academic databases, namely Lens.org, Emerald Insight, and Google Scholar. The review focused exclusively on peer-reviewed, open-access journal articles published in English between 2020 and 2024, thereby capturing the most current academic discourse and empirical developments in the field. Eligibility criteria were defined to guarantee scientific quality and relevance. Only scholarly articles with recognized citation potential, published in peer-reviewed journals, were considered. The studies were required to explore key dimensions of the integrated tourism product (ITP), including its definition, structural configuration, and design methodologies, as well as the perceptions of tourists and key stakeholder groups. A meticulous search strategy was implemented using a combination of Boolean operators (e.g., *AND*, *OR*) and targeted keywords such as: *"definition of integrated tourism product"*, *"ITP structure"*, *"design model for tourism products"*, and *"stakeholder engagement in tourism"*. These search terms were iteratively refined to maximize both sensitivity and specificity of the results retrieved. To ensure consistency and analytical depth, each retrieved article was subjected to a two-stage screening process: first, through title and abstract review, followed by full-text analysis. Articles that met all inclusion criteria were then coded thematically, enabling structured data synthesis and comparison across studies. The findings were analyzed using a narrative synthesis approach, which allowed for the integration of qualitative insights and theoretical contributions. This approach not only highlighted thematic convergences and divergences across the literature but also identified research gaps, methodological limitations, and opportunities for future inquiry in the domain of integrated tourism product development.

4   Assessment of the Structure of the Tourism Product and Destination Offer from the Perspective of UNWTO and Contemporary Literature

The World Tourism Organization (UNWTO) defines the tourism product as "a combination of tangible and intangible elements, such as natural, cultural, and man-made resources, attractions, facilities, services and activities around a specific center of interest" (UNWTO, 2024). From a narrower perspective, the tourism offer

refs to the range of goods and services made available to tourists (Gołembski, 2002), which can be examined either at the destination level (macro perspective) or from the standpoint of individual tourism enterprises (micro perspective) (Kurek, 2007). Tourist supply is typically concentrated in areas with distinct touristic value, and it is demand that drives movement toward these locations. Unlike most other forms of economic activity, the tourism product necessitates the physical presence of the consumer at the place of consumption.

In market terms, the tourism offer of a destination does not function as a conventional offer with civil law implications. Rather, it is conceptualized territorially, viewed through two interpretive lenses: the subjective, as constructed by the destination itself, and the psychological, shaped by tourists' expectations and perceptions. This dual framework delineates the specific elements of a destination's tourism offer, which include the intrinsic touristic values, attractions, and services provided.

The core components of the destination offer comprise:

1. **Accommodation systems and supplementary services**, including pre-tourist services, which vary depending on the type and pattern of tourist flows and preferences of different visitor segments.

2. **Events**, which serve as temporal extensions of tourism activity across the year. While generally considered supplementary, in cases where events constitute the main reason for visitation, they are treated as primary tourism attractions.

3. **Tourism information**, which facilitates the integration and interpretation of disparate tourism elements, enhancing the coherence and attractiveness of the overall offer.

4. **Public services**, which are essential for ensuring a secure, clean, and health-conscious environment, thereby supporting tourist comfort and satisfaction throughout their stay.

5   Conceptualizing, Structuring, and the Role of Stakeholders in the Development of the Integrated Tourism Product

A review of the academic literature reveals a frequent yet often unelaborated use of the term *integrated tourism product*. In numerous studies, the concept is taken as self-evident, with minimal attention paid to its formal definition or theoretical underpinnings. Few works attempt to delineate a comprehensive structure for what constitutes such a product. In some cases, the term is applied pragmatically

depending on the regional context under study, while other scholars treat it as a subcategory of regional tourism products or within the broader framework of integrated tourism development.

Among the limited definitions available, the most explicit is offered by Aleksander Panasiuk, who states:

"An integrated tourism product should be understood as an offer of a tourist area developed by entities providing services in the tourism market, including commercial actors (hotels, restaurants, transport providers, vendors, operators of cultural, entertainment, recreational and sports facilities, etc.) and public actors (tourist destinations, i.e., local government authorities), as well as tourism organizations that provide direct regional services, tourism bodies, regional authorities, direct collaborations, organizations, and possibly tourism clusters." (Panasiuk, 2017)

This definition, however, lacks further theoretical development, particularly with regard to its internal structure. A noteworthy attempt to conceptualize a structural framework for the integrated tourism product is presented by Bulgarian scholars Zlatka Grigorova and Ivanka Shopova, in the context of the Smolyan region. Their proposed model outlines a multi-step process for the development of competitive integrated tourism products, involving: the identification of tourism resources; evaluation of regional uniqueness; segmentation and market targeting; quality assurance; authenticity and innovation; and ultimately, integrated management involving multiple stakeholders (Grigorova & Shopova, 2013).

While there is broad consensus in the literature that commercial entities play a crucial role in the development and delivery of tourism products, there remains an open question as to the timing and scope of stakeholder collaboration. Is cooperation more productive during the creation phase, or after the tourism product has already been developed, when stakeholders focus on marketing and delivery?

Grigorova and Shopova's model indicates that integration is more prominently reflected in the management phase of tourism products, rather than in their initial conceptual design. Stakeholder involvement, in their view, is instrumental for facilitating the implementation and delivery of an already-defined product. In contrast, Panasiuk (2017) proposes a closer identification between the integrated and territorial tourism product, emphasizing the need for institutional engagement to effectively satisfy tourist demand.

Given that responsibility for product development lies with both public and private stakeholders, their respective roles become critical. Public authorities are expected to contribute through infrastructure development, destination branding, policy frameworks, and tourist information services. Meanwhile, private entities hold primary responsibility for service provision and commercial operations.

While public tourism services are offered by national, regional, or local institutions, the attractiveness of a destination is often generated by private-sector offerings (Panasiuk, 2017).

Panasiuk (2016) also draws attention to the issue of information asymmetry between service providers and tourists. A substantial portion of the structural components of the tourism product remains unknown to individual tourists. Conversely, there are specific elements of a territorial tourism product that are only evident from the perspective of the visitor, and often go unnoticed by product managers—namely, the implicit motivations that draw tourists to a specific destination.

Thus, the development of an integrated tourism product requires more than the mere coexistence of supply-side actors or isolated tourism services within a defined territory. Rather, it necessitates the intentional creation of conditions for coordinated action among tourism enterprises, local authorities, and regional tourism organizations. These actors must actively support territorial cohesion and foster collaborative mechanisms that ensure the integrated development, management, and delivery of a tourism product aligned with regional competitive advantages.

6 Integrated Diversification of the Regional Tourism Product

The diversification of tourism products represents a complex process of sectoral restructuring within the tourism system, driven by the emergence and development of new types of tourism and recreational activities in a given region (Korn & Kol, 2018). Benur (2015) identifies various forms of diversification, including *parallel* and *integrated* diversification. He characterizes integrated diversification as a form of tourism product assembly that may involve combining existing products, developing entirely new ones, modifying current offerings, or various combinations thereof. This strategy can target both the retention of existing tourism markets and the attraction of new ones.

Integration is often encouraged through collaboration among providers of different tourism products, enabling them to create coherent packages, themes, and destination imagery. Such collaboration may also extend to joint marketing initiatives and shared information technology platforms (Buhalis, 2000; Go & Govers, 1999). Cooperative promotion efforts are more likely to succeed when compatible sites and attractions are located in close spatial proximity, near established tourist routes, or integrated into newly designed travel itineraries (Jansen-Verbeke & Lievois, 1999; Nordin, 2003).

The importance of integrated tourism product diversification lies not only in its potential to add value for tourists—by broadening the range of travel motivations and expanding tourism movement forms—but also in its capacity to stimulate regional growth and development through a wider portfolio of tourism products. This, in turn, addresses key challenges in optimizing regional tourism (Korn & Kol, 2018), while also contributing to the long-term development of regional space through the emergence of new mechanisms for unlocking its tourism and recreational potential (Korn & Kol, 2018).

The creation of an integrated tourism product ensemble can generate cumulative effects by connecting the perceptions and emotional experiences of tourists—offering more than the sum of individual product elements. In doing so, integrated products enhance destination image, increase tourist satisfaction, and strengthen regional or destination competitiveness.

On the other hand, the integrated diversification of regional tourism products implies the need for the formulation of a strategic framework for both the development of recreational areas and for the region itself as a tourism destination. The realization of such strategies requires the active involvement of all relevant stakeholders in the regional tourism development process.

For integrated diversification to avoid merely extending holiday packages without real complementarity among the component products, it is essential to engage tourism actors in the product design and proposal phases. Failure to do so may lead to poorly constructed integrated products, resulting in inconsistent destination branding and unsatisfactory tourist experiences.

Furthermore, the tourism industry is spatially fragmented, with development concentrated in a few high-growth poles. Its current distribution is highly uneven—both between and within countries, regions, and localities—raising additional concerns regarding equitable regional development and the need for spatially balanced diversification strategies.

7 The Integrated Tourism Product Model: The Role of Stakeholders and Negotiations in Co-Creating the Product

The development of an integrated tourism product represents a complex process of interactions among multiple stakeholders operating at various local, regional, and national levels. Within this framework, the concept of integrated tourism has been proposed as a way to better understand the role of tourism in the development of

rural areas, taking into account its complexity and cross-sectoral nature. This approach is not limited to the economic dimension of tourism but also encompasses social, cultural, environmental, and institutional aspects, creating a wide network of relationships among actors operating in diverse yet interdependent contexts that influence the content and functioning of the tourism product (Benur & Bramwell, 2015).

According to Bousset et al. (2010), integrated tourism requires a clear structuring of relationships among stakeholders, encompassing the local economy, natural and cultural resources, and public and private institutions. For such integration to be successful, negotiations among stakeholders emerge as a crucial factor, as they enable consensus-building, interest alignment, and the management of power asymmetries between parties.

To better conceptualize these complex interactions, this paper proposes a conceptual model built upon four foundational pillars that do not function as separate linear steps, but rather as interwoven and co-active processes. Initially, attention is given to identifying and categorizing the actors involved in the creation of the tourism product. These include the local community, representing the human and cultural resources of the territory; public authorities, which hold competencies in institutional governance and strategic planning; and the private sector and tourism organizations, which possess the technical expertise and market capacities to structure and promote the tourism offer.

Following this identification, the process continues with defining the scope of action and common objectives. Stakeholders engage in a dialogue phase where they articulate their interests, goals, and capacities they bring to the collaborative table. This process allows the construction of a shared vision while simultaneously identifying points of convergence and divergence. It is precisely at this juncture that the fundamental importance of negotiations is highlighted—as a mechanism for managing divergences, building consensus, and ensuring that decision-making is the outcome of a fair and inclusive process. Negotiations contribute not only to harmonizing interests but also to fostering a culture of cooperation in which all parties feel represented and committed.

The outcome of this collaborative process is the formalization of cooperation through strategic and operational documents that define the components of the integrated tourism product, the governance mechanisms, and implementation strategies. Such a product is not merely a package of offerings, but a complex construct that reflects deliberate agreements among stakeholders regarding the content, function, and values to be transmitted to the visitor. It is also the result of a social process in which trust-building and the resolution of challenges through negotiation play a vital role.

To visually illustrate this theoretical approach, the following conceptual diagram synthesizes the way in which stakeholders interact and how the integrated tourism product is built through a structured process of negotiation. The diagram presents the local community, public authorities, and tourism organizations as interconnected links through a mechanism of interaction in which negotiation forms the functional core of product creation. This interaction, through dialogue, partnership, and institutional coordination, leads to the development of a tourism product that is contextually appropriate, economically sustainable, and socially inclusive.
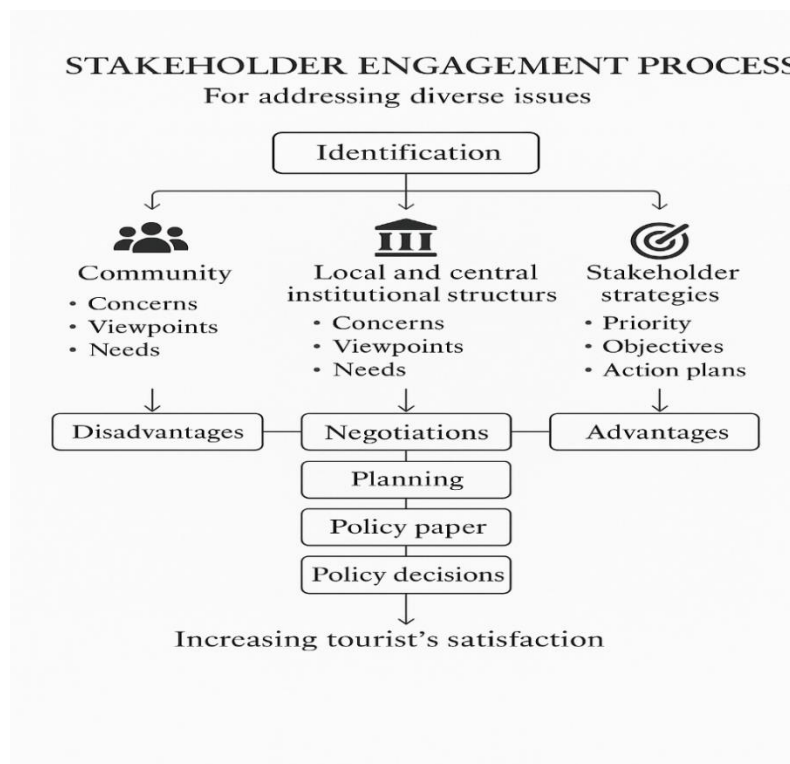
Figure 1
Stakeholder Engagement Process
Source: Authors

In conclusion, the proposed model does not offer a universal solution but provides a suitable framework for application in different contexts, particularly in rural territories with diverse resources and underdeveloped collaboration among stakeholders. Integration, both as a concept and practice, remains the core challenge, and negotiation is the key element that connects stakeholders to transform tourism potential into a sustainable developmental reality.

Conclusions

text This study provides a comprehensive conceptual and theoretical contribution to the discourse surrounding the development of integrated tourism products (ITPs), highlighting the pressing need to transition from fragmented and intuition-led approaches to a strategically structured and stakeholder-driven model. The integrated tourism product is here reconceptualized as a dynamic, multidimensional construct that emerges from the deliberate alignment of institutional, commercial, and community interests through negotiated cooperation.

The literature analysis and conceptual synthesis demonstrate that stakeholder engagement is not an ancillary element to tourism product development, but rather a foundational condition for its success. In contrast to prevailing models that situate integration predominantly within the implementation or marketing stages, the model advanced in this study positions **negotiation** as a **core mechanism within the creation phase** of the ITP. This repositioning elevates negotiations from a technical procedure to a strategic function capable of fostering consensus, managing asymmetries in resources and power, and ensuring procedural equity among all actors involved.

Furthermore, the study emphasizes that integration should not be interpreted merely as structural assemblage of tourism components, but as a strategic, participatory, and territorially contextualized process. The proposed model reinforces the role of institutional frameworks, governance coherence, and local identity in shaping a product that is economically viable, socially inclusive, and environmentally responsive.

By embedding negotiation at the heart of stakeholder interaction, the model contributes a novel paradigm to the field—one that advances beyond linear or unidirectional planning approaches. The integrated tourism product, in this sense, becomes not only a tool for tourism competitiveness but also a **catalyst for sustainable territorial development**, fostering regional cohesion, identity consolidation, and value co-creation.

This research encourages future empirical validation of the model across diverse geographical contexts, particularly in rural or underdeveloped areas where tourism potential remains underutilized. In doing so, it invites further inquiry into the mechanisms through which stakeholder negotiations can be institutionalized as part of destination management systems, thereby reinforcing the practical relevance and transformative potential of the integrated tourism product concept.

Acknowledgement

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Cybersecurity Policy for a Sustainable Circular Bioeconomy: An Overview

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Abstract: A sustainable circular bioeconomy includes interconnected complex supply chains in which data is shared with various stakeholders such as manufacturers, farmers, and researchers. It also relies on sensitive data acquisition via IoT sensors, posing unique cybersecurity risks. This study offers an overview of the cybersecurity threat landscape in a sustainable circular bioeconomy. It assesses cybersecurity policies addressing the risks of interconnectedness, data sensitivity, operational technology vulnerabilities, and emergent technologies. It analyzes critical elements such as data governance, operational technology security, end-to-end supply chain data protection, incident response, recovery, training, and awareness. Furthermore, it proposes a holistic approach comprising the integration of sustainability initiatives into cybersecurity operations.

Keywords: circular, bioeconomy, sustainability, cybersecurity,

1   Introduction

The circular bioeconomy (CBE) has had various definitions during the last decade, with a common framework for sustainable bioeconomy and the achievement of SDGs. For the European Commission, in their "Circular Economy Action Plan", the CE is the economic space where the value of products, materials, and resources is maintained in the economy for as long as possible with a minimal waste generation [1]. To supplement this vision, the Ellen MacArthur Foundation describes the circular economy as keeping goods, components, and materials at their peak usability and worth at all times, distinguishing between technical and biological cycles [2].

The two concepts share a focus on the sustainable and efficient use of resources that produce the least amount of waste. These ideas are entirely consistent with the Sustainable Development Goals, which aim to balance countries' social, economic, and environmental progress and ensure that by 2030, all people live in peace and prosperity [3].

According to [4], bioeconomy businesses can considerably boost their competitiveness by incorporating innovative technologies and digitalization into their operations. The implementation of more efficient digital systems and other innovative technology shortens operational time, enhances product quality, attracts more customers, and expands into new markets faster.

Digitalization is closely related to the notions of industrial economic sectors, particularly the new industrial models known as Industry 4.0 and 5.0 because it reflects a considerable change in manufacturing and production processes caused by the integration of digital technologies[5]. In that regard, digitalization, globalization, and sustainability are three critical growth avenues for businesses today. Digitization can speed up data management, knowledge generation, and innovation processes, allowing for a more efficient and sustainable transition to production [6].

CBE represents a transformative sector that relies its efficiency and productivity on digitalization and interconnectedness. However, it introduces significant cyber risks and vulnerabilities to critical infrastructure, including bio-refineries, smart agriculture, and supply chain managing systems. Also, cybersecurity involving CBE is a pressing issue that lacks specific frameworks. The interconnectedness within CBE systems stimulates innovation and sustainability but expands the attack surface for malicious actors, potentially leading to disruptions in production, data breaches, and economic losses.

This review article delves into the relationship between cybersecurity policy and sustainable CBE, focusing on the evolving threat landscape, international cybersecurity frameworks tailored to CBE, and best practices. This paper will add to the discussion of secure digital transformation in sustainability-driven economies, assisting researchers in creating strong cybersecurity measures for a resilient circular bioeconomy.

2 Overview

2.1 Circular Bioeconomy and Its Digital Transformation

According to [7], the circular economy is based on five guiding principles: a) regeneration of ecosystems; b) minimization of waste and avoiding non-essential

products; c) prioritizing biomass flows for basic human needs; d) using and recycling ecosystem by-products; and finally, e) using renewable energies while minimizing total energy use.

The circular bioeconomy requires an integrative perspective, as biomass is produced and used by many economic sectors, such as agriculture, manufacturing industries, energy, and pharmaceuticals.

Digital transformation in industrial sectors is an essential enabler of the circular economy because it allows for the collection and analysis of data related to assets and processes, which improves decision-making and optimizes processes by generating more significant flows of data and digital information [8]. Furthermore, it allows for the analysis of vast amounts of data on resource consumption, product performance, and waste generation, making it easier for businesses to identify possibilities to cut and reuse resources [9].

McKinsey and HBR conducted research to assess digital maturity in 22 industries, focusing on criteria such as digital spending, business processes, work digitization, digital asset stock, transactions, etc. As a result, information technology tops all industries, followed by media, banking and insurance, and professional services. These four industries have created a digital enablement culture that encourages end-user acceptance and usage, broadens their offers, enables self-service, and more. According to the survey, the public and government, healthcare, hotel, construction, and agriculture sectors are the top five laggards in terms of digital adoption initiatives and programs. The gap in digitization in healthcare and agriculture is due to the highly regulated nature of both sectors [10]. Agriculture and hunting, according to the same survey, have the lowest digitization scores across all categories and criteria (Figure 1). Over the last two decades, automatic guidance has been used on more than half of the land planted by maize, cotton, rice, sorghum, soybean, and winter wheat. By 2024, 85% of US farmers will have used at least one precision farming technique, such as GPS or remote sensing(Olmstead, 2024).

Figure 1.

Digital Transformation of the US Agriculture Sector[10]

According to the same research, digital transformation refers to how technology is altering the way manufacturing organizations function by automating administrative operations, providing better customer experiences, and increasing overall productivity. Manufacturing digitization encompasses RPA, 3D printing, knowledge work automation, predictive analytics for forecasting, mobile apps for frontline staff management, ERPs, RFID tracking, and more. Figure 2 illustrates the average digital adoption rate, calculated based on a digitization score of 3.75. According to Foundry's Digital Business Study, 89% of all manufacturing organizations have embraced a digital-first business model or plan to pursue digital transformation activities in the near future [10].
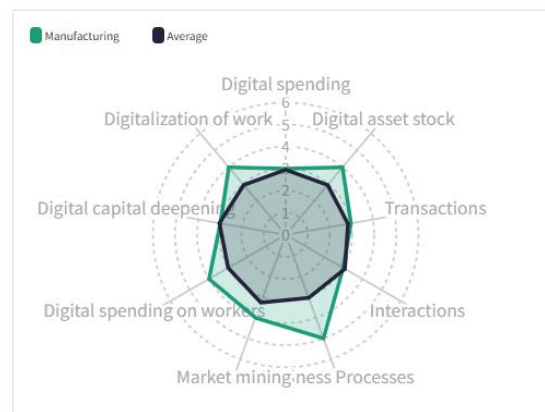

Figure 2.

Digital Transformation of the US Manufacturing Sector[10]

For example, in the agri-food sector, digitization can improve operations without requiring additional infrastructure, thanks to automated production and smart manufacturing technologies that enhance production efficiency and reduce resource consumption. One such current digital technology that permits remote device connectivity in agriculture has resulted in smart agriculture and precision farming, which are replacing conventional practices and promoting sustainable development [11]. The findings of the study of [12] in industrial organizations revealed that larger companies and those with a higher level of product innovation are more likely to achieve higher degrees of digital transformation. The research showed that digital transformation presents challenges for small and medium-sized businesses.

2.2 Digitalization in the Bioeconomy

Digitalization as a process is closely related to the notions of Industry 4.0 and 5.0 since it signifies a dramatic shift in manufacturing and production processes brought about by the integration of digital technologies. According to various studies, advanced digital technologies, such as digital applications, geospatial technologies, immersive environments, open and crowd-based platforms, proximity, blockchain, AI, Internet of Things (IoT), informatics, robotics, and 3D printing, among others, support the sustainable optimization process known as "sustainable business practices" in certain industries [13]. For instance, digital technologies make it easier to monitor environmental footprints, offering measurable data for sustainability indicators and encouraging innovation in product development and supply chain management [14].

The study by [15] determines which technologies are most extensively employed in industrial systems to fulfill particular SDGs. AI and geospatial technologies, for example, can be easily adapted to different business functions and processes to improve sustainable development; geospatial technology, in particular, collects critical environmental data for decision-making on energy resource management, climate change, and air and water quality. In addition, GPS can assist decision-makers in making better traffic management decisions and improving precision agriculture.

Regarding blockchain, although it is a relatively new (2008) technology, its implementation is spreading in production systems [13]The blockchain can help with transparency, traceability, and efficient resource management by improving corporate social responsibility and ensuring transparency and fairness in contract and payroll management, as well as tracing product life cycles, improving supply chain transparency, and encouraging responsible consumption. It can also monitor greenhouse gas emissions, encouraging the transition to a low-carbon economy[16].

2.3   Cybersecurity Risks in the Circular Bioeconomy

Digitally connected global enterprises benefit from numerous new opportunities, but business executives must not overlook the associated risks. According to [5] research, risks in the bioeconomy industry can be divided into five categories: a) security risks, b) technology risks, c) social risks such as professional obstacles for entrepreneurs and employees using digital tools, d) client capabilities in using digital tools, and e) additional hazards.

2.3.1   Risks related to IoT devices, smart agriculture, and bioinformatics.

For example, cybersecurity risks influence the rapid evolution of Information and Communication Technologies (ICT) in modern agriculture. Potential attacks on various intelligent agricultural systems can lead to serious security issues in the dynamic and distributed cyber-physical environment. These threats are mainly related to cybersecurity, data integrity, data loss, and online disconnection of heavy machinery connected online, among others [17]. A cyber-attack on an agricultural or food company is more feasible, as digitalization and the use of many devices connected to the Internet provide more opportunities for potential (cyber)criminals in areas that were previously too difficult to attack or too far away to approach physically [18].

Other examples are bioinformatics initiatives, which frequently require complicated and interdisciplinary tasks such as data gathering, processing, analysis, interpretation, and visualization. These tasks can present a variety of risks and uncertainties, including data quality, dependability, validity, reproducibility, scalability, security, and ethical concerns.

In 2023, the agri-food business saw around 160 cyberattacks, making it the ninth most attacked globally, creating supply chain disruptions. This business is susceptible because it is just starting to digital, and many producers still use antiquated IT technologies to run their operations[19].

Some examples of recent cyber-attacks reported by [20] were:

- In 2023, Dole was the target of a sophisticated ransomware assault in which attackers gained access to the personnel data of about 3,900 US workers. Dole's operations were severely damaged, resulting in an estimated loss of $10.5 million.
- Mondelez, the corporate behemoth behind Oreos, experienced a data breach that was detected in February 2023, during which attackers targeted its law firm, Bryan Cave. This affected over 50,000 current and past employees, and the extent of the harm took months to assess.

3 Cybersecurity Threat Landscape in the Circular Bioeconomy

The digitalization of biological processes and the interconnected systems within the circular bioeconomy network increases the attack surface and creates new vulnerabilities. Hence, integrating cybersecurity and biosecurity is primordial to protect sensitive data, strengthen sustainability efforts, and develop effective cybersecurity measures[21]. The following sections describe some of the principal threat vectors in CBE

3.1 Industrial Vulnerabilities

Industries within CBE, such as biomanufacturing and bioprocessing, depend on automation, IoT, AI, and cloud computing for production processes, which increase the number of cyber threats. Inadequate segmentation between IT and operational technology (OT) networks can allow attackers to infiltrate OT critical systems.

Moreover, the OT environment was isolated from IT networks, but using real-time data sensors to increase efficiency and connectivity gives cyber criminals access to OT environments that are not appropriately secured. As a result, IoT sensors and devices bring vulnerabilities to smart biomanufacturing. They possess weak encryption and default passwords, which give hackers easy access to exploit these connections[22], [23].

Additionally, AI-driven bioprocesses are vulnerable to AI training data poisoning, which can contaminate and affect production[24]. OT systems, such as Industrial Control Systems (ICS) and Supervisory Control and Data Acquisition (SCADA) systems, are widely used in bioprocessing plants. Using legacy software and hardware with known security flaws, remote ICS access, ICS-targeted malware, and zero-day vulnerabilities constitute major threats to the systems[25], [26]. Also, denial-of-service attacks and rogue firmware updates on bioreactors controlled by PLCs can disrupt the systems, causing product contamination and financial losses[27].

3.2 Supply Chain Vulnerabilities

CBE depends on global supply chains comprised of different stakeholders in processes such as raw material sourcing, manufacturing, distribution, logistics, and waste management, which adds entry points for cyberattacks. Malicious actors can infiltrate at any stage of the supply chain, disrupting the operations[28]. Additionally, the dependence of third-party vendors on software, hardware, data storage and processing, logistics, and transportation constitute critical vulnerabilities that create backdoors for cyber criminals[29].

Blockchain and Enterprise Resource Planning (ERP) are used for raw material traceability and logistics management. Blockchain records and data manipulation attacks can introduce contaminated or counterfeit materials into production processes. Thus, it can compromise the supply chain's traceability and reliability, affecting the quality of the products and customer trust[30].

3.3 Data Vulnerabilities

Bioeconomy industries collect, process, manage, and store highly sensitive data such as biological, proprietary bioprocesses, protocols, intellectual property (IP) related to clinical trials, pharmaceutical development, and bioengineering, which are high-value targets for attackers[31], [32]. IP theft and misuse of bioinformatics data can lead to bioweapon production and manipulation of critical biological systems, which pose significant security threats. Moreover, data breaches within circular systems are a rising issue involving privacy, ethical usage, and regulatory non-compliance, which can lead to legal consequences and financial penalties.

3.4 Ransomware and Cyber Espionage

Ransomware is an evolving threat across CBE. Food and agricultural sectors are the most vulnerable to these attacks, which leads to a cascading effect that impacts time-sensitive operations such as planting and harvesting, which can cause food shortages and economic losses [33]. Bio-based manufacturing, primarily pharmaceuticals, is a critical target affecting healthcare industries. These attacks alter control systems in biorefineries, waste management, and renewable energy infrastructures, compromising environmental safety [34], [35].

The development and innovation of sustainable technologies are the basis of CBE. Hence, IP theft and marketing intelligence regarding novel biomanufacturing processes, renewable energy techniques, sustainable agriculture, and strategic plans constitute valuable assets for technological and economic advantage. Cyber espionage involves different actors such as competitor companies, nations with strategic interests in bio economies, and industrial espionage groups. It significantly impacts innovative initiatives within organizations, giving an unfair advantage to competitors and hindering growth and sustainable practices[36].

4 Recommended Countermeasures and Best Practices

Risks and threats are constantly emerging within CBE. Therefore, a multi-layered security approach is the most suitable option for safeguarding innovation, research, and sustainability actions. In addition, various strategies are presented below:

1. Cyber biosecurity is an emerging field that lacks specific cybersecurity policy frameworks. In this context, current cybersecurity policies must be adapted to this field. ICS and SCADA networks used in biomanufacturing processes require adopting these guidelines to strengthen security levels. Table 1 lists international frameworks and their relevance to circular bioeconomy.

Framework	Description	Relevance	Reference
National Institute of Standards and Technology (NIST) Cybersecurity Framework (CSF)	Comprehensive guidelines for cybersecurity risk management for protecting critical infrastructure. It focuses on five aspects: Identify, Protect, Detect, Respond, and Recover.	It applies to bio-industrial facilities such as biomanufacturing and biorefineries.	[37]
ISO 27001	International standards for information security management systems	It protects bio-based data, including genomic, biorepositories, and biotechnology research.	[38]
General Data Protection Regulation (GDPR)	European Union's personal data privacy and security regulations	It protects genomic data privacy and ensures compliance of biotech industries.	[39]
Cybersecurity & Infrastructure Security Agency's (CISA) ICS security guidelines	Offers directions to protect ICS environments	It secures automated processes in different industries, such as biomanufacturing and precision agriculture.	[40]
SANS Institute's OT Cybersecurity Critical Control	It comprises five critical ICS controls: Incident Response, Defensive Architecture, Network visibility monitoring, Secure Remote Access, and Risk-Based Vulnerability Management.	It provides specific guidelines regarding OT, which is widely used in circular bioeconomy.	[41]

Table1.
International cybersecurity framework and circular bioeconomy relevance

2. General cybersecurity practices are fundamental for enhancing a secure posture. These practices include strong password implementation, multifactor authentication (MFA), updating software and firmware, network segmentation, secure data backups and storage, comprehensive cybersecurity training to staff, developing and implementing incident response plans, regular security audits, penetration testing, and vulnerability assessments.

3. Specific cybersecurity practices addressing the challenges in circular bioeconomy include[42], [43], [44]:

- Cybersecurity policies for AI include AI-driven bioengineering operations, ethical AI governance, and AI accountability policies.

- Zero-trust architecture implementation in digital biomanufacturing platforms to protect IP and genetic databases

- Intrusion Detection Systems (IDS) implementation for cyber threats monitoring in smart biomanufacturing facilities.

- Blockchain and ERP systems protection via quantum-resistant cryptography and MFA.

- Supply chain cybersecurity: Blockchain-based traceability for resource sourcing and IoT security, including device authentication and end-to-end encryption for data flow.

- Data protection via encryption, anonymization techniques

- Cyber Threat Intelligence, including AI-based analysis for threat detection.

Conclusions

This document discusses the cybersecurity threat landscape within the sustainable circular bioeconomy (CBE). It highlights that CBE involves complex, interconnected supply chains and relies on sensitive data acquired through IoT sensors, which creates unique cybersecurity risks. This study emphasizes the importance of addressing these risks through robust cybersecurity policies and practices. It also proposes a holistic approach that integrates sustainability initiatives into cybersecurity operations. Additionally, international cybersecurity standards and regulations provide a solid baseline to address risks and vulnerabilities in circular bioeconomy. However, it is encouraged that a tailored security guideline be developed, considering its unique characteristics. Cybersecurity awareness is key between the main actors in each circular bioeconomy sector. Policymakers, businesses, and researchers are required to develop and implement cybersecurity national-level strategies addressing the principles of the CBE.

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From Desire to Loyalty: Building Destination Loyalty through the Example of Sárvár

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Abstract: Tourism marketing's key component is enhancing the competitiveness of destinations, which can be achieved through effective communication tools. As consumer decisions in the tourism industry are often based on emotional factors, building a destination's image and developing an appropriate marketing strategy are crucial. Sárvár, as a prominent health tourism destination, heavily relies on experience-based marketing, highlighting the therapeutic effects of thermal water and the available relaxation opportunities. What factors contribute to Sárvár's tourism success? What strategies and methods can be applied to turn potential visitors into returning tourists? What opportunities do online marketing tools and mobile applications offer in tourism, and how do they influence consumer behavior? In this publication, I answer these questions by examining Sárvár's marketing communication tools through the AISDALSLove model, which is a more recent version of the widely known AIDA model. The AISDALSLove model is a marketing communication framework that analyzes consumer behavior and decision-making processes in seven steps. These steps are closely interconnected and aim to gradually build consumer commitment and loyalty. I hope that my analysis will contribute to Sárvár's future marketing communication activities and serve as a good example for other cities.

1 Introduction

Transforming products into brands through marketing activities has become a common practice. This process involves enhancing products with unique characteristics that distinguish them from competitors, making them easily recognizable, allowing for innovative advertising appearances, and ultimately generating additional profit for their owners.

In recent years, competition has intensified to such an extent in fields like tourism, investment promotion, and many others that municipalities and cities have increasingly adopted branding strategies. But what exactly does this activity entail?

Cities do not merely focus on selecting logos and slogans; they consciously build their identity and image. Their goal is to create a more attractive perception of

themselves, positioning them more favourably against nearby or even distant competitors. This branding activity targets multiple audience segments:

1. **Residents**: The inhabitants of a city can actively participate in shaping its image, identity, and reputation, thereby fostering community pride.

2. **Tourists:** Strengthening tourism not only boosts the local hospitality and service industries but also enhances commercial activities.

3. **Investors**: Attracting both local and external investors can lead to infrastructure development, job creation, and the long-term growth of the settlement.

As a result, city branding becomes a complex and strategic tool that contributes to economic, social, and cultural benefits. [1]

2 The Specificities of Tourism Marketing in the Tourism Sector

Since both the AIDA and AISDALSLove models primarily focus on traditionally defined products, it is essential to clarify the specific characteristics of tourism products. Tourism products or services exhibit distinct attributes from multiple perspectives.

Tourism marketing can be defined as a specialized branch of service marketing. [2] Understanding its characteristics stems from the unique aspects of service marketing. According to Veres (2021)[3], the key characteristics of tourism marketing are:

- It involves movement, as well as staying and engaging in activities at the destination.
- The travel destination and stay differ from the permanent place of residence.
- Both the movement and stay are temporary.
- The purpose of travel is predetermined.
- The service provider plays a crucial role.
- Seasonality is a significant factor.
- It consists of interconnected processes.
- Intermediaries play a key role in the sales process.
- The service consumption process is associated with high perceived risk.
- The substitutability of services is high.
- Marketing communication is of paramount importance.

Due to the nature of tourism marketing, marketing communication plays an especially significant role. When analysing its importance, it is crucial to consider

the transformation of travel habits, demographic shifts within the traveling audience (particularly the growing proportion of young, Generation Z tourists), and the factors influencing travel decisions and pre-planning phases.

Traditional marketing communication tools are increasingly ineffective—or entirely inadequate—for reaching young people (Generation Z) and those under 35. This demographic's media consumption habits are drastically different from older generations, making them accessible almost exclusively through digital channels. [4]

Over the past years, or even the last decade, one of the biggest challenges in corporate marketing communication planning has been the dramatic decline in the effectiveness of traditional communication tools such as television, radio, outdoor advertisements, and print media. Concurrently, online solutions, such as blogs, social media platforms, Google Ads, YouTube advertisements, and mobile applications, have gained prominence. [5]

The adoption of these new tools requires a new marketing approach, emphasizing the precise identification of target groups. This is essential for accurately understanding and characterizing consumer behavior. [6]

The emergence and growing influence of new communication tools also significantly impact tourism marketing. When planning offline and online marketing strategies, the following tourism-specific characteristics must be considered:
- The unique attributes of the "tourism product."
- The evolving media consumption habits of tourism consumers, both domestic and international.
- Changes in the age structure of target groups.
- The increasing role and significance of digitalization in communication.

David Ogilvy (1985) dedicated an entire chapter of his book to the topic of international travel. However, since the digital revolution, organizing and conducting travel has become significantly more streamlined. As a result, the goal of tourism marketing is to introduce services as early as possible in the planning phase, ensuring that the promotional messages closely align with the real-life experiences awaiting travellers. [7]

3   The Process of Travel Decision-Making

To accurately determine which marketing communication tools are most effective at different stages of the travel decision-making process, it is essential to understand the steps involved in this process. These steps are also outlined in the National Tourism Development Strategy 2030 – Tourism 2.0.[8]

Inspiration	Planning	Reservation	Travelling	Experience	Sharing
• Segment-based marketing messages and sales	• Smart offers and travel planning support	• Support for online booking options	• Check-in and online payment solutions	• Creating high-quality experiences at the destination level	• Collecting customer feedback

Primarily digital process → Primarily physical process → Digital process

Figure 5
The process of travel decision-making[8]

At the initial stage of the travel process, it is crucial to capture the attention of relevant travel segments. This requires the creation of engaging and high-quality digital content and ensuring its continuous availability.[8]

The second key task is facilitating travel planning, which involves providing personalized recommendations and user-friendly tools tailored to individual preferences. [8]

For successful sales, it is essential to ensure a smooth and seamless booking process. [8]

To transform traditional travel processes and enhance their efficiency, the integration of physical service providers and digital technologies is a primary objective. [8]

Creating and maintaining a high-quality customer experience at both the destination and service levels is fundamental. [8]

The final stage of the travel process focuses on encouraging experience sharing, as well as collecting and analyzing customer feedback. [8]

The process flowchart clearly demonstrates that, nowadays, tourists not only engage in personal travel experiences but also predominantly organize their trips in the digital space. Therefore, in my study, I focus on analysing online marketing communication elements.

4 Online Platforms

4.1 Paid Online Advertisements

Today, a vast selection of online marketing tools is available. Alongside and in place of traditional banner ads, rich media solutions are gaining prominence, offering a more interactive and visually engaging experience. These can be seen as modern versions of traditional magazine advertisements, where embedded creative elements—either smaller placements within articles or larger front-page visuals—are designed to capture attention, encourage engagement, and effectively reach the target audience through the given medium. [9]

Social media platforms, particularly Facebook and Instagram, play a crucial role in precisely targeting audiences. Geotargeting technology used in Facebook campaigns allows ads to appear in the local language of the target country, making them more effective in reaching the desired audience. In addition to social media campaigns, paid pre-roll ads, such as those appearing before YouTube videos, are becoming increasingly popular. On the world's largest video-sharing platform, promotional videos and nation-branding films often appear before videos with millions or even billions of views, serving as powerful tools for tourism and national marketing communication. [9]

4.2 Website

Websites serve as compasses for marketing communication, acting as landing pages for campaigns while also helping measure visitor traffic and demographics. They are the primary online touchpoints where potential visitors and service providers connect. [9]

Developing a well-designed and effectively executed website is thus of strategic importance. Consistent and cohesive messaging on the site not only encourages visitors to travel but also provides essential on-site information that enhances their experiences and strengthens their satisfaction with the destination. [9]

4.3 Social Media Pages

Beyond websites, managing official social media profiles is equally crucial. [10]

Social media platforms like Facebook no longer only target younger generations—older age groups are also actively engaged on these platforms daily. [9]

A Facebook page serves multiple functions:

1. Information hub: it provides essential details about the destination, helping visitors access key information.

2. Navigation tool: it offers useful links and subpages, aiding users in finding relevant resources.

3. Engagement and entertainment: it shares entertaining content to maintain audience interest and boost social media presence effectiveness. [9]

5 From the AIDA Model to the AISDALSLove Model

When defining marketing objectives, a company seeks to increase either spontaneous or aided brand awareness or the rate of repeat purchases, depending on the type of campaign being executed (branding or direct response). To understand how communication campaigns function, it is crucial to examine the psychological mechanisms through which advertising influences its audience. In other words, how the marketing mix is mentally represented in the consumer's mind.

Marketing communication professionals must be aware of how their advertisement will affect the identified and targeted market segment. The marketing objective system must effectively guide the target audience to a higher level of purchase readiness. [11]

The hierarchy-of-effects models have attempted to map consumer responses throughout different historical consumer eras. These theories assume that advertising processes are perceived by consumers as a series of emotional and cognitive transformations.

In 1898, businessman E. S. Elmo Lewis formulated the fundamental principles of advertising:

"Attract attention, maintain interest, create desire, and drive action." [12]

From the initials of these principles, the AIDA model was born—one of the most widely recognized impact models in advertising to this day. The fundamental premise of AIDA is that the primary goal of advertising is to evoke a desire for ownership, leading to the purchase of a product or service.

When generating desire is challenging, the goal can be achieved by first stimulating interest. If spontaneous interest is not naturally present, the first task is to capture attention. According to the model, eliciting attention is the minimum requirement—an advertisement that fails to do so cannot be successful.

However, the AIDA model is based on two assumptions that limit its broad applicability:

1. Consumer passivity: the model assumes that consumers passively receive information.

2. Linear information processing: it presumes that consumers always progress through the stages in the same order:

   o Attention → Interest → Desire → Action

   o Regardless of prior knowledge, emotions, or previous experiences. [13]

While desire-driven advertising remains effective today, marketers have recognized that AIDA is not universally applicable and is only effective for certain product categories (e.g., sensory-driven consumer goods). Despite its limitations, AIDA remains a foundational model, as all subsequent hierarchy-of-effects models have either evolved from it or been defined in contrast to it.

To better understand how communication campaigns function, we must analyse how contemporary impact hierarchy models have been structured, building upon the AIDA model.

To do this, we must identify three key consumer response variables in advertising campaigns:

1. Cognitive Dimension (Thinking) – The consumer's perception of the informative content of an advertisement.

   o Common metrics: recall, recognition, comprehension.

2. Affective Dimension (Feeling) – The consumer's emotional response to an advertisement.

   o Common metrics: likability, attitudes, emotional engagement.

3. Conative Dimension (Experience-Based Behavior) – Factors influencing future purchasing behavior, based on past product experiences (memories, subconscious or conscious details from previous interactions).

   o These variables capture the mental and psychological processes occurring in consumers (process variables). [5]

One of the biggest shortcomings of earlier models was their failure to consider the post-purchase effect—that is, how a purchase influences future decision-making and brand relationships.

A positive purchasing experience can lead to long-term brand loyalty, encouraging repeat purchases and fostering positive brand perceptions. [14]

Recognizing this, Sheldon (1911) introduced the AIDAS model, which added a "Satisfaction" stage after Action, highlighting the importance of post-purchase experience.

Later, Rogers (1983) proposed the Diffusion of Innovations Theory, which introduced stages such as:

- Knowledge → Persuasion → Decision (Acceptance/Rejection) → Implementation → Confirmation (continued acceptance, discontinuation, or rejection).

Building on these ideas, Bovee et al. (1995) further developed the concept, suggesting that advertising and other marketing communication tools should reinforce customer satisfaction in the post-purchase phase.

While the marketing community enthusiastically embraced hierarchical explanations of advertising effects, concrete evidence proving that traditional marketing measurements (such as brand awareness, brand familiarity, brand preference, and purchase intention) truly reflect how advertising influences purchasing remains inconclusive. [15]

Ultimately, there is no guarantee that every advertising impact results in a purchase.

The evolution of advertising's broader communicative role and brand development strategies has led researchers to expand upon the AIDA model. To address its limitations, additional key elements were introduced, such as:

- Search (consumer actively seeking information),
- Like/Dislike (emotional response to the brand),
- Share (social sharing of experiences),
- Love/Hate (strong emotional attachment or rejection).

This led to the development of the AISDALSLove Model, which represents a more comprehensive and experience-driven approach to consumer decision-making.

6   Methodology – Introduction to the AISDALSLove Model

In the AISDALSLove model, Professor Wijaya further developed the variables of the AIDA model, refining them at different stages and introducing additional elements:

- "S" (Search) – The process of actively seeking information.

- "L" (Like/Dislike) – The consumer's emotional response (preference or aversion).

- "S" (Share) – The act of sharing experiences with others.

- "Love" (Love/Hate) – The development of strong emotional attachment or rejection.

Additionally, the author categorized advertising effects into short-term and long-term impacts, highlighting their distinct influence on consumer behavior. [16]
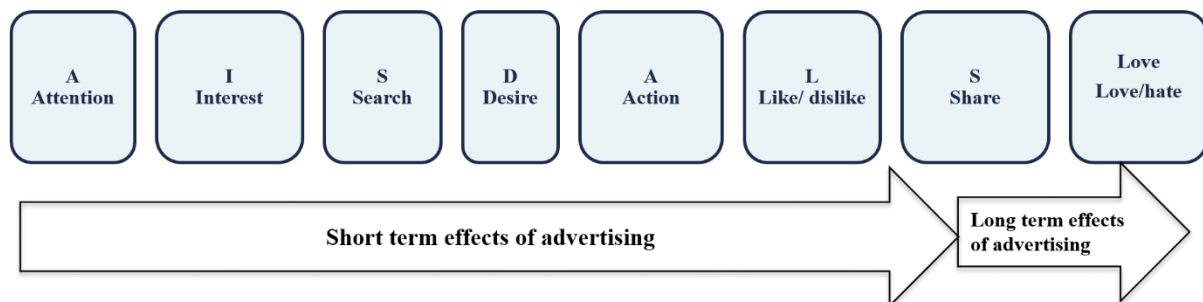
Figure 6
AISDALSLove Model[16]

Based on the above diagram, it can be concluded that the stages from attention to action and like/dislike represent short-term effects, whereas sharing and, especially, love/hate have long-term effects. The newly introduced elements (Search, Like/Dislike, Share, and Love) can be explained as follows. [16]

Search (S)

This element reflects the idea that today's consumers are increasingly critical. They do not immediately accept information obtained from advertisements as credible, nor do they instantly develop a desire to purchase—regardless of how engaging the advertising message is. Instead, consumers seek additional information from other sources before making a purchase decision.[16]

During the search process, consumers explore their environment to find relevant data for making a rational decision. [17]

The search process includes both internal and external searches:

- Internal search involves retrieving stored information, past experiences, and emotions from memory to assess available alternatives.

- Consumers rely on previous knowledge to evaluate options before making a choice.

Like/Dislike (L)

This element is closely linked to post-purchase experiences, particularly when a purchase was influenced by advertising. If consumers like the product, they generally feel satisfied and may take further actions, such as repurchasing or reordering it. Satisfaction can be defined as an attitude-like judgment that develops after a consumption experience. [18]

The significance of the like/dislike effect in the post-purchase stage is why Sheldon (1919) added an "S" (Satisfaction) to the AIDA model, leading to the AIDAS model. Later, Rogers referred to this stage as "Confirmation", while Bovee et al. also called it "Reinforcement". This consumer experience can trigger a snowball effect, where the consumer shares their experience with others about the advertised product, further influencing the brand's perception.

Share (S)

In today's world, where information technology has erased traditional boundaries, consumers can take radical actions that significantly impact a brand's reputation. These actions are driven by their positive or negative experiences with a product.

Moreover, the growing number of social media users allows consumers to freely express their opinions and share their experiences with the world. As a result, brands must provide exceptional consumer experiences that motivate users to share their stories. [16]

Love/Hate

A long-term effect of advertising is that consumers may either love or hate the advertised brand or product. A consumer who was initially interested in the product due to an advertising message (whether visual or verbal) and had a positive experience during use will likely share their experience and develop positive emotions toward the brand. This level of brand affection can grow over time, evolving from indifference or dislike into brand obsession and deep loyalty. [16]

Consumers may also develop love for a brand if they feel connected to its creative concept or story. This connection is often built on deep consumer insights and, when reinforced by a positive brand experience, can lead to long-term brand loyalty and even a sense of ownership. There is no better way to establish lasting brand loyalty than by continuously nurturing the brand-consumer relationship, ensuring that the brand remains present and relevant in the consumer's life. [16]

On the other hand, if a negative experience results in dissatisfaction with the advertised product, consumers may spread negative word-of-mouth, shaping a poor public perception of the brand.

Instead of love and loyalty, dissatisfied consumers may feel frustration or even hatred, which can manifest in various ways, including public complaints, social media criticism, and boycott movements.

7   Brief Introduction of Sárvár

Sárvár is located in the eastern part of Vas County, along the Rába River, and is the second-largest settlement in the county after Szombathely, with a population of approximately 15,000 residents. From a hydrographic perspective, the city and its surroundings are well-endowed, as both the Rába River and the Gyöngyös Creek flow through it.

The undisputed main attraction of Sárvár is the Sárvár Spa and Wellness Bath, whose newly expanded complex opened its doors on December 1, 2002, welcoming visitors seeking relaxation and healing. This development laid the foundation for a series of further investments, including:

- the construction of VitalMed Hotel,
- Sárvár's joining the European Royal Spa Towns Association in 2004,
- the opening of the four-star Bassiana Hotel,
- the completion of Park Inn Hotel in 2006,
- the establishment of a new camping site,
- and finally, the launch of the Spirit Hotel Royal Thermal Spa in 2008. [19]

In 2010, the spa underwent another major development worth 3 billion forints. On October 19, 2012, Sárvár officially received the designation of a medicinal resort, celebrating this achievement with a formal ceremony.

As a result of a one-year qualification process, two areas of the city—"Sárvár – Gyógyvarázs" and "Sárvár – Arboretum"—were officially classified as healing destinations. [20]

Sárvár stands out not only for its architectural and natural attractions but also for its diverse events and festivals. The city hosts a variety of cultural programs, including the International Folklore Festival, brass band festivals, the Vármeeting, and the most famous event, the Simon-Judas Fair. These programs provide excellent entertainment not only for locals but also attract a large number of tourists to the city. [19]

Over the past three decades, in addition to the development of the spa and modernization of infrastructure, numerous significant municipal and state investments have taken place, contributing to the city's growing tourism industry. Since the political transition, substantial funding has also been allocated to the modernization of education and healthcare systems, further strengthening the city's development. [20]

The economic growth of Sárvár, its outstanding role in tourism, and its vibrant cultural life have all contributed to making it one of Hungary's most popular spa towns. In terms of guest nights, Sárvár has consistently ranked among the top ten most visited destinations in the country. [20]

8 Analysis of Sárvár's Marketing Communication Tools Using the AISDALSLove Model

City marketing, when utilizing various tools effectively, can significantly contribute to a city's success, recognition, and reputation. However, achieving long-term, substantial results requires a consciously planned, strategically thought-out, creative, and economically efficient approach that involves multiple stakeholders working together. [21]

According to my opinion Sárvár serves as a great example of a town that effectively applies marketing tools while also incorporating creative ideas. In the following sections of my study, I will present specific examples of how the town ensures that tourists leave satisfied after their stay and even return multiple times in the future.

For my research, I primarily relied on secondary data, which I obtained from the Hungarian Central Statistical Office, along with my own data collection efforts. I would like to express my gratitude to Krisztina Holpert, a representative of Sárvár Tourist & TDM Nonprofit Ltd., for her valuable assistance in answering my questions.

8.1 Attention

The primary objective of advertising is to capture the attention of potential customers—in this case, tourists. If this initial phase fails, the advertisement immediately fails, preventing any further progress in the decision-making process. The first stage of the AIDA model is thus crucial—if the message does not grab attention, it will not reach the target audience, and as a result, no purchase (or visit) will occur.

Previous research and professional articles confirm that advertising activities today take place primarily in the digital space. Krisztina Holpert also emphasized this point, stating that Sárvár primarily reaches potential tourists via online platforms, especially social media and its own website. The key reason for this strategy is that online platforms allow a much wider target audience to be reached at a lower advertising cost. However, she highlighted that printed brochures remain popular among visitors, regardless of age, as they provide a tangible source of information about local attractions and current events.

8.2 Interest

If the first step succeeds and the message reaches the target audience, an effective advertisement must then spark interest. At this stage, advertising must encourage potential visitors (tourists) to develop an interest in Sárvár's attractions. If this fails,

consumers will not proceed further in the decision-making process, and conversion will not occur.

Sárvár uses various campaigns to increase interest in its attractions. These campaigns often include interactive games, where winners are selected from among participants. The prizes are sponsored by TDM partners, such as Sárvár Spa & Wellness Bath, Spirit Hotel, and Park Inn Hotel.

For example "Collect Coins, Gain Experiences!" was an online campaign required visitors to click on as many appearing coins as possible within a given timeframe. The more coins a player collected, the higher they ranked on the leaderboard. As a result, the TDM office registered 7,000 new newsletter subscribers.

Launched during the COVID-19 pandemic, the "Relax Campaign" differed from traditional promotional activities. Instead of focusing on giveaways or increasing newsletter subscriptions, it aimed to provide a sensory relaxation experience. This unique approach aligned with the public's heightened need for stress relief and mental well-being during the lockdown period, offering content and stimuli designed to evoke calmness rather than drive direct sales or engagement metrics.

The TDM recorded sounds from different parts of the city, such as:

- the bubbling waters of the thermal baths,
- birdsong from the arboretum,
- the sauna ambiance at Spirit Hotel,
- the crackling of firewood.

These sounds were compiled into a "close-your-eyes" relaxation campaign, allowing people to enjoy a piece of Sárvár from home during lockdowns.

The campaign received highly positive feedback, including suggestions for enhancements, such as:

- adding a visual counter,
- incorporating breath-in/breath-out guides,
- improving the sensory experience further.

Inspired by this feedback, the "Relax 2.0" campaign was created, which won the Marketing Diamond Award from the Hungarian Marketing Association in 2023.

8.3   Search

In the previous section, I explained how the "Search" phase begins after a successful interest phase—at this point, potential visitors seek additional information to verify whether the advertised claims align with reality.

When planning a trip, a tourist typically looks for more details about:

1. the main attractions (since this is the primary reason for visiting),

2. accommodation options,

3. upcoming events and entertainment programs.

The most effective platforms for this are official websites and social media pages.

Unfortunately, I was unable to access annual traffic data for www.sarvar.hu. Instead, I used www.similarweb.com, a digital market research and web analytics platform, to collect publicly available data for September.

According to data from SimilarWeb for September 2024, the website recorded a total of approximately 8,900 visits, indicating a decline compared to the previous month. The average duration of a visit was 42 seconds, with users viewing approximately 1.5 pages per session, suggesting relatively brief engagement per visit.

In terms of traffic sources, the majority of users arrived via organic search (55.73%), followed by direct access to the site (21.51%). These figures highlight the continued importance of search engine visibility in attracting visitors.

Analysis of device usage revealed that 67.21% of users accessed the website through mobile devices, while 32.79% utilized desktop computers, underscoring a clear dominance of mobile traffic and the growing need for mobile-optimized content and interfaces.

In order to evaluate the effectiveness and reach of social media platforms in Sárvár's tourism marketing strategy, an assessment was conducted of the town's official accounts across major platforms. The follower counts, recorded during the research period, reveal significant differences in audience engagement across channels. Facebook emerged as the dominant platform, with approximately 21,000 followers, indicating its central role in digital outreach. In contrast, Instagram accounted for a more modest 1,472 followers, suggesting limited but potentially visually driven engagement. TikTok, while increasingly popular globally, had only 34 followers at the time of analysis, reflecting its underutilization or relatively recent adoption within Sárvár's official digital communication strategy. These figures clearly indicate that Facebook remains the most important social media platform for Sárvár, followed by its official website as the second most relevant information source.

I have compiled September's website traffic data for Sárvár's main attractions and major hotels using SimilarWeb. The following table presents this data, showing how different establishments perform in attracting online visitors.

Attractions	Visitor datas	Accommodations	Visitor datas
Sárvár Thermal and Wellness Bath	85 090	Spirit Hotel Thermal Spa***** Sárvár	58 903
Ferenc Nádasdy Museum Sárvár	1488	Park Inn by Radisson Sárvár Resort & Spa	16 506
		Ensana Thermal Sárvár	229 239
		Melea The Health Concept	7851

Figure 7

Additional website traffic data for the month of September based on the analysis of similarweb.com

The data in the table show that the highest number of visitors, totalling 85,090, visit the website of the Sárvár Spa and Wellness Bath. This is followed by the website of the Spirit Hotel Thermal Spa***** Sárvár, which records 58,903 visitors. This comparison also confirms that tourists primarily seek information about the attraction itself.

8.4   Desire

The next step in the advertising message process is creating desire. Even if the message reaches the target audience, it fails if it does not align with their needs or if they cannot relate to it. Creating travel desire is primarily achieved through images, videos, and influencer collaborations. I believe that influencers play a key role in tourism, as tourism products cannot be tested or exchanged like regular goods. Therefore, travel decisions are greatly influenced by recommendations from friends, acquaintances, and trusted sources. A popular influencer can effectively promote a destination and influence potential travellers. So far, Sárvár has only occasionally collaborated with influencers. The most recent significant collaboration was in 2019, when stylist and influencer Schreiter Lilla created a video showcasing Sárvár's attractions, which was very well received.

8.5   Action

The final element of the AIDA model is action, which is realized through the actual purchase—that is, when the visitor truly travels to the destination. Digital tools also play a primary role in planning the journey and compiling the travel package.

The website www.sarvar.hu can be described as highly user-friendly, with several modules designed to assist tourists with bookings. The current package offers of accommodations are up to date, and if a traveller wishes to make a reservation, the website immediately redirects them to the official site of the selected accommodation. The same applies to attractions: www.sarvar.hu displays the latest opening hours and ticket prices, and it also provides hyperlinks to the official pages of the attractions.

A particularly creative feature is the Trip Planner module. Every post and subpage on the site can be easily saved according to the user's individual interests. All it takes is a click on the heart icon in the header. Additionally, users can save personal notes and text snippets among their favourites. Highlighted sections of the site can likewise be stored in the personal space by clicking the heart icon. These saved contents can be especially useful later, for instance during the vacation, when visitors want to check the opening hours of a service provider, the schedule of a specific event, or when they wish to read more about an attraction on-site or watch a related video.

Another innovative solution is the GoGreen application, which was added to the Green Destinations Top 100 Stories list in October 2024. GoGreen is an innovative initiative that allows users to receive personalized tips on how to make their trip to Sárvár more environmentally friendly. These tips can also be shared on social media platforms, enabling those who wish to inspire others to travel "greener" to do so with ease. The platform is available in six languages, and certain tips are accompanied by more detailed, blog-style information.

8.6   Like/Dislike

While the AIDA model ends with action—that is, the purchase—the AISDALSLove model adds an additional element: liking or disliking. Since online platforms now allow guests to evaluate their stay by reviewing the destination, attraction, accommodation, and other services after their visit, it becomes particularly important that they leave with positive experiences. A negative review can, over the long term, significantly reduce the number of future bookings. Therefore, even in this final phase, guest satisfaction is of key importance. The primary goal is for visitors to gain enriching, positive experiences during their stay, leave satisfied, and provide a favourable evaluation of the city.

I conducted a brief analysis regarding the number of likes received by posts published on the Sárvár TDM Facebook page. In my analysis, I examined the posts from January 1, 2024, to October 28, 2024, as illustrated in the diagram below.

Figure 8

User reactions to Facebook posts

The diagram shows that during the booking period preceding the peak season, the number of positive reactions to individual posts is exceptionally high. These spikes correspond to prize games and promotional campaigns. The TDM office intentionally schedules advertising campaigns during the booking period, as this is when they aim to capture the attention of potential tourists.

Overall, it can be said that paid advertisements receive more likes, although there is no significant difference between the high, shoulder, and off-seasons. This may be due to the fact that health and wellness tourism is less affected by seasonal fluctuations. The comments on the Facebook page are predominantly positive, with only a few users noting overcrowding at the spa or complaining about prices. A small number of comments also suggest that the winners of the prize games should be announced on the Facebook page.

The TDM does not respond to comments on Facebook—neither to positive nor negative feedback. This may be because the page is managed by an external marketing agency, or because the TDM staff are responsible for numerous other tasks in addition to handling public relations. On a positive note, the posts published every 2–3 days are timely and feature consistent visual branding. The content is relevant not only for tourists but also for local residents. In addition, tourists can also rate the city and its attractions on the website szallas.hu.
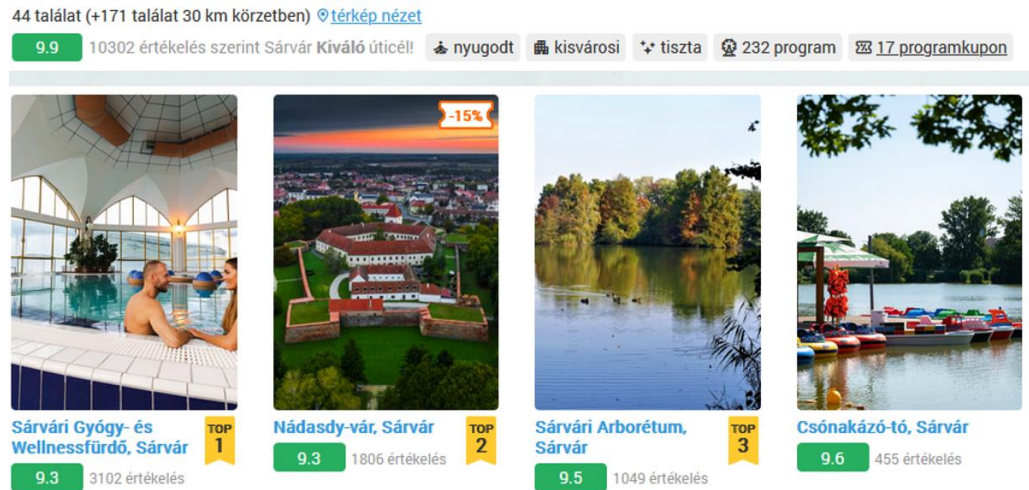
Figure 9
Reviews of Sárvár on www.szállás.hu

The figures show that 10,302 tourists rated the city of Sárvár, and based on their feedback, it received a score of 9.9 out of a possible 10. The city's main strengths, as highlighted by visitors, are that it is peaceful, small-town in character, and clean. Among the attractions, the Sárvár Spa and Wellness Bath ranks first based on 3,102 reviews, earning a score of 9.3. The other landmarks also received ratings above 9 points. All of these data indicate that tourists visiting Sárvár are highly satisfied with the city's attractions and recreational opportunities, and they leave their vacation with pleasant experiences.

8.7   Share (Social Sharing & Recommendations)

Sharing is also an element of the AISDALSLove model, which measures whether visitors share their experiences with others and whether they recommend the city to friends and acquaintances. This element of the model is relatively difficult to measure, as asking tourists whether they would recommend the destination might result in a positive response on a survey, but it remains uncertain whether the recommendation actually takes place later on. In my study, I compared destinations based on how many times the name of the town is mentioned with a hashtag in individual Facebook posts.

	City	Total guest traffic (number of guest nights)	Volume of hashtag posts ('000)	Ranking based on hashtags
2.	Hévíz	854 380	28	5.
3.	Hajdúszoboszló	764 908	18	7.
4.	Bük	631 864	4	9.
5.	Zalakaros	607 334	26	6.
6.	Sárvár	461 727	15	8.
7.	Debrecen	447 928	371	2.
8.	Szeged	419 331	399	1.
9.	Gyula	404 728	74	4.
10.	Győr	372 168	179	3.

Figure 10

Frequency of hashtags (mentions) used in Facebook posts

The table presents the 10 most visited spa towns in Hungary for the year 2023, excluding Budapest due to its unique status. Sárvár ranks 6th on this list, ahead of several larger cities such as Debrecen, Szeged, and Győr. Although the number of hashtags mentions depends on numerous factors—such as the city's marketing activity, the engagement of local residents, the activity of visiting tourists, and even the size of the city—these mentions cannot be filtered exclusively for tourism-related posts. Therefore, the data includes all posts in which the town is mentioned, regardless of topic.

In terms of hashtag mentions, Sárvár ranks 8th, which places it in the strong mid-field. Considering the city's size, I believe this represents a respectable position compared to other settlements.

8.8   Love/Hate

The final element of the model—love or hate—aims to assess whether a destination can build a loyal customer base, consisting of visitors who return regularly and recommend the city to others, thereby generating positive word-of-mouth for the destination. Loyalty can be fostered through loyalty programs and exclusive offers.

According to a survey conducted last summer by Sárvár Tourist & TDM Nonprofit Ltd., approximately 70% of tourists visiting Sárvár are returning guests. [22]

Of the nearly 1,000 respondents, 55% had visited the spa town at least four times, and 74% stated that they definitely plan to return in the near future. Only 16% expressed uncertainty. The high proportion of returning guests is not only characteristic of domestic visitors. The responses show that 60% of international visitors had also previously been to Sárvár. [22]

The data clearly indicate that Sárvár enjoys a high rate of repeat visitors, even though the city itself does not offer an official loyalty program for tourists.

However, the hotels do operate loyalty schemes and related promotions, which allow them to keep track of their regular guests.

Conclusion

In conclusion, my study affirms that emotionally engaging, experience-based marketing plays a central role in tourism—especially when it involves digital content and campaigns tailored to the needs of specific target groups. Sárvár serves as a good example for other cities, as it successfully utilizes online marketing tools, with particular emphasis on social media campaigns, interactive games, and creative content.

In my analysis, I highlighted the key elements that have become indispensable in modern online marketing. These include a well-functioning, user-friendly website featuring creative solutions, as well as a social media presence that is up-to-date and visually consistent. It would be worthwhile to expand the city's presence beyond Facebook to platforms like Instagram and TikTok, which are increasingly preferred by Generation Z and Alpha users.

As a recommendation, I suggest placing greater emphasis on responding to negative comments, as negative feedback can also offer valuable insights into how to improve operational tasks more effectively and prevent recurring complaints or issues in the future.

While it may seem that a high number of returning guests eliminates the need for further engagement—since they revisit the destination year after year without additional promotional efforts—I believe it is still important to pay attention to loyal guests. Offering exclusive deals through direct marketing tools tailored specifically to them can strengthen this bond. Retaining loyal customers generally requires far less money and effort than attracting new ones.

Sárvár's example clearly demonstrates how strategic marketing communication and conscious development of tourism products can result in a high rate of returning visitors. This study offers relevant insights for other destinations aiming to enhance their competitiveness.

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Physiological and Neurological Factors in Virtual Reality: A Survey-Based Analysis

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Abstract: Virtual Reality (VR) technology offers immersive, multisensory experiences that have transformative potential across entertainment, education, and professional domains. However, its use is also associated with a range of physiological and neurological responses that remain underexplored in large-scale user populations. This study investigates the prevalence, severity, and predictors of such responses through a survey-based analysis of 205 VR users. Participants completed a structured online questionnaire assessing their VR usage patterns, symptom experiences, and demographic background. Results indicate that the most frequently reported symptoms include nausea, headaches, visual fatigue, and neck discomfort, though these effects were generally mild and infrequent. Psychological symptoms such as anxiety, disorientation, and diminished motivation were reported less often but showed a strong association with higher daily screen exposure. In contrast, demographic factors like age and gender had limited predictive value. Notably, educational background and technical familiarity were linked to more functional and diverse VR use. The findings support prevailing theories of sensory conflict and cognitive overload while highlighting the cumulative role of digital lifestyle in shaping user responses. Future research should incorporate objective measurements and stratified sampling to better capture the complex interaction between immersive technology and human neurophysiology.

Keywords: Virtual Reality, Simulation, Cybersickness, Human Factors in VR, Immersive Technology, VR-Induced Symptoms, Screen Time Exposure

1 Introduction

Virtual reality (VR) offers immersive experiences that engage multiple sensory systems simultaneously, creating environments that feel compelling and, at times, indistinguishable from physical reality. While this technological potential opens new avenues for learning, entertainment, and simulation, it also introduces a range of human responses that warrant systematic investigation. This section focuses on the effects of VR exposure on the human body and brain, organized into two broad but interconnected categories, physiological and neurological responses. Physiological responses refer to observable bodily effects such as nausea, visual

strain, musculoskeletal discomfort, and changes in autonomic function. In contrast, neurological responses encompass sensory conflicts, cognitive alterations, emotional reactions, and perceptual disturbances. Although analytically distinct, these domains often overlap, for example, dizziness and disorientation may arise from both vestibular disruption and cortical processing demands. Understanding how these effects emerge and interact is essential for improving VR system design, guiding responsible use, and minimizing adverse outcomes.

2 Human Responses to Virtual Reality

2.1 Physiological

One of the most prevalent immediate physiological responses to immersive VR exposure is nausea, accompanied by autonomic symptoms akin to classic motion sickness, such as increased salivation, pallor, sweating, dizziness, and stomach discomfort. These symptoms result primarily from sensory mismatches between visual motion cues and vestibular feedback (e.g. visual motion without corresponding vestibular input), triggering activation of the sympathetic nervous system, as demonstrated by elevated heart rate and increased skin conductance. [1] Ohyama et al. (2007) demonstrated that exposure to discordant visual-vestibular motion in VR can selectively increase low-frequency heart rate variability power, indicative of sympathetic activation, without a concurrent parasympathetic modulation. [2]

Visual (oculomotor) symptoms, including eyestrain, blurred vision, dryness, and headaches, arise largely due to vergence-accommodation conflicts caused by the stereoscopic displays of VR head-mounted devices (HMDs). This conflict compels ocular muscles and the ciliary accommodation reflex into continuous exertion, exacerbating visual fatigue, particularly during extended VR sessions. Additionally, prolonged exposure to VR screens emitting blue-enriched light can suppress melatonin secretion, potentially affecting circadian rhythms and delaying sleep onset. [3] Dymczyk et al. (2024) observed that 30 minutes of VR with a strong depth conflict led to a post-exposure rise in SSQ (Simulator Sickness Questionnaire) oculomotor scores (e.g. eyestrain, blurred vision) in participants. [4]

Spatial disorientation and disturbances in balance occur due to conflicts among visual, vestibular, and proprioceptive inputs, resulting in impaired postural stability, vertigo, and increased body sway both during and immediately following VR immersion. Users commonly experience transient difficulties with real-world orientation, manifesting as misjudgments of direction and reduced postural control even after removing the headset. [5] For example, Akizuki et al. (2005) found that

30 minutes in VR led subjects to misjudge their limb position and sway more, even after removing the HMD, indicating lingering proprioceptive aftereffects. [6]

Cardiovascular and stress reactions are significant, especially in emotionally intense VR scenarios. Studies document measurable increases in heart rate, blood pressure, and salivary cortisol levels, reflecting sympathetic nervous system activation similar to real-world fight-or-flight responses. This stress response can also occur during physically active VR scenarios, highlighting the physiological realism of virtual simulations. [7] Martens et al. (2019) reported that 20 minutes of a stress-inducing VR elevator scenario elevated heart rate and even altered heart rate variability indices indicative of stress. [8]

Musculoskeletal symptoms, frequently described as "VR neck" or shoulder discomfort, result from sustained muscle tension induced by the weight and ergonomic demands of VR headsets, causing strain particularly in the cervical spine, shoulders, and upper back. Repetitive movements and extended periods in unnatural postures further contribute to muscle fatigue and joint discomfort. [9] Kim and Shin (2021) quantified this effect: performing an hour-long office task in VR caused a 25–30% increase in neck muscle exertion (measured via EMG) compared to doing the task at a normal desktop. Participants also reported 60% higher neck discomfort and 18% higher shoulder discomfort after using the VR headset. [10]

Finally, general physical symptoms include fatigue, drowsiness, general malaise, and transient bodily discomfort. These diffuse symptoms are frequently reported after prolonged VR exposure and can impact user performance and safety immediately post-experience. [11] Sharples et al. (2008) found in a large-scale survey that over 80% of VR users reported at least some symptoms (ranging from fatigue to nausea) following use. [12] General physical symptoms can also include transient aches that don't fit neatly into one category.

2.2 Neurological

Neurologically, VR-induced responses are largely driven by sensory conflicts, characterized by mismatches between visual inputs and vestibular or proprioceptive feedback. This conflict is neurologically interpreted as an indication of toxin ingestion or neurological disturbance, thus activating protective mechanisms such as nausea and dizziness, key components of cybersickness. The intensity of these symptoms correlates closely with the severity of visual-vestibular conflicts, and this conflict-driven model remains the predominant explanation for VR-induced motion sickness. [13] Unexpectedly, individuals with less postural sway before and during VR exposure (a potential indicator of greater stability) reported more cybersickness symptoms in an HMD environment, contradicting the predictions of postural instability theory. [14] However, not all findings agree, and sensory conflict remains the dominant explanatory model.

Cognitive impairments also commonly occur, primarily due to the substantial cognitive load associated with processing complex, multi-sensory VR environments. VR users often experience temporary reductions in memory retention, slowed reaction times, diminished attention, and impaired cognitive-motor coordination immediately following immersive experiences. This transient cognitive decline is primarily related to mental fatigue and attentional demands induced by the sensory-rich VR environment. [15]

Spatial disorientation arises from neurological disruptions in the integration of visual, vestibular, and proprioceptive signals, causing temporary misjudgments of spatial orientation and depth perception upon exiting VR. Users frequently report difficulty accurately estimating directions, distances, and object positions in the real world immediately after immersive sessions, reflecting neurological recalibration in the brain's spatial processing regions. [16] As demonstrated in the work of Riecke and Wiener (2007), participants who were asked to point to cardinal directions after navigating in VR made significantly larger errors compared to a real-world navigation task, indicating a loss of true orientation. [17] In extreme cases, users in VR who physically rotate many times (perhaps in a twisting game or exploring an environment) often lose track of how much they have turned in reality, a phenomenon known as visual dominance. [18]

Headaches are another common neurological outcome, frequently resulting from prolonged oculomotor strain, incorrect headset alignment (particularly incorrect interpupillary distance), screen flicker, or low frame rates. These conditions induce ocular muscle tension and trigeminal nerve fatigue, leading to tension-type headaches or even migraines, particularly in predisposed individuals. [19] As noted by Rebenitsch and Owen (2016), an epidemiological observation is that a notable subset of users, especially those prone to headaches or migraines, consistently experience VR-induced headaches even in the absence of nausea. [20] VR-induced headaches are usually short-term and respond to rest (removing the headset, closing one's eyes) or analgesics if needed.

Although rare, epileptic reactions are a serious neurological concern related to VR, especially in photosensitive individuals who may experience seizures triggered by rapid visual stimuli, flashing lights, or repetitive patterns commonly found in VR content. [21] Approximately 1 in 4,000 people in the general population has photosensitive epilepsy, where certain flickering in the frequency range of ~3–60 Hz can provoke a seizure. [22] Careful content moderation and user screening can mitigate this risk effectively.

Psychological responses, including heightened anxiety, transient dissociation (such as feelings of depersonalization or derealization), and mood changes (e.g., post-VR blues), are induced by the immersive, emotionally charged nature of VR. Users frequently report intense emotional reactions to virtual stimuli, demonstrating VR's strong psychological impact, which can be therapeutic but also overwhelming when unexpected. [23] As documented by Zimmer et al. (2019), users have reported

anxiety spikes, especially if they are prone to anxiety disorders, when confronted with stressful VR situations such as public speaking or survival scenarios. Empirical research using a refined virtual reality adaptation of the Trier Social Stress Test (TSST-VR) found higher self-reported anxiety and elevated physiological stress markers compared to a less immersive task, confirming that VR can amplify emotional stress. [24]

Sleep patterns can be influenced by pre-sleep VR use, depending on the content and intensity of the experience. While stimulating or stress-inducing VR sessions may risk delaying sleep onset due to cognitive arousal, some immersive environments designed for relaxation have been shown to improve sleep quality. For example, one study combining immersive VR with slow breathing found reduced pre-sleep anxiety, lower heart rate, and shortened sleep onset latency in adolescents. [25]

Short-lived perceptual distortions, such as misperceptions of limb positions, motion aftereffects, or skewed depth perceptions, are common post-exposure neurological phenomena, reflecting temporary neural recalibration within perceptual and sensorimotor pathways. One commonly reported distortion is the sense that the real world feels subtly "off" or unreal immediately after coming out of VR (as discussed under dissociative symptoms). [26] These aftereffects typically resolve within minutes to hours but indicate significant transient neuroplasticity induced by VR exposure. [27]

Cybersickness, the overarching syndrome encompassing many of these neurological and physiological responses, includes nausea, dizziness, visual discomfort, autonomic disturbances, and cognitive impairments. It represents the composite impact of neurological and physiological challenges posed by VR, significantly influencing user experience and acceptance, and necessitating ongoing technological improvements and user-adaptive strategies to reduce symptom severity and incidence. [28]

3   Research Methology

This study aimed to investigate Virtual Reality (VR) usage patterns and their associated physiological and neurological effects. Research was conducted with a questionnaire in early 2025 using convenience sampling. Participants were recruited through digital platforms such as Discord, Telegram, Facebook interest groups, and university mailing lists.

The research addressed three core questions: (1) how frequently and for what purposes individuals use VR; (2) what symptoms are experienced during or after VR use; and (3) how demographic factors (age, gender) and individual differences relate to usage patterns and symptom severity. Based on prior literature, frequent

use is expected, especially for entertainment, education, creativity, social interaction, and fitness. Users are likely to report symptoms such as nausea, eye strain, headaches, dizziness, and anxiety, primarily driven by sensory conflict and cognitive load. Higher usage is anticipated among younger individuals and males, whereas females are expected to report greater symptom intensity; these patterns are presumed to be moderated by prior exposure and individual sensitivity.

The questionnaire consisted of 14 questions, systematically divided into three sections. The first section comprised five questions to assess participants general technology use and prior exposure to virtual reality. Respondents reported their average daily hours spent on work-related digital applications and gaming activities, indicated whether they owned a VR device, evaluated the likelihood of using VR in their professional life, and stated whether they had previously used VR technology.

The second section of the questionnaire assessed current VR usage patterns and self-reported effects. Participants indicated the frequency of their VR use, the type of device employed (PC-connected or standalone), and the extent to which they engaged in various VR applications, including entertainment, work, education, creative activities, social interaction, fitness, and healthcare, using a six-point frequency scale ranging from "never" to "always." This section also assessed the self-reported frequency of symptoms experienced during and after VR sessions using a six-point scale. These symptoms included nausea, eye strain, headaches, musculoskeletal discomfort, anxiety, aggression, diminished interest in real-world activities or relationships, difficulties distinguishing between virtual and physical environments, and sleep disturbances.

The third section focused on demographic information to enable subgroup comparisons. Participants were asked to report their age, gender identity, highest level of formal education, and areas of professional qualification, selecting from a predefined list that included disciplines such as economics, engineering, military and security, healthcare, natural sciences, education, information technology, arts, and social sciences. Multiple responses were permitted for the latter item, allowing participants to indicate up to four areas of specialization.

Previous research on virtual reality and simulation-related symptoms served as the basis for shaping the questionnaire's content and focus. Relevant constructs (e.g., "discomfort," "anxiety," "visual fatigue") were operationalized into measurable variables using numerical scales. A pilot test with a small sample (n=10) was conducted to evaluate the clarity, relevance, and structure of the items, after which the instrument was refined accordingly to ensure comprehensibility and internal consistency.

Although the reliance on self-reported data and the use of non-probability sampling limit the generalizability of the findings and introduce potential biases (e.g., recall and social desirability bias), the study yields valuable preliminary insights into the relationship between user characteristics, VR usage patterns, and associated

physiological and neurological phenomena. These findings serve as a foundation for future experimental research using controlled methodologies and objective physiological measurements.

4   Results

4.1   Research Sample

Of the 290 total respondents, 98 identified as female (33.8%) and 191 as male (65.9%). One respondent (0.3%) selected a non-binary option, this response was excluded from further analysis due to insufficient representation. The sample was therefore predominantly male, which may reflect existing gender disparities in VR usage or technology-oriented communities.
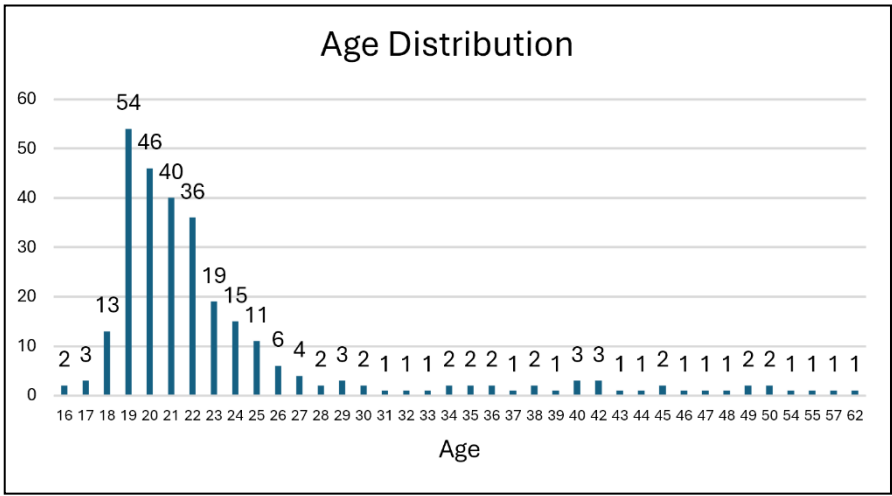
Figure 1

Age Distribution (Edited by the author based on research data)

The age of respondents ranged from 16 to 62 years (M = 23.73, SD = 7.73). As shown in Figure 1, the distribution is positively skewed (skewness = 2.52, SE = 0.143), indicating a strong concentration of younger participants. Kurtosis (6.314, SE = 0.285) suggests a leptokurtic distribution, with a pronounced peak and heavier tails compared to a normal distribution. A majority of respondents (54 at age 18, 46 at age 19, and 40 at age 20) were between 18 and 21 years old, comprising the modal

cluster. Representation declines sharply after the mid-20s, with sporadic responses from older age groups. This suggests the sample primarily reflects younger, possibly student-aged, VR users, which aligns with trends in digital media adoption and gaming culture.

4.2   Research Results

Out of 290 respondents, 60 individuals (20.7%) reported owning a VR device at home, while the majority (79.3%) did not. However, 205 participants (70.7%) indicated prior experience with VR, suggesting that a significant portion of VR engagement occurs through shared, institutional, or public access rather than personal ownership. Regarding modes of use, 86 respondents reported using PC-based VR, while 59 used standalone headsets. Notably, 89 participants were unable to specify the type of VR device used, indicating either limited familiarity or indirect exposure (e.g., brief trial sessions). This highlights potential gaps in user awareness of technical specifications, particularly among casual or first-time users.
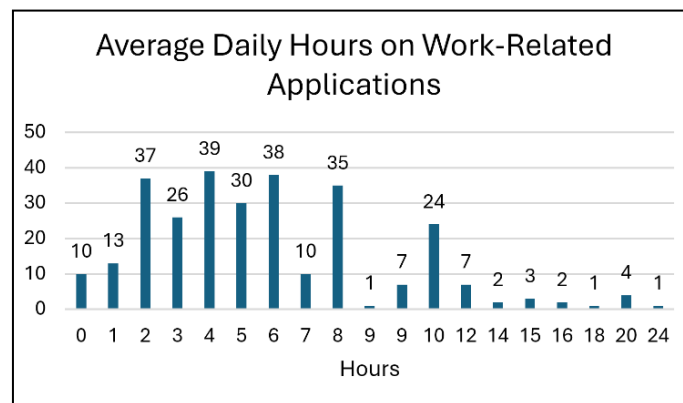
Figure 2

Average Daily Hours on Work-Related Applications (Edited by the author based on research data)

Participants reported a wide range of daily hours spent on work-related applications, from 0 to 24 hours (M = 5.76, SD = 3.88). As illustrated in Figure 2, the distribution is positively skewed (skewness = 1.38, SE = 0.143), indicating a concentration of responses at lower hour values with a long tail extending toward higher durations. The modal group reported 4–6 hours per day, with peaks at 4 (n = 39), 6 (n = 38), and 5 hours (n = 30). A substantial portion also reported 7–8 hours (n = 35 each), aligning with standard full-time work durations. Fewer participants reported extreme usage (e.g., 12+ hours), though a small subset indicated 16 to 24 daily hours, suggesting cases of intensive digital workload or continuous system access.

The kurtosis value (3.14, SE = 0.285) suggests a mesokurtic distribution, slightly more peaked than normal. Overall, the data reflect a heterogeneous sample with both moderate and extended digital work engagement, likely influenced by occupational roles and remote work habits.
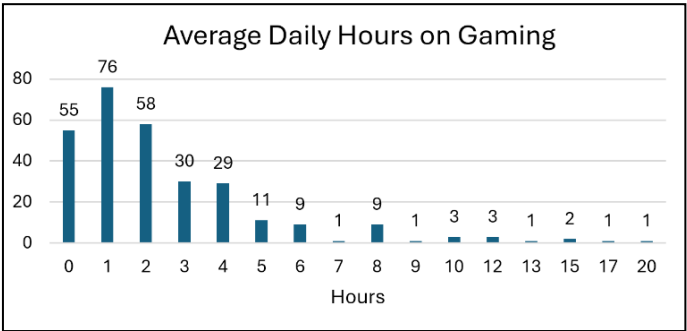
Figure 3

Average Daily Hours on Gaming (Edited by the author based on research data)

Participants reported daily gaming durations ranging from 0 to 20 hours (M = 2.55, SD = 2.94). As shown in Figure 3, the distribution is strongly positively skewed (skewness = 2.51, SE = 0.143) and highly leptokurtic (kurtosis = 8.49, SE = 0.285), indicating a sharp peak with heavy right-tailed extremities. The mode was 1 hour per day (n = 76), followed by 2 hours (n = 58) and 0 hours (n = 55), suggesting that the majority of respondents engaged in gaming casually or not at all. A steep decline is observed beyond 3 hours, with only a small subset reporting extensive daily gaming ($\geq$ 6 hours). This distribution reflects a primarily low-to-moderate gaming population, with a few high-engagement outliers, consistent with broader trends in general user behavior across age groups and lifestyle patterns
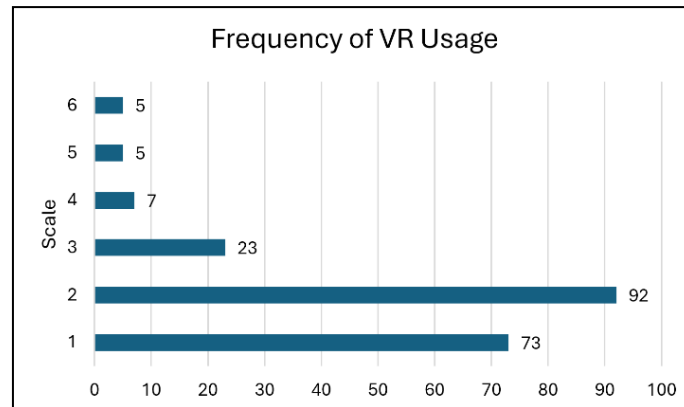
Figure 4

Frequency of VR Usage (Edited by the author based on research data)

VR usage frequency was measured on a 6-point scale (1 = "never" to 6 = "always"), yielding a mean of 2.00 (SD = 1.11). As illustrated in Figure 4, the distribution is positively skewed (skewness = 1.71, SE = 0.170) and moderately leptokurtic (kurtosis = 3.40, SE = 0.338), indicating a concentration at the lower end of the scale. The majority of respondents reported minimal usage: 92 selected level 2, and 73 selected level 1. Only 17 participants (8.3%) reported frequent or consistent VR use (levels 5–6), suggesting that regular engagement with VR remains limited within the sample. These results reflect early-stage or casual adoption patterns among most users, possibly influenced by access, familiarity, or the novelty of the technology.
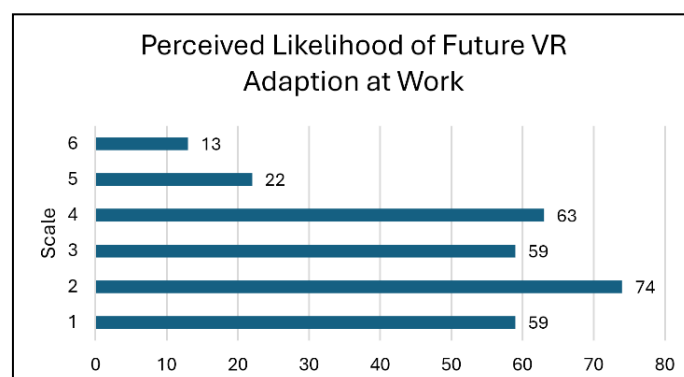
Figure 5

Perceived Likelihood of Future VR Adaption at Work (Edited by the author based on research data)

Participants rated the likelihood of VR adoption in their future work environment on a 6-point scale (1 = "very unlikely" to 6 = "very likely"), with a mean score of 2.84 (SD = 1.41). As shown in Figure 5, responses are moderately dispersed and approximately symmetrical (skewness = 0.40, SE = 0.143), with a slight platykurtic tendency (kurtosis = –0.68, SE = 0.285), suggesting a flatter distribution than the normal curve. Most responses clustered around the mid-range: 74 participants selected level 2, while 63 selected level 4. Equal numbers (n = 59) chose level 1 ("very unlikely") and level 3, indicating overall ambivalence. Only 13 respondents (4.5%) expressed high confidence in future VR integration (level 6). These results reflect cautious optimism but also considerable uncertainty regarding the professional integration of VR technologies.

Usage of VR

Healthcare Purposes	Mean: 1,39 | Std. Deviation: 0,90
Education	Mean: 1,49 | Std. Deviation: 1,06
Work	Mean: 1,62 | Std. Deviation: 1,12
Social Interaction	Mean: 1,88 | Std. Deviation: 1,58
Sports & Fitness	Mean: 1,63 | Std. Deviation: 1,22
Creative Activities	Mean: 1,50 | Std. Deviation: 1,06
Entertainment	Mean: 2,92 | Std. Deviation: 1,86

■ Never ■ Very Rarely ■ Rarely ■ Often ■ Very Often ■ Always
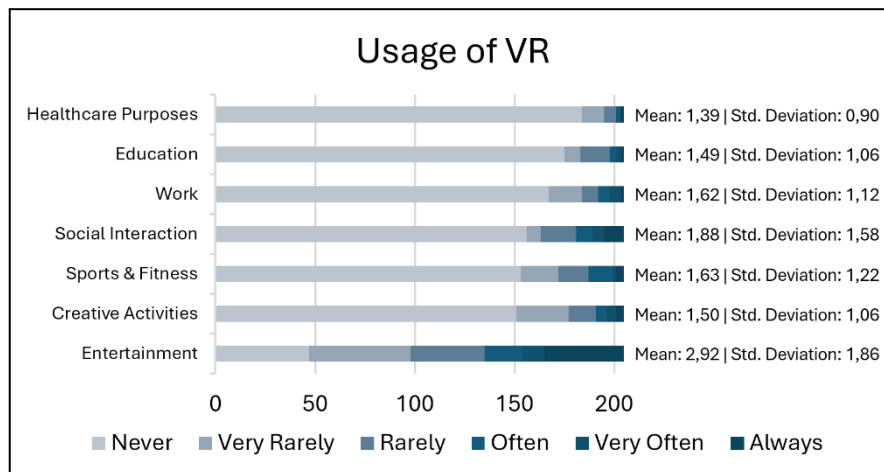
Figure 6

Usage of VR (Edited by the author based on research data)

Participants rated the frequency of VR use across seven domains on a 6-point scale (0 = Never, 5 = Always). As shown in Figure 6, entertainment was by far the most frequent use case (M = 2.92, SD = 1.86), reflecting the dominant role of recreational applications in current VR engagement. The high standard deviation suggests substantial variation, with some users employing VR for entertainment almost daily, while others do so only occasionally. In contrast, all other domains showed considerably lower mean values. Healthcare purposes (M = 1.39, SD = 0.90), education (M = 1.49), and creative activities (M = 1.50) were among the least frequent, indicating minimal integration into users' daily routines. Slightly higher values were recorded for work (M = 1.62), sports and fitness (M = 1.63), and social interaction (M = 1.88), though the latter still fell below the midpoint of the scale.

These patterns suggest that while users may recognize the potential of VR across diverse contexts, in practice its use remains largely limited to entertainment. The

relatively low adoption rates in functional domains may be attributed to content limitations, lack of institutional implementation, or user preferences. Notably, higher variability in domains like social interaction and fitness points to emerging interest, but also uneven access or awareness. Overall, the findings reflect an early-stage adoption landscape where non-entertainment VR applications have yet to reach widespread use.

Figure 7

Frequency of Symptoms Experienced During VR Use (Edited by the author based on research data)

Participants assessed the frequency of ten common symptoms associated with VR exposure on a 6-point scale (0 = Never, 5 = Always). As shown in Figure 7, the overall prevalence of symptoms was low, with all mean values falling between 0.74 and 1.20. This indicates that, on average, most symptoms were experienced rarely or very rarely. The most commonly reported issues were nausea (M = 1.20, SD = 1.40), headaches (M = 1.12, SD = 1.31), neck and shoulder pain (M = 1.10, SD = 1.27), and eye fatigue (M = 1.04, SD = 1.17). These are consistent with symptoms typically linked to cybersickness and prolonged headset use. Their relatively higher standard deviations suggest that while many users experience these symptoms infrequently, a smaller subset may encounter them more regularly or intensely. In contrast, symptoms related to psychological and behavioral effects, such as aggression (M = 0.79), anxiety and stress (M = 0.74), and reduced interest in activities (M = 0.75), were rated as occurring less frequently. Difficulty distinguishing virtual from real environments (M = 0.79) and reduced social interest (M = 0.88) also showed low overall incidence, suggesting minimal psychological

disorientation among the majority of users. The data suggest that while physical symptoms are more prominent than psychological ones, they remain mild in frequency for most respondents. Nonetheless, their presence highlights the need for ergonomic improvements, adaptive session design, and user education on optimal usage practices (e.g., breaks, posture, device calibration) to mitigate discomfort.
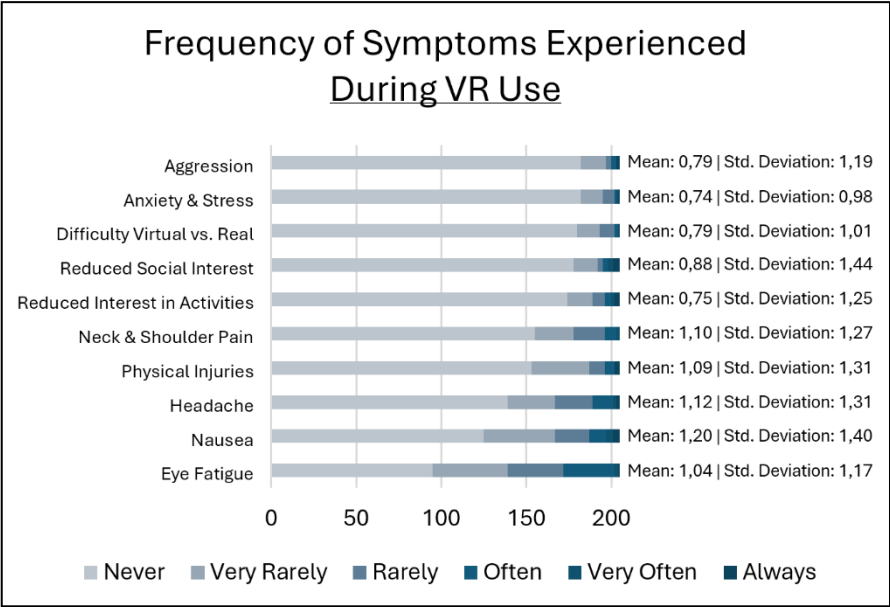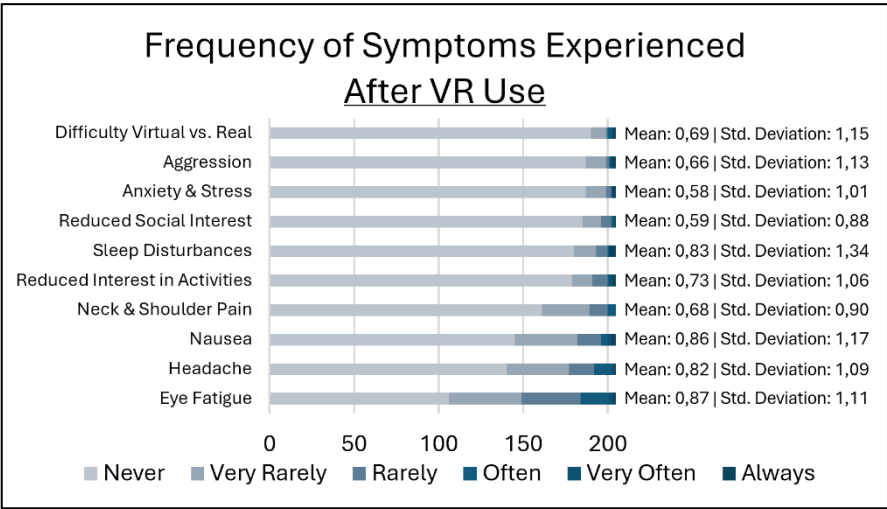

Figure 8

Frequency of Symptoms Experienced After VR Use (Edited by the author based on research data)

Participants rated the frequency of 10 symptoms experienced after VR sessions on a 6-point scale (0 = Never, 5 = Always). As shown in Figure 8, average symptom ratings remained low overall, with all means falling below 1.0, indicating that post-VR symptoms were generally experienced very rarely to rarely. The most frequently reported symptoms were eye fatigue (M = 0.87, SD = 1.11), nausea (M = 0.86, SD = 1.17), and sleep disturbances (M = 0.83, SD = 1.34), suggesting mild physical or cognitive aftereffects for some users. Headache (M = 0.82) and reduced interest in activities (M = 0.73) were also reported with slightly elevated frequency, though still below moderate levels. Psychological and social symptoms, including anxiety and stress (M = 0.58), reduced social interest (M = 0.59), and aggression (M = 0.66), were among the least frequently endorsed. Difficulty distinguishing virtual from real environments (M = 0.69) also remained low, indicating minimal disorientation post-use.

Overall, the data suggest that most participants experienced few adverse effects after VR use. Symptoms were generally infrequent and mild, with a slight tendency toward physical discomfort rather than psychological impact. These findings highlight the relative safety of VR use in typical consumer settings but point to the

importance of monitoring fatigue and recovery, especially with extended or repeated use.

4.3   Relations Between Variables

The analysis revealed several statistically significant correlations ($p < .01$, two-tailed), offering insight into how demographic, educational, and behavioral factors relate to VR use and its associated effects. Educational attainment emerged as a notable predictor of functional VR engagement. Individuals with higher education levels were more likely to use VR for fitness or sports ($r = .226$), for work-related purposes ($r = .188$), and to utilize PC-based VR systems ($r = .227$). Similarly, participants with an IT background showed a positive correlation with PC-based VR usage ($r = .242$), suggesting that both formal education and domain-specific expertise facilitate access to more complex or task-oriented VR applications.

Daily work-related screen time showed moderate to strong positive correlations with several psychological and cognitive difficulties during VR use. Specifically, higher screen time was associated with increased levels of anxiety and stress ($r = .392$), reduced interest in real-world social interactions ($r = .489$), lower motivation for real-life activities ($r = .477$), and difficulty distinguishing between virtual and physical environments ($r = .497$). These findings suggest that high digital workload may intensify cognitive fatigue and reduce the psychological separation between immersive virtual content and everyday experience.

Interestingly, respondents who reported unfamiliarity with VR systems, or indicated not knowing which platform they had used, tended to report significantly fewer adverse symptoms. These participants experienced less nausea ($r = -.309$), eye fatigue ($r = -.414$), and physical discomfort or injuries ($r = -.358$). This likely reflects limited exposure rather than increased resilience, pointing to the cumulative effects of prolonged VR interaction on physical well-being.

In contrast, age showed no significant correlation with any measured variable, indicating that it had no predictive power in the present sample. Gender also showed limited influence: a small negative correlation was observed with VR use for entertainment ($r = -.188$), suggesting marginally higher usage among male respondents. Although the correlation between gender and work-related screen time reached statistical significance ($r = .042$), its effect size was negligible and not meaningful in practical terms.

Taken together, these results indicate that factors such as educational background, digital literacy, and screen time exposure are more strongly associated with patterns of VR use and symptom reporting than demographic characteristics such as age or gender. The findings underscore the need to consider individual lifestyle and professional context when assessing user experiences and risks in immersive environments.

Conclusions

This study examined the physiological and neurological responses associated with virtual reality use, based on self-reported data from a broad user sample. The research was guided by three key questions concerning usage patterns, symptom experience, and the role of demographic and individual factors.

Regarding the first question, it was initially assumed that VR would be used frequently, particularly for entertainment, education, creativity, social interaction, and fitness. The results partially confirmed this: although prior experience with VR was relatively common (70.7%), ownership and regular use were limited. Only 20.7% of respondents owned a VR device, and the average usage frequency was low (M = 2.00 on a 6-point scale). Among usage domains, entertainment was dominant (M = 2.92), while all other purposes, including education, fitness, and work, scored well below the midpoint. These findings indicate that despite growing familiarity, practical VR adoption remains largely confined to leisure contexts.

In relation to the second question, it was expected that users would report symptoms such as nausea, eye strain, headaches, dizziness, and anxiety, due to sensory conflicts and cognitive load. The data confirmed the presence of these effects, but at generally low levels. Symptoms experienced during VR sessions had low average ratings (M = 0.74–1.20), with nausea, headaches, and neck/shoulder pain being most common. Post-use symptoms were even less frequent (all means < 1.0), with eye fatigue, nausea, and sleep disturbances being most notable. Psychological symptoms such as anxiety, aggression, and depersonalization occurred rarely. Thus, while adverse effects are present, they are typically mild and infrequent.

As for the third question, it was hypothesized that age and gender would influence both usage frequency and symptom severity, anticipating higher usage among younger males, and increased symptoms among females. However, the data did not support these assumptions. Age showed no significant correlation with any variable, and gender had only a weak, negative association with VR usage for entertainment. Instead, stronger predictive relationships were observed with educational attainment, IT background, and daily screen exposure. Specifically, higher education and technical expertise were linked to increased functional VR use, while prolonged screen time correlated with elevated reports of anxiety, disorientation, and diminished motivation for real-world activity. These results suggest that usage patterns and vulnerability to symptoms are shaped more by digital lifestyle and cognitive load than by demographic identity alone.

Overall, the findings align with existing literature on cybersickness and attentional fatigue, underscoring the role of sensory mismatch and extended screen engagement in driving discomfort. Although self-report data have inherent limitations, the consistency between participant responses and prior studies supports the reliability of observed trends. Future research should employ objective measurements (e.g., EEG, heart rate, eye-tracking) and compare user groups based on sensitivity and prior experience. It would also be valuable to examine whether repeated VR use leads to adaptation or increasing mental and physical strain over time.

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Rethinking Cybersecurity: How Serverless Architecture Redefines Risk Management

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Abstract: Serverless computing is revolutionizing cybersecurity risk management with the introduction of new features—ephemeral functions, event-driven execution, and shared responsibility—that upend traditional security practices. In serverless environments, individual functions execute for a brief time to complete targeted tasks before they become non-existent, meaning security controls must quickly react to protect these fleeting processes rather than watch over static, long-lived systems. Additionally, since serverless applications react dynamically to events like user behavior or data triggers, they bring new vulnerabilities that require innovative threat detection and mitigation techniques. The shared responsibility model further complicates the matter by dividing security roles between cloud providers who secure the underlying infrastructure, and organizations who must protect and manage their own code and configurations. This work explores these singular attributes to illustrate how conventional security methodologies need to be reassessed and how more dynamic, recent models can protect against the novel types of attacks native to this adaptive computing paradigm.

Keywords: Serverless computing, serverless security, cybersecurity, cloud technologies

1 Introduction

Serverless computing is a cloud architecture model that provides a new paradigm in which developers write code without provisioning or managing the underlying infrastructure. The paradigm conceals the complexity of server management, resource scaling, and provisioning and allows organizations to deploy applications instantly and scale them dynamically according to demand. Major cloud computing service providers, such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud, have introduced serverless computing platforms in the guise of AWS Lambda, Azure Functions, and Google Cloud Functions, which are gaining traction rapidly due to their ability to improve cost savings and performance. As companies increasingly adopt serverless models to automate and reduce overhead, it is important to take into account the security ramifications of this emerging architecture.

While serverless computing benefits are obvious, it also introduces new cybersecurity challenges that cannot be addressed by conventional security tools. In conventional systems, where the security controls are designed to protect long-running, static infrastructure and applications, serverless environments consist of short-lived, event-driven functions that are ephemeral and dynamically scaled. Such characteristics introduce new vulnerabilities in areas such as monitoring, data integrity, and access control. In addition, the shared responsibility between cloud providers in serverless architecture, where cloud providers are responsible for securing the underlying infrastructure while organizations must secure their applications and configurations, makes the security responsibilities harder to demarcate. With serverless environments changing increasingly on a daily basis, today's cybersecurity best practices that have been optimized for more conventional on-premises and cloud architecture are not adequate to address these emerging risks.

This paper discusses the cybersecurity challenges introduced by serverless architectures and argues that traditional risk management practices must be re-evaluated. By discussing the distinctive features of serverless computing—ephemeral functions, event-driven execution, dynamic scaling, and shared responsibility model—this paper aims to provide an end-to-end perspective on why existing security measures are insufficient. Besides, the goal is to identify and propose new, agile risk management techniques that can be adopted to protect organizations from the emerging threats of serverless environments. Through this research, the paper hopes to contribute to the current debate regarding how cybersecurity practices must evolve to cope with the rapid pace of development in cloud computing technologies.

2   What is Serverless Computing?

Serverless computing is a model of cloud computing whereby the cloud providers automatically take care of the infrastructure needed to run applications so that developers need not worry about server provisioning, scaling, and server maintenance. Under serverless architecture, the developers code which runs as a function of specific events or triggers rather than worrying about the life cycle of an application or system. The term "serverless" may be misunderstood as suggesting an absence of servers, but in reality, technically servers are used to execute the code; instead, the only variation is that the developers no longer have to care about the underlying hardware or infrastructure. All the issues related to management are taken care of by the cloud provider, and users only pay for actually consumed resources used in executing the code, rather than server running time.

Among the features of serverless computing are ephemeral functions. They are temporary and serve to conduct a specific job once they are presented with an event and proceed with termination as soon as they have completed the task. By being transient in nature, serverless functions prove extremely resource-optimized in usage since resources get used only as long as it takes for a function to run. Unlike legacy long-running processes, there is no requirement for servers to remain in operation all the time, which can translate into cost savings.

Serverless architectures are naturally event-driven. This implies that function execution is initiated by events, like an HTTP request, a file upload to cloud storage, or a database change. The system dynamically responds to such triggers by executing the corresponding function based on the event. This method facilitates live, scalable response to user interaction or system changes without constantly monitoring or manually responding to such interaction. Event-driven computing facilitates simple addition of flexibility with minimal overhead in the implementation of complex workflows and integrations.

Serverless platforms scale applications automatically as needed. When invoking a function, the cloud provider provisions adequate resources to execute the function. When there is high traffic or demand, additional instances of the function are created to serve the load. When there is low demand, resources are de-allocated to avoid any wastage of resources. This dynamic scaling model helps organizations achieve high performance and cost-effectiveness in the sense that they do not pay for any computing resources except when running.

Several major cloud providers offer serverless computing platforms, each of which has a different feature and capability:

- AWS Lambda is one of the best-known serverless platforms on which developers can execute code in response to a wide range of triggers, from data changes in Amazon S3 to HTTP requests via Amazon API Gateway or DynamoDB table updates. Developers pay only for compute time consumed in executing their functions on AWS Lambda, with events automatically scaling by frequency (Amazon Web Services, n.d.-a), (Amazon Web Services, n.d.-b).

- Similar to AWS Lambda, Google Cloud Functions is a serverless environment where code can be run by reacting to events such as file uploads, HTTP requests, or messages from other Google Cloud services like Pub/Sub. Google Cloud Functions shares tight integration with other Google Cloud services, and therefore it would be a viable choice for firms already established within the Google framework (Google, n.d.).

- Microsoft's Azure Functions is another serverless platform where developers can run code that executes as a consequence of events from Azure resources such as Blob Storage, Event Hubs, or HTTP requests. Azure Functions also provides multiple hosting plans for different workloads with both consumption-based and dedicated resource options (Microsoft, n.d.).

These platforms are designed to simplify application development and deployment by abstracting out infrastructure concerns so developers can focus on crafting code that responds to specific triggers in a scalable and cost-effective manner.

3 Traditional Cybersecurity and Its Limitations

Traditional cybersecurity models were designed with the idea of static, long-lived systems where resources are allocated to specific tasks for extended periods of time. In these settings, security controls are designed to protect against attacks on infrastructure components, such as servers, networks, and databases, that are intended to run all the time. Common elements of these types of systems include firewalls, intrusion detection systems (IDS), and antivirus software that are designed to protect well-defined, static environments.

For example, firewalls are configured to control incoming and outgoing traffic based on preconfigured rules, with the assumption that the network and the applications it supports are relatively static. Similarly, intrusion detection systems (IDS) monitor network traffic for signs of malicious behavior, based on the assumption that threats will manifest in detectable patterns and can be discovered through ongoing monitoring. This model aligns well with traditional, monolithic apps where the infrastructure below does not undergo dynamic change and risk can be addressed by layered security controls.

Risk in classical cybersecurity is based on a relatively static threat model. In this model, risks are contemplated based on a stable environment—always-on servers with known attack vectors and expected behavior. Security strategy is one of protecting these long-lived systems from attack that could exploit known weaknesses, such as unauthorized access, data theft, or denial-of-service attacks. Risk analysis puts a high priority on perimeter protection, endpoint security, and access control management.

In contrast, serverless computing is a dynamic environment where threats can quickly evolve. Serverless functions, as ephemeral and event-driven entities, don't conform to traditional models of perpetual operation. Instead of maintaining concerns over a running system, security analyses must look into how to secure code, data, and interactions triggered on specific events. This calls for a shift away from the static risk model to one that can keep pace with highly dynamic, unpredictable behavioral patterns that emerge with the instantaneous scaling and transient nature of serverless systems. Threats in this environment may arise from atypical sources or in unpredictable manners and therefore might be harder to assess and mitigate with traditional approaches.

The conventional security tools were built to address the specific risks associated with static environments, where the infrastructure, applications, and resources are relatively stable and predictable. Some of the most common tools include:

- Firewalls are one of the most fundamental security controls in traditional environments. Firewalls enforce network traffic policies, either allowing or blocking data packets based on IP addresses, protocols, and port numbers. While firewalls remain important in a serverless environment, they are not sufficient on their own because serverless functions are event-driven and do not require persistent inbound or outbound network connections.

- IDS and IPS try to detect and prevent malicious activity by inspecting network traffic for suspicious behavior or known attack signatures. These products utilize signature-based detection, anomaly detection, or heuristic analysis, and function well for established systems with predictable traffic flows. However, in serverless, where functions can have brief lifetimes and scale in unpredictable ways, these tools are not able to give visibility for ephemeral workloads or real-time threat detection (Abdulganiyu et al., 2023).

- Antivirus software existed to identify and remove threats in the form of viruses, malware, and other malicious code on long-lived systems. They are all focused primarily on detecting signatures of known malware and file system scanning for vulnerabilities. With the use of serverless architecture, focus is shifted from endpoint protection at an individual level to protection of the execution environment and ensuring that dynamically executed functions are not exposing vulnerabilities. Antivirus software is less effective because serverless functions do not always have a persistent filesystem and may live for the duration of the function call.

- Legacy systems rely on user authentication, authorization, and access control mechanisms (e.g., role-based access control or multi-factor authentication) to manage who is allowed to access resources. In serverless computing, although IAM remains core, dynamic scaling and the event-driven nature of serverless require more fine-grained and adaptive controls, e.g., fine-grained permissions that have the ability to secure the execution of individual functions or resources (Singh et al., 2023).

Traditional cybersecurity controls and practices have proven to be effective in safeguarding against threats in static, long-lived systems. However, the dynamic, short-lived nature of serverless computing creates significant gaps in these security models, since they fail to account for the quick, event-driven execution of functions. As serverless computing continues to evolve, the limitations of these traditional tools become increasingly apparent as new, dynamic approaches to cybersecurity are created that can more successfully protect these dynamic environments.

4 How Serverless Computing Redefines Risk

In traditional computing environments, applications run as long-lived, persistent processes that maintain state over time. Security controls for these environments are designed to monitor and protect these persistent systems from ongoing threats, usually through continuous scanning and endpoint protection. In serverless computing, however, the ephemeral function model is a serious threat. These short-lived, stateless functions are created, executed, and destroyed in rapid succession. A typical serverless function may only have a few milliseconds or seconds to live before it terminates. Because serverless functions are so short-lived, traditional security tools that work based on constant monitoring and inspection of long-lived processes are poorly equipped to respond to threats in real-time. An attacker could take advantage of a vulnerability in the short lifespan that a function is alive and evade traditional security systems that otherwise would be able to detect malicious behavior in a static system (Lynn et al., 2017).

Serverless functions have no lasting states or lengthy-lived data, which complicates it to detect an attacker's activity in the system. That means typical detection and logging facilities may not know if a serverless function is compromised or experiencing an attack. For example, if an attacker can inject dangerous code into a running ephemeral function, tracing out such an attack after the function has already ended becomes highly unlikely. Stateless ephemeral functions are typically stateless, i.e., they do not retain context of previous execution. While this design provides flexibility and scalability, it also limits the ability to trace or correlate attacks between different instances of a function. Since they do not have a "memory" of previous happenings, attackers at times are able to remain unnoticed between consecutive function calls. In order to safeguard transitory functions, security controls must be fast, agile, and operating within the brief execution windows such functions offer. These can include real-time threat analysis, function-level monitoring, and response capability that prevents security holes from being opened in such transient settings.

Serverless architecture is naturally event-driven, where functions are invoked by specific events, such as an HTTP request, a change to a cloud storage bucket, or a message in a queue. While this event-driven model introduces flexibility and scalability, it introduces new vulnerabilities as well. Since serverless functions execute in response to external triggers, attackers can likely utilize these triggers to launch attacks. For example, an attacker can form a malicious request or input specifically designed to exploit a bug in the code of the called function. Traditional security models that rely on continuous, static observation of systems may not take into account the dynamic nature of event-driven calls, and thus functions are exposed when they are called by malicious or malformed events.

In a serverless system, multiple events can trigger multiple functions that interact with each other. Without isolation, an attacker might exploit the interaction between

these functions. For instance, if a function writes data to a database and another reads data from the database, a malicious event can taint the data or establish unnecessary interactions between these functions. Event-oriented architectures make it more difficult to correlate between functions and identify malicious behavior. A series of what appears to be innocuous events could be leveraged by an attacker so that collectively, they may be damaging. These spread-out attacks then move beyond what traditional threat-detection systems, usually pattern-finding in nature within a particular universe, are designed to detect. Threat detection in a world of events requires sophisticated monitoring software that can watch events in real time, correlate them between functions, and recognize any abnormal or suspicious activity that deviates from the anticipated patterns of events.

Serverless computing platforms are designed to dynamically scale based on demand, allowing organizations to easily add or delete function instances based on traffic surges or declines. While this dynamic scaling capability is one of the most important benefits of serverless architecture, it also offers some security challenges. Because serverless functions automatically scale up and down based on event load, they can inadvertently bring new areas of attack surface. For instance, during traffic spikes, an increased number of serverless functions may lead to an increased number of entry points that attackers can take advantage of. Traditional security controls, such as firewalls or intrusion detection systems, may struggle to keep up with severely fluctuating environments and variable resources.

Demand-driven automated scaling can also lead to resource misuse. When an attacker sends a lot of requests, it may trigger the scaling activity, which may deluge the system and even lead to service downtime (denial of service). The scaling may also reveal public unnecessary or incorrectly configured services, which become possible points of entry for attackers. Classical security models rely on pre-set settings, static network addresses, and deterministic workloads. Dynamic scaling serverless environments, by contrast, create a context in which resources are constantly changing in amount, location, and configuration. It is difficult to enforce uniform security policies upon a changing environment.

To counter dynamic scaling risks, companies must deploy scalable, adaptable, and dynamic security controls alongside the application. Such controls could be real-time traffic monitoring, dynamic scaling triggers that are set through automation, and fine-grained security policy which can be adapted dynamically whenever the system is scaling. In a serverless environment, the shared responsibility model divides security duties between the customer and the cloud provider. While cloud providers manage the underlying infrastructure, such as the servers, networking, The security of the infrastructure is guaranteed by the cloud provider, including the servers, the data centers, and the serverless platform. The providers often include robust security controls, including encryption, IAM (Identity and Access Management), and access control, to allow customers to secure their functions and data. However, the security controls are contingent upon the customer's configurations and practices used for them to function.

While the infrastructure is kept secure by the cloud provider, the customer must keep their code, configurations, and application logic secure. This includes IAM role and permission management, event trigger configuration, function endpoint security, and encryption of sensitive data. Since serverless environments can scale automatically and involve event-driven interactions, customers must maintain strict control over the security of the functions themselves. The shared responsibility model is a double-edged sword. On the one hand, it encourages greater flexibility. On the other hand, it places great responsibility on organizations to configure and lock down their serverless environments properly. Misconfigurations such as too liberal access controls or inadequate logging leave organizations vulnerable to severe threats. To preclude these threats, organizations must create extensive security policies that set clearly the division of responsibility between the customer and the cloud provider. Regular security audits, security testing automation, and adherence to best practices are crucial to ensuring that the division of responsibility of security is being adequately fulfilled.

5 The Need for Agile Cybersecurity Strategies

As increasingly more organizations turn to serverless computing, the need for adaptive security models has never been more acute. Static environment-based security models, though, are not well-positioned to keep up with the dynamic and fleeting nature of serverless environments. Serverless functions are transient and event-driven, and thus there is a need for security to respond quickly to changing conditions. An adaptive security model is one that dynamically adapts with the system, continuously keeping an eye on the environment and adjusting security controls accordingly. With serverless architecture, the randomness and volume of workloads make it a necessity to have a more fluid security strategy. That is, a departure from traditional perimeter defense approaches and embracing continuous monitoring, rapid threat detection, and dynamic response capabilities. This type of response enables security controls to scale and evolve with the serverless application, reacting to danger in real time as opposed to static, preconfigured expectations. Adaptive security frameworks enable businesses to remain ahead of changing threats and new attack surfaces brought about by the serverless paradigm. Automation is at the core of serverless environment security due to the speed and volume at which serverless functions operate. In a traditional setup, manual intervention to patch vulnerabilities, observe system health, and neutralize threats may be effective. However, the transient lifecycle of serverless functions—coupled with dynamic scaling—makes it unfeasible to implement manual security components. Security automation provides the tools to detect, respond to, and neutralize threats in real-time.

Automation can be used in various key domains of serverless security:

- Automated solutions can scan for vulnerabilities on a continuous basis, monitor for suspicious activity, and identify possible threats. In event-driven architectures, security solutions can trigger responses as soon as suspicious activity is detected, preventing further damage.

- Automated incident response mechanisms can quickly quarantine or disable impacted functions, reducing response time and minimizing damage risk. For example, in case of malicious payload, automated security controls can halt further execution of the impacted function or roll back to a known good state.

- Automation also guarantees serverless applications conform to security best practices and regulatory requirements for compliance. Automated security audits can run continuously on code deployments, configurations, and access policies so that any divergence from compliance standards is detected and fixed in real-time.

Automating such critical security procedures allows organizations to keep a high level of protection in a highly dynamic environment while minimizing human error and operational overhead.

Two modern security models—Zero Trust and micro-segmentation—are particularly relevant in the serverless environment. Both are designed to address the challenges posed by dynamic, distributed environments, where traditional perimeter-based security falls short.

- Zero Trust security architecture is built on the "never trust, always verify" tenet. Under a Zero Trust architecture, no internal or external entity can ever be trusted implicitly. All access requests, internal to the organization's network or external, must be authenticated, authorized, and validated at all times. This is a perfect approach for serverless architectures, with functions called by many different sources and not bound to a network or resource pool (Rose et al., 2020).

- Zero Trust in the serverless case means every function being individually authenticated and authorized before execution. This can be achieved by imposing robust identity and access management (IAM) controls that restrict only the legitimate code to execute, regardless of where it is invoked. With the use of Zero Trust, organizations can contain the blast radius of any compromise such that even if a single function has been compromised, the attack cannot spread throughout the system (Rose et al., 2020).

- Micro-segmentation is segmenting the network and resources into isolated, small segments where security policies are applied at a granular level. In serverless architecture, it implies that each function or service is an isolated entity with its own security policies. Micro-segmentation minimizes the lateral movement within the application, where if an attacker breaks into one function, it is difficult to reach the rest of the application (Sheikh et al., 2021).

- Micro-segmentation in the serverless model ensures that security controls are being applied at each individual function rather than relying on the perimeter defenses. It provides more fine-grained access control and mitigates the effect that could be caused by an attack (Sheikh et al., 2021).

In adaptive environments like serverless environments, threat intelligence has a leading position in anticipatory security. Threat intelligence includes the gathering of information, its analysis, and use regarding potential threats and weaknesses. It can be used to predict and divert attacks before the resulting damage is inflicted. As serverless computing evolves quickly and the threat landscape evolves continuously, organizations must refresh their threat intelligence constantly in a bid to outsmart attackers.

With more sophisticated cyberattacks targeting serverless infrastructure, predictive risk management is not optional. Integrating threat intelligence into serverless security operations helps organizations identify patterns of behavior that can indicate an impending breach, even before one happens. Threat intelligence feeds can, for instance, provide real-time intelligence about changing attack vectors, which can help security systems automatically update detection mechanisms and adapt to changing threats.

Moreover, incorporating threat intelligence into security automation platforms allows for faster response times. For example, when a vulnerability is discovered in a popular serverless framework, security systems may automatically patch or reconfigure access controls ahead of time to prevent exploitation before the attack has registered its impact.

Conclusion

As serverless computing continues to transform application development and deployment, there is a need to acknowledge the unique cybersecurity risks that accompany this revolution. The event-driven, ephemeral nature of serverless functions in conjunction with auto-scaling and event-driven architectures defies the traditional security paradigms, which were designed for static, long-lived systems. The shared responsibility model only compounds this complexity, dividing security responsibility between the cloud providers and organizations, both having their respective roles to play.

To address these challenges, organizations must adopt agile and adaptive security strategies that can keep up with the rapidly changing serverless environments. This includes leveraging automation for threat detection and response, embracing new security models like Zero Trust and micro-segmentation, and integrating real-time threat intelligence for proactive risk management. It is only by knowing the particular vulnerabilities of serverless computing and taking appropriate, adaptive security steps that organizations can successfully protect their applications and data in this new environment.

Finally, serverless computing has huge benefits of flexibility, scalability, and cost-effectiveness. But at the cost of having to redesign and rethink cybersecurity processes to take into account the requirements of this rapidly changing and fast-paced technology. As increasing numbers of companies adopt serverless models, it is important that cybersecurity approaches move in tandem so security is never an afterthought, but embedded in serverless computing.

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Strengthening the Position of Farmers in the Dairy Value Chain in Light of the EU Common Agricultural Policy (CAP): Insights from Albania

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Abstract This article analyzes the position of Albanian dairy farmers within the value chain by assessing their power in price negotiations, access to markets, and integration with processors and retailers. Using the framework of the EU Common Agricultural Policy (CAP), which aims to strengthen farmers' positions in the value chain, the study evaluates how Albanian dairy farmers align with these objectives and identifies key challenges. The analysis highlights structural weaknesses, such as fragmented production, weak bargaining power, and limited access to financial and technological resources, which hinder competitiveness. The study aims to identify ways to empower farmers within the dairy value chain by leveraging policies and programs provided by the European Union, particularly the "Farm to Fork" Strategy. Through a comprehensive approach implemented in the framework of the project ""Farm to Fork Academy for Green Western Balkan-our common European future" financed by EU, involving focus group discussions, interviews with key stakeholders, and secondary data analysis, the study provides an in-depth assessment of the current state of the sector and the positioning of farmers within the value chain. Furthermore, it offers concrete recommendations to enhance farmer cooperation, improve quality standards, and implement fair trading mechanisms. The study suggests that government and international partners should support investments in infrastructure and technology, including the establishment of milk collection centers and advanced dairy farm equipment. Additionally, fostering farmer cooperatives would strengthen their bargaining power and improve access to financing and markets. If the right policies are implemented with full support from the EU and national stakeholders, the dairy sector has the potential to increase rural incomes, enhance the quality of life in rural areas, and contribute to overall economic development.

Recommendations focus on policies that could enhance farmers' roles in the value chain, including cooperatives, improved market access, and better financial instruments.

Keywords: agriculture, dairy sector, value chain, Albania

1 Introduction

Albania's agriculture remains one of the country's principal economic pillars, contributing around 18% to the Gross Domestic Product (GDP) and providing employment for a significant portion of the rural population. The agricultural landscape in Albania is characterized by approximately 350,000 farms with an average farm size of 1.2 hectares. These farms are often highly fragmented—divided into three to five separate parcels—which poses serious challenges for mechanization, operational efficiency, and overall production effectiveness. Despite the inherent challenges due to fragmentation and small-scale production, Albania's agricultural sector has experienced notable improvements in recent years. This progress is largely attributed to both internal investments and robust international support, particularly through European Union (EU) initiatives such as the IPARD program. These efforts have resulted in better infrastructure, enhanced access to modern technology, and improved market connectivity. The gradual shift from traditional production methods toward more sustainable, modern practices is opening new avenues for increasing productivity and competitiveness in both domestic and export markets. Within this broader agricultural context, dairy sector stand out due to the significant impact on rural incomes and economic development: The dairy sector is a key contributor to Albania's livestock production. It is critical for the direct income of rural families and for ensuring local food security. However, it faces numerous challenges such as low average yields, inadequate cold storage facilities, and insufficient organization among farmers.

The government's focus on strengthening the position of farmers in the value chain is a central element of the Common Agricultural Policy (PPB) for 2023–2027, particularly through Objective 3, which emphasizes enhancing negotiating power, boosting competitiveness, and promoting better organization among farmers. This policy framework advocates for improved synergy within the value chain, market orientation of production, and increased transparency, all of which are crucial for enabling farmers to secure fair prices and sustainable incomes. The overarching goal of this paper is to identify the challenges that hinder dairy farmers from positioning themselves more effectively within the value chain. It also aims to evaluate the opportunities offered by EU policies and funding mechanisms and to propose specific interventions that bolster the technological and negotiating capacities of these producers.

The Common Agricultural Policy (CAP) of the European Union (EU) for 2023-2027 outlines several key objectives, including Objective 3: "Strengthening farmer position in food chain" [2]. This objective focuses on creating conditions that enable farmers to enhance their bargaining power, increase competitiveness, and improve organization in their interactions with processors, traders, and exporters. The intervention measures under this objective are linked with: a) strengthening cooperation among farmers, b) enhancing synergies within value chains, c) supporting the development of market driven production models, d) fostering research and innovation, e) increasing market transparency, and, f) ensuring effective mechanisms against unfair trading practices.

2   Objectives and Methodology

The study is structured around several specific objectives: To evaluate the production capacity, organizational structure, and main challenges of dairy farmers.

- To investigate factors affecting farmers' bargaining power—including input costs, quality standards, and group organization—and understand how these affect overall profitability

- To examine how the "Strengthening the Position of Farmers in the Food Value Chain" objective of the Common Agriculture Policy (CAP) can be practically implemented, especially in the context of fragmented farm structures in Albania.

- To provide a basis for targeted recommendations to address main challenges faced by the dairy value chain stakeholders.

This study adopted a sequential, mixed-methods design that wove together qualitative fieldwork and quantitative secondary-data analysis to capture both the lived experience of Albanian dairy farmers and the structural forces that shape their bargaining position. We began with a scoping exercise in early 2024, mapping all relevant actors—from smallholders and collectors to processors, input suppliers, and policy-makers—and refining the research questions through informal conversations and a review of national policy documents. The exercise produced a stakeholder matrix that later guided purposeful sampling in the field.

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Primary data were gathered between September and December 2024. Thirty five semi-structured interviews (average length one hour) were conducted with 20 farmers of varying herd sizes, five processors, three input suppliers, two Ministry of Agriculture and Rural Development officials and five experts .To explore group dynamics and surface shared concerns, we organized three focus-group discussions in Tiranë, Lushnjë and Berat, with participation of around 30 participants in total stratified by farm size and gender. In addition, a Workshop at national level brought producer organizations, processors' associations, extension officers, NGOs and EU-project staff to the same table, allowing us to test preliminary findings and discuss the feasibility of proposed interventions. All sessions were recorded with informed consent, transcribed verbatim, anonymised and stored in an encrypted repository that also contains our reflexive field notes.

Parallel to the fieldwork, we compiled a longitudinal quantitative dataset that merges INSTAT agricultural statistics (2000-2023), Ministry of Agriculture and Rural Development subsidy records (2019-2024) and international sources such as the FAO, World Bank and EU Market Observatory. We also assembled a policy corpus covering the CAP Strategic Plan 2023-27, the Unfair Trading Practices Directive, IPARD III guidelines and key national support schemes (e.g., Albanian Governments :Decrees VKM 130/2024 and VKM 581/2024).

Quantitative insights were merged in a SWOT matrix that stakeholders scored for likelihood and impact during a feedback workshop, helping to prioritize strategic options. Finally, triangulation across data types and actor groups ensured that divergent perspectives were reconciled; any anomalies were followed up through four short telephone calls with the relevant respondents.

Key issues discussed during focus groups

For the value chain analysis of the dairy sector, a list of semi-structured questions was developed to identify the key challenges and opportunities influencing the performance of farmers and other stakeholders, with a particular focus on farmer's position in the value chain. Key questions that guided this process include the following:

1. What are the main challenges confronting farmers in the value chain?
2. How can farmers strengthen their position in the value chain to add value to their products?
3. Is it feasible for farmers to negotiate better conditions with other value chain actors, particularly regarding pricing and production?
4. Is it realistic for farmers to influence decision-making within the value chain regarding the value of the product?
5.

The methodological steps followed are detailed in the Table 1

Phase	Activity	Purpose	Main Outputs
1	**Scoping & stakeholder mapping**	Identify key actor categories (farmers, processors, collectors, input dealers, policy-makers) and refine research questions.	Stakeholder matrix; interview & focus-group guides.
2	**Primary data collection** **• Semi-structured interviews** **• Focus groups** **• Consultative meetings**	Elicit first-hand perceptions of constraints, opportunities, and power relations.	28 interview transcripts; 3 focus-group recordings; 5 consultative-meeting minutes.
3	**Secondary-data compilation**	Assemble time-series on herd size, milk output, prices, subsidies, and policy measures from INSTAT, MARD, EU, FAO, and World Bank sources.	Harmonized dataset (2000-2024); policy document library.
4	**Analytical synthesis** • Descriptive statistics • Thematic coding • SWOT analysis	Quantify performance trends; distil cross-cutting themes; assess strengths, weaknesses, opportunities, threats.	Value-chain map; SWOT matrix; evidence tables.
5	**Triangulation & validation**	Cross-check findings across data types and stakeholder groups; present preliminaries in a feedback workshop.	Revised findings; consensual policy recommendations.

Table 1
Research Design and Sequence

3 Limitations of the study

Despite incorporating both primary and secondary data, the study has several limitations. The main challenges include the lack of available statistics for some indicators and the absence of recent data for others. Additionally, the interviews and focus group discussions were based on an indicative sample, which introduces a margin of error in the collected data. Furthermore, some stakeholders were unavailable for direct interviews, affecting the depth of information gathered. To mitigate these limitations, a complementary analysis of primary and secondary data was conducted.

4 Literature Review

The food value chain plays a crucial role in determining the economic and social sustainability of agricultural sectors worldwide. Understanding farmers' positions within this chain is essential to improving their market access, bargaining power, and profitability. In the context of Albania, the dairy value chain holds significant importance due to its contribution to rural livelihoods and national food security.

The food value chain encompasses all activities involved in the production, processing, distribution, and consumption of food products. According to Kaplinsky and Morris (2001), a value chain perspective helps identify key actors, their relationships, and value-added activities at each stage. Porter (1985) highlights the importance of competitiveness and efficiency within value chains, emphasizing the need for upgrading strategies.

Studies by Gereffi et al. (2005) distinguish between producer-driven and buyer-driven value chains, which are critical in understanding power asymmetries in agricultural markets. The food value chain in developing countries often suffers from inefficiencies related to infrastructure, financial constraints, and lack of market linkages (Trienekens, 2011). In Albania, similar challenges affect the agrifood sector, requiring policy interventions to enhance competitiveness and sustainability (FAO, 2019).

Farmers' positions in the food value chain are influenced by factors such as access to inputs, market power, institutional support, and bargaining capabilities. Studies by Barrett et al. (2010) and Swinnen and Maertens (2007) suggest that smallholder farmers often face disadvantages in global value chains due to limited access to technology, finance, and information.

In Albania, research indicates that farmers struggle with low bargaining power and are often price takers due to fragmented production systems and weak cooperative structures (World Bank, 2020). Strengthening farmers' roles through collective

action, contract farming, and value chain integration has been proposed as a solution to enhance their market participation (Gellynck & Kühne, 2008).

Market power :The food supply chain in the EU is characterized by high levels of concentration among retailers and processors, leading to asymmetries in market power. Research by Hendrickson et al. (2018) highlights the challenges that farmers face when negotiating prices due to the dominance of large supermarkets and agribusiness corporations. The EU's response includes competition law enforcement, aiming to prevent monopolistic behaviors that undermine farmers' profitability (Bonanno & Lopez, 2014).

Another crucial aspect of EU policy is price transparency. The EU Market Observatory for agricultural markets provides farmers with real-time data on market prices and trends, improving their ability to make informed production and marketing decisions (European Commission, 2022). Transparency initiatives such as these are linked to reduced price volatility and better income predictability for farmers (Tothova, 2011).

5   EU Policy Framework

 European Union (EU) has established a comprehensive policy framework aimed at improving farmers' positions within the food value chain. These policies focus on increasing transparency, strengthening market power, and ensuring fairer distribution of value. The Common Agricultural Policy (CAP), competition law, and specific legislative measures such as the Unfair Trading Practices (UTP) Directive play a crucial role in shaping the dynamics of agricultural markets. The EU's Common Agricultural Policy (CAP) serves as the cornerstone of agricultural policy in Europe, aiming to ensure fair incomes for farmers, food security, and rural development (European Commission, 2021). The CAP's latest reforms emphasize market orientation, sustainability, and direct support schemes to enhance farmers' economic resilience.

One of the key components of the CAP is the strengthening of Producer Organizations (POs) and Cooperatives, which enable farmers to consolidate their bargaining power in negotiations with processors and retailers (Swinnen, 2015). Moreover, CAP reforms promote risk management tools, including insurance schemes and income stabilization mechanisms, to support farmers against price volatility and external shocks (Matthews, 2018).

The EU has also implemented the Unfair Trading Practices (UTP) Directive (EU Directive 2019/633), which addresses power imbalances in the food supply chain. The directive prohibits unfair practices such as late payments, unilateral contract changes, and last-minute order cancellations, thereby ensuring fairer treatment for

farmers (European Commission, 2020). Studies indicate that such measures significantly improve farmers' negotiating positions and income stability (Crespi & Saitone, 2019).

6 Current Situation in dairy sector

The dairy sector is a cornerstone of Albania's agricultural system and plays a crucial role in both local food consumption and export potential. Livestock production—notably milk and meat—constitutes a major component of the country's agro-industrial chain, with dairy products representing an essential element of the national food supply. According to unpublished data from the Ministry of Agriculture and Rural Development, the livestock segment contributes around 45% of the overall value of Albanian agriculture.

Over the past decades, there has been a significant decline in the number of livestock. Data covering the period from 2000 to 2023 indicate a cumulative reduction of approximately 48% for cattle, 30% for sheep, and 36% for goats. Even when focusing on the more recent period (2019–2023), the declines remain considerable: cattle numbers fell by about 27%, sheep by 20%, and goats by 24%. These trends underscore the urgent need for targeted interventions to address the challenges threatening the sustainability of livestock production.

Milk production in Albania has experienced both significant growth and notable decline over the years. From 1990 to 1996, total milk production nearly doubled—from 517,000 tons to 1,044,000 tons—reflecting favorable conditions and improvements in agricultural practices during that period. The production peaked at 1,156,000 tons in 2017, but thereafter it began to decline, reaching 901,000 tons by 2023 (a reduction of approximately 22%). Breaking down the numbers by animal type, cattle milk dropped by about 22%, while milk production from sheep and goats decreased by roughly 26% and 20% respectively.

Despite the decline in total production volumes, there is a positive trend in milk yield per animal. The average yield per cow increased substantially—from 1,398 liters in 1990 to 3,157 liters in 2023, which represents an improvement of over 125%. This enhancement in productivity is more pronounced in larger farms that benefit from modern technologies and improved management practices, although small-scale farms still struggle with limited access to such advancements. Milk production by category during 1990-2023 is analysed in the following table

Category	1990	1996	2017	2022	2023	Change in %
Cows	421,000	895,000	983,000	825,000	765,000	-22.15%
Sheep	44,000	70,000	87,000	69,000	64,400	-25.98%
Goats	52,000	79,000	87,000	76,000	70,000	-19.54%
Total	517,000	1,044,000	1,156,000	970,000	901,000	-22.08%

Table 2
Milk production by category during 1990-2023
Source: INSTAT (2024)

7 Support for the Dairy Sector in Albania (2019-2024)

The dairy sector is a key pillar of Albania's agricultural economy, playing a critical role in sustaining rural livelihoods and contributing significantly to the country's overall food production. Recognizing its importance, the government has implemented targeted support measures for the dairy sector for the period 20192024. These measures are designed to enhance productivity, modernize production, and ensure sustainable development through two main channels: the National Support Scheme and the Investment Scheme.

Under the national scheme, financial support is provided directly based on the "base number" of animals in a herd, with differentiated payments for cattle on one hand and for small ruminants (sheep and goats) on the other.

For cattle, particularly those raised for reproduction, the government offers support of up to 10,000 lek per head for farmers with a minimum of 10 cows. However, for herds that exceed 50 head, the benefit is reduced by 50%—unless the farmers are registered as part of a formal cooperative or farmer group. This structure is intended to reward smaller, more efficient operations while encouraging collaboration among farmers.

For small ruminants, farmers who own at least 100 head of sheep or goats are eligible for a payment of up to 1,200 lek per head. Similar to the cattle scheme, for herds exceeding 300 head, the benefit is halved unless the farm operates under a recognized cooperative framework. This tiered payment system reflects an effort to balance support across different scales of operation while promoting organized, collective action in the sector.

Complementing the direct payments, the Investment Scheme is aimed at modernizing the dairy sector by improving infrastructure and facilitating access to modern technology. This scheme focuses on two primary areas: i) Construction of Facilities:: The government provides financing that covers 50% of the total taxable invoice value for building facilities designed for the expansion and improvement of animal rearing. To qualify, new facilities must meet minimum capacity requirements—specifically, they should be capable of housing at least 10 cows or 100 small ruminants. The maximum benefit available per subject under this scheme is capped at 15,000,000 lek. And ii) Modernization of Equipment::To further support the modernization process, the Investment Scheme also covers the purchase of essential equipment and machinery. This includes tools that enhance operational efficiency and improve the overall management of livestock farms. Here too, 50% of the total taxable invoice value is financed, with a maximum cap of 5,000,000 lek per subject.

8   Organization of the Dairy Value Chain in Albania

The dairy value chain in Albania is a complex system involving a diverse array of stakeholders who collectively influence the quality, safety, and market price of milk and its by-products. At the core of this chain are the dairy farmers, whose operations vary significantly in scale.

The governance of Albania's dairy value chain is critical to ensuring high product quality and food safety. The sector involves various stakeholders—ranging from smallholder farmers and cooperatives to private collection centers and processing factories—that must work in close coordination to deliver milk and dairy products that meet established standards.

A central challenge within the value chain is the lack of consistent, long-term relationships between small-scale dairy farmers and large processing companies. Research shows that many small farmers prefer short-term, "spot" transactions, opting to sell their milk to the highest bidder at the time of delivery. In fact, only about 44% of farmers reported having a long-term contract with the same buyer. This instability undermines investments in quality improvements and infrastructure, as neither party feels secure in their ongoing collaboration.

In contrast, larger processors, with better financial resources and technological expertise, are able to dictate terms and impose rigorous quality standards on their suppliers. For example, one of the largest processing companies in Berat, "Erzeni," emphasizes the use of written contracts. These contracts detail the payment terms, hygienic standards (such as acceptable microbial and antibiotic residue levels), and delivery deadlines. Through such agreements, processors can secure a steady, high-

quality milk supply, while offering technical support—such as providing milking equipment and veterinary advice—to help farmers meet these standards.

The figure 1 below traces the journey of milk from **farm gate to household table**, highlighting the distinct stakeholders that shape both the flow of product and the distribution of value.

Overall, the figure illustrates a delicate equilibrium. Farms supply the raw material; collectors and processors transform and police quality; distributors, retailers, and traders impose commercial discipline; and consumers signal value. Strengthening weak links—especially cold storage at farm level, cooperative bargaining, and certification support for small processors—could move more of the final retail euro back toward producers, making the Albanian dairy chain both fairer and more resilient.
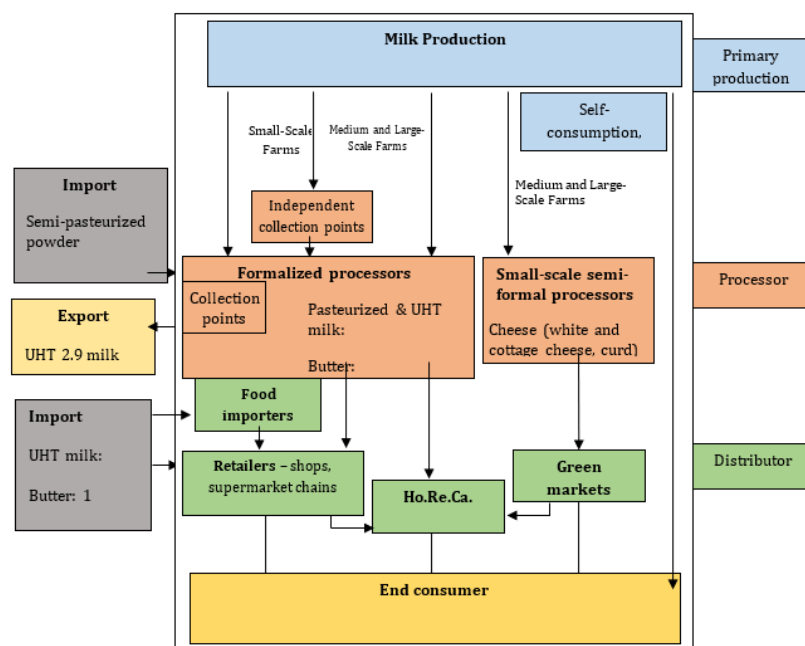

Figure 1
Dairy value chain Map
Source; AGT & DSA. (2021a). Milk Sector Study Report

Example: The AGS Model: AGS, company , operates in the Durrës, Sukth–Vadardhe regions. AGS employs a dual-contract system that clearly specifies all conditions of cooperation, from minimum milk quantities and quality parameters (microbiological and physico-chemical standards) to payment terms and delivery

schedules. AGS works closely with farmers through its dedicated veterinary team, which conducts daily quality checks and provides continuous technical advice. In a five-year partnership with a group of farmers in Baldushku, Tirana, AGS established a centralized milk collection center that has improved both the consistency of supply and the overall quality of the milk received. However, while group contracts can stabilize milk prices, they may also create challenges if one member decides to withdraw, potentially disrupting the entire collective arrangement. (Authors interviews , 2024)

9 SWOT Analysis

Strengths (S)	Weaknesses (W)
• Suitable natural and climatic conditions create an ideal environment for producing high-quality milk. • A strong tradition in milk production and traditional dairy products, such as white cheese and cottage cheese, which have a stable market and a good reputation. • Consumer trust and preference for local, fresh, and natural products, especially milk.	• High costs for livestock feed and veterinary services negatively impact farmers' incomes. • Labor shortages due to migration, declining interest among young people, and high labor costs threaten the sustainability of livestock farming. • Lack of cooperation and weak negotiation skills prevent farmers from benefiting from economies of scale and achieving unified market access • Low production levels, reliance on traditional methods, and limited use of modern technologies reduce competitiveness with imports. • The lack of standards and certifications for food safety requirements restricts access to international markets. • Difficulties in financing and investment prevent local farmers from keeping up with larger competitors. • Limited knowledge of food safety, standards, and market demand, pricing, and distribution channels weakens farmers' market positioning.

Opportunities (O)	Risks (T)
• Growing demand for local and organic products in both domestic and international markets presents export opportunities for farmers. • Support from EU programs and rural development funds offers financing opportunities for modernizing equipment, improving standards, and expanding into EU markets. • Investments in technology, such as new processing lines, hygiene equipment, and modern management systems, can enhance productivity and improve product quality.	• Competition from imported products, often offered at lower prices and with established standards, challenges the competitiveness of domestic products. • Climate change and environmental factors can negatively impact production, increasing uncertainty for farmers. • Food safety concerns may lead consumers to prefer products with international certifications, disadvantaging domestic products that lack quality certification. • Bureaucratic procedures and high certification costs create barriers to accessing EU markets. • Operating in an oligopolistic market increases the risk of discriminatory pricing for farmers, limiting their bargaining power.

9   Key Findings

High cost of inputs Farmers consistently report that one of the most pressing challenges is the high cost of inputs. These include essential feed components such as soybean mixes and protein supplements, which are critical for animal nutrition. Many farmers produce a portion of their own feed, yet they still need to purchase supplements. Financial constraints make it difficult to benefit from economies of scale, and the limited capacity to purchase inputs in bulk further drives up production costs. Delays in government support—for example, late reimbursement of subsidized fuel—exacerbate these challenges, with one participant noting, "The fuel is reimbursed late; it has lost its value."

Labor Shortages and Dependence on Family Work: Another major challenge is the shortage of labor. Due to the emigration of young workers and a general low interest in agricultural jobs, dairy farms are forced to rely heavily on family labor. In many cases, processes that require external labor—especially tasks perceived as unpleasant, like handling manure—are almost entirely neglected. This heavy dependence on family labor not only limits the scale of production but also hinders the adoption of more efficient, modern practices.

Inadequate Milk Storage and Processing Facilities: Proper milk storage is essential for preserving quality, yet many farmers face significant infrastructural challenges. Without adequate refrigeration, milk quality deteriorates rapidly, forcing farmers to sell at lower prices or rely on immediate, often informal, sales channels. This deficiency in storage infrastructure ultimately leads to losses in both product quality and profitability.

*Collective organization and bargaining power :*The lack of cooperatives and farmer associations weakens farmers' bargaining power. During consultation meetings, a lack of cooperation and trust among farmers was evident: "*We don't have unions, we have nothing.*" Even where they exist, farmers' unions and associations are often inactive or ineffective: Limited cooperation prevents farmers from influencing decision-making and price setting. They are almost always subject to the prices set by processors, with little control over the final value of milk. This is due to the dominance of a few large processors, the absence of long-term contracts, and the lack of horizontal cooperation among farmers.

On the other hand, *the absence of formal contracts and transparency* leaves farmers with little or no influence over the terms of sale. Regarding their formal relationships with dairies, farmers report that contracts with collectors are rare: Additionally, weak collective organization prevents the standardization of practices and the establishment of fair mechanisms for value sharing, further disadvantaging farmers in the supply chain.

Insufficient Training and Technical Support: A recurring theme in the discussions is the limited access to structured training programs. Most training is provided through international projects rather than consistent local institutional support. This gap in technical guidance—ranging from proper milking practices to effective herd management—restricts the farmers' ability to adopt modern technologies and improve the overall quality of their milk. The lack of continuous, locally-driven technical support further hinders innovation and sustainable development.

Limited Acces to finance: Results from the consultation meetings indicate that government support for farmers in the dairy sector is insufficient to meet the sector's needs and promote its development. Regarding livestock support, farmers consider it inadequate and difficult to access:. Farmers state that, under these conditions, they are not motivated to increase their livestock numbers and require greater support:. Additionally, some farmers expressed frustration with the investment scheme, particularly regarding difficulties in obtaining construction permits for stables: Many subsidy schemes also require formal documentation that small farms often lack (e.g., licenses, active taxpayer status, proof of ownership). Without these documents, farmers are unable to access support schemes.

Recommendations

Recommendations are designed to address the persistent challenges facing smallholder farmers and to enhance their competitiveness within the value chain.

These recommendations are built on an integrated analysis of the current situation, which highlights issues such as high input costs, fragmented production, insufficient infrastructure, weak market relationships, and limited access to finance and modern technology. The overarching goal is to achieve sustainable development and improve the position of dairy farmers through coordinated policy measures and targeted interventions.

Strengthening Cooperative Models and Micro-Collaboration

One key recommendation is the establishment of "micro-models" of cooperation. Small groups of farmers are encouraged to band together to share the costs of essential investments, such as the installation of cooling tanks. By forming these small, organized groups, farmers can lower individual expenses, improve milk quality, and create a foundation for more formal cooperative structures in the future. This model, tested successfully in the Myqeqeja Farm project in collaboration with the processor Erzeni, has demonstrated that such an approach not only enhances hygienic standards but also reduces operational costs. In addition, participation in these cooperatives opens access to EU funding instruments like IPARD and national schemes, which can further support modernization efforts.

Promoting Formal Contractual Relationships

Enhancing contractual relationships between farmers and local processors is another critical measure. Currently, many dairy farmers operate on a spot-market basis, leading to unstable prices and uncertain market access. The recommendations call for the promotion of short-term, written contracts between farmers and processors. These contracts should clearly specify payment terms, quality standards (including microbial load, antibiotic residues, and somatic cell counts), and delivery timelines. Pilot projects can help educate farmers on the benefits and specifics of formal contracts, while technical support from experienced partners can ensure that these arrangements are effectively implemented. By stabilizing prices and guaranteeing markets, such contracts would reduce uncertainty and enable both farmers and processors to plan long-term investments with confidence.

Enhancing Training and Practical Support

The report emphasizes that one of the fundamental issues in the sector is the lack of continuous, practical training. To address this, it is recommended that practical field schools be established to transfer essential knowledge and skills. These schools should focus on areas such as ration management, feed planning, and basic accounting. For example, centers like Center for Technology Transfers, operating in the country could host regular training sessions, where farmers can immediately see the benefits of improved practices and begin adopting modern techniques. Such training programs would not only enhance the technical capabilities of individual farmers but also foster greater collaboration and innovation across the sector.

Supporting Value-Added Product Development

To increase the overall value of dairy products, the recommendations stress the need to support initiatives that help farmers add value to their raw milk. This could be achieved through micro-grants that enable family farms to set up basic processing lines—for instance, for the production of cheese or yogurt. Moreover, creating quality seals such as "Local Albanian Milk" would help differentiate domestic products in both local and export markets. Implementing these measures, especially in medium and large farms, can encourage product diversification and even promote agro-tourism, thereby opening new revenue streams.

Easing Access to Finance and Navigating Bureaucracy

A significant barrier for many dairy farmers is the complexity of accessing financial support. The recommendations suggest leveraging Agricultural and Rural Assistance Centers (QABR) to help farmers navigate the cumbersome procedures associated with funding applications. Successful models in regions like Pukë, Kukës, and Dibër have demonstrated that such centers can provide essential administrative and technical assistance. By replicating these models nationwide, the government can improve farmers' access to critical financial resources, enabling them to invest in modern equipment and infrastructure.

Implementing the "Milk in Schools" Program

Finally, the document advocates for the implementation of the "Milk in Schools" scheme, based on the EU "From Farm to Table" model. This program aims to establish stable, guaranteed markets for local dairy products by ensuring that primary schools are supplied with fresh, locally produced milk. Such a program would not only improve the nutrition of children but also stabilize domestic demand for dairy products, contributing to the broader development of rural economies. Close collaboration among ministries, municipalities, and farmer groups is essential to ensure that this program is successfully implemented and that it benefits all stakeholders involved.

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The problems of health care financing and the financing of family medicine

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Abstract: The aim of my study is to illustrate GP financing through a practical example. My main question is what factors determine how much a district and a doctor are paid, and what factors they have to pay. I have chosen a case study type of thesis. From the results we can see that the community of practice increases the income and the work experience brings also increases it. The financing of GP practices in Hungary is a complex system that depends on a number of factors. Recent legislative changes and changes in the economic environment have a significant impact on the operation of GP practices. In order to ensure sustainability, it is important to continuously improve the system and to increase the attractiveness of general practice.- not motivated to see many patients because they do not receive more money - Lack of doctors - Indicators are independent the work of doctor for example vitamin D - There is no correlation between work and support - For better work (local labor) is not supported - There are hiden costs (papers, cleaning, administration).

Keywords: health care, business case, Óbuda

1   Introduction

Many other countries have health care in Hungary. Primary health care is one of the foundations of Hungary's health care system.To operate, there needs to be revenue, paid for by the state, to cover the costs. How and to what extent it is financed has a major impact on the quality and availability of services. Lower levels of funding also mean lower quality of equipment and services. The aim of this study is to present and analyse the financing of general medical practices, with particular reference to recent legislative changes. I will present and analyse current practice through a case study.

GP practices in Hungary are financed by the health insurance system. Funding is based on the remuneration rules set by the National Health Insurance Fund Management (NEAK), which are determined by taking into account population size, qualification multipliers and other factors. Recent legislative changes, such as the BM Decree 83/2022 (30.12.2002), have had a significant impact on the financing of general practitioners.

2　Health care data

The amount spent on health care in our country has been steadily increasing year on year, as shown in the first graph. This is not the question here, but whether this increase is sufficient to cover the cost of services and materials.

Figure 1
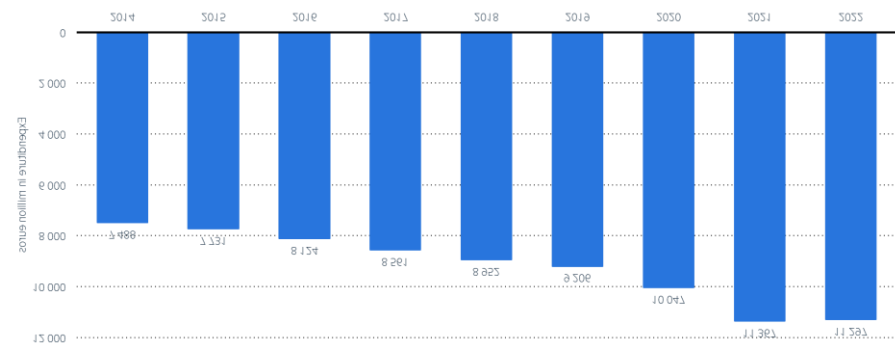Healthcare in Hungary.
Source: Statista 2024a

With the population shrinking, the number of general practitioners per habitants is steadily increasing, which could be a good sign, but our case study shows that the background is not necessarily stable. Figure 2.
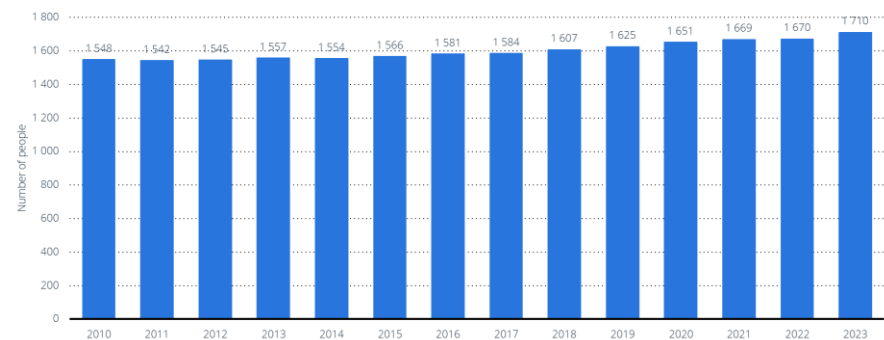
Figure 2
Number of people per general practitioner and family paediatrician in Hungary from 2010 to 2023.
Source: Statista 2024a

In fact, as we can see in Figure 3, the number of GPs per capita is steadily decreasing. The reason for this is that the number of doctors is constantly decreasing.
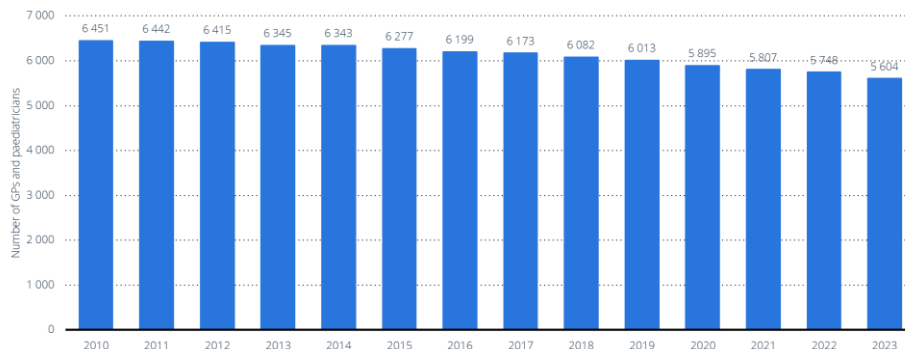
Figure 3
Number of general practitioners and pediatricians in Hungary 2010-2023.
Source Statista 2024a

3 Business case

In Óbuda There are some districts of doctors

Óbudai street 3 districts

Ányos street 5 districts

Viziorgona street 5 districts

Füst Milán street 4 ditricts

Pete Ferenc square 1 district

Vöröskereszt street 2 districts

Vörösvári street 5 districts

Total 25 districts

the habitants number was 122 661 in 2023 and there are 21 doctors for this population (Óbuda Health care, 2025).

The income of GP practices comes from several sources. These include a basic fee based on population, qualification multipliers and case-fees. The qualification multipliers take into account the qualification of the doctor and the length of time

spent in the practice, while the case-fees are based on patients who are not in the practice but are eligible for care.

The main elements and delivery of GP care financing:

Fixed fee (determined by taking into account the population of the district to be served, the number of surgeries or the disadvantaged situation of the municipality),Additional territorial fee (additional fee based on the type of municipality served by the general medical service, taking into account the location of the population in the area of the general medical district, additional fee to cover the costs of the visit of the patient by the doctor), a performance-related fee (calculated by taking into account the number (age) of insured persons registered with the general medical service, the multiplier for the qualifications of the doctor providing the service and the degressivity factor, outpatient fee (fee for the provision of emergency care to insured persons not registered with the service), additional remuneration for specialists (in the case of specialists working at least 20 hours per week, with the proviso that the provider of general practitioners is obliged to use the additional remuneration to supplement the salary and income directly paid to the specialist),equipment and property support fee (overhead allowance for general practitioners operating a general practitioner service with a territorial obligation to provide care), remuneration for results achieved in the indicator system legal relationship monitoring fee (NEAK, 2018).

The economic situation of GP practices has also undergone changes in recent decades. Funding has not followed inflation, as there are some items that have not changed for several years or decades. This has put a significant strain on the economic situation of the practices. In addition, the rise in overheads and changes in professional expectations have contributed to the overall deterioration in the economic situation of GP practices.

To illustrate funding, let's look at an example.

Age		previous month persons	This month persons	Point/ age
0-4	4,5	394	396	1782
5-14	2,5	335	351	877,5
15-34	1	71	70	70
35-60	1,5	0	0	0
60+	2,5	0	0	0
Total		800	817	2729,5

Figure 4
Support.
Source NEAK, 2018.

As we can see on Figure 4. Age-group aggregate base point ------> 2 729,5 and . Degression-adjusted base point score ------> 2 559,453. We can receive it as 2400*2729 square root = 2559,4.

Next incomes are:

3. Multiplier for qualifications 1.3 if the doctor has 2 degrees

4. Multiplied degressed point /performance point----->3 327,289

7. Fee per point (HUF) 209,929 It has not changed for 30 years

10. Performance fee for the current month (HUF) 698 500 = 4*7

Number of ad hoc treatments -------------- : 24

Charged per treatment (Ft/treatment): 600,000

Charged per case (Ft) : 14,400 if somebody cannot go to the own doctor,

Status checks in the month of completion ----------------------------------

Eligible checks and their fees (HUF) -------------------- : 113; 5 700

Not possible, number of checks required ------------------------ : 726.

Doctors reveice support based on vaccinations as we can see in Table 1.

	target group	results .	Own values	Best 50%	Best 25%	points	Own value
Gy01 Meningococcal vaccination (2-11 months of age)	86	72	83,7	85,2	92,6	0	2,625
Gy02 Meningococcal vaccination (12-24 months of age)	99	89	89,9	78,78	88,89	3	2,625
Gy03 Administration of colecalciferol preparation	255	76	29,8	32	48,36	0	0
Gy04 Percentage of exclusively breastfed (target group min 7)	20	18	90	86,36	100	1,5	3
Gy05 Screening under 6 years of age 4	444	404	90,99	81,36	90,9	3	3
Gy06 Anaemia screening	96	37	38,5	39,6	48,18	0	0,75
Gy07 Screening tests at age 5	58	48	82,75	70,5	85,18	1,5	2,625
Gy10 Treatment with antibiotics	792	3	0,42	2,39	1,5	3	3
total							18

Table 1
Vaccination support Source NEAK, 2018.

Next unit is overhead support. It is 520 000 HUF per month Further improvements to the financing system are important for the sustainability of GP practices. Reducing inequalities between practices, further supporting community practices and encouraging preventive activities are key. To make general practice a more

attractive career, it is necessary to raise the prestige of the profession and provide attractive career prospects for young doctors. This is shown in the following tables.

Practical time (years)	Amount financed (plus public charges) (HUF/month)	Amount financed (plus public charges) (HUF/month)	Gross guaranteed minimum wage (Ft/month)	Part of the medical income payable as gross salary (HUF/month)
0–2	89 800	*79 469*	296 400	**296 400**
3–5	155 000	*137 168*	296 400	**296 400**
6–10	278 100	*246 106*	296 400	**296 400**
11–15	336 300	297 611		**297 611**
16–20	368 400	326 018		**326 018**
21–25	425 200	376 283		**376 283**
26–30	473 400	418 938		**418 938**
31–35	499 000	441 593		**441 593**
36–40	553 400	489 735		**489 735**
41–	676 200	598 407		**598 407**

Table 2

Outside of community of practice.

Source NEAK, 2018.

Practical time (years)	Amount financed (plus public charges) (HUF/month)	Amount financed (plus public charges) (HUF/month)	Part of the medical income payable as gross salary (HUF/month)
0–2	239 600	*212 035*	**296 400**
3–5	413 300	365 752	**365 752**
6–10	741 600	656 283	**656 283**
11–15	896 900	793 717	**793 717**
16–20	982 300	869 292	**869 292**
21–25	1 133 800	1 003 363	**1 003 363**
26–30	1 262 300	1 117 080	**1 117 080**
31–35	1 330 600	1 177 522	**1 177 522**
36–40	1 475 700	1 305 929	**1 305 929**
41–	1 803 200	1 595 752	**1 595 752**

Table 3

Practice community supports.

Source NEAK, 2018.

Practical time (years)	Amount financed (plus public charges) (HUF/month)	Amount financed (plus public charges) (HUF/month)	Part of the medical income payable as gross salary (HUF/month)
0–2	299 400	*264 956*	**296 400**
3–5	516 700	457 257	**457 257**
6–10	927 000	820 354	**820 354**
11–15	1 121 100	992 124	**992 124**
16–20	1 227 900	1 086 637	**1 086 637**
21–25	1 417 300	1 254 248	**1 254 248**
26–30	1 577 900	1 396 372	**1 396 372**
31–35	1 663 200	1 471 858	**1 471 858**
36–40	1 844 600	1 632 389	**1 632 389**
41–	2 254 000	1 994 690	**1 994 690**

Table 4

Strict practice community supports.

Source NEAK, 2018.

Practical time (year)	Specialist allowance plus social contribution tax (HUF/month)
0-3	138 000
4-6	149 500
7-9	161 000
10-12	172 500
13-15	184 000
16-18	195 500
19-21	207 000
22-24	218 500
25-27	230 000
28-30	241 500
31-33	253 000
34-36	264 500
37-39	276 000
40-42	287 500
43-45	299 000
46-48	310 800
49-	322 800

Table 5

Assistant supports. Source
NEAK, 2018.

Tables 2-4 show how much funding is available for doctors working individually or in private practice. Table 5 shows the funding for assistants. The more medical experience someone has and the more they collaborate, the more money they can receive.

Conclusions

The financing of GP practices in Hungary is a complex system that depends on a number of factors. Recent legislative changes and changes in the economic environment have a significant impact on the operation of GP practices. In order to ensure sustainability, it is important to continuously improve the system and to increase the attractiveness of general practice.

- not motivated to see many patients because they do not receive more money
- Lack of doctors
- Indicators are independent the work of doctor for example vitamin D
- There is no correlation between work and support
- For better work (local labor) is not supported
- There are hiden costs (papers, cleaning, administration).

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"Vanishing" pax Americana as the current rational choice for the United States

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Abstract: We discuss recent global policy elements of the USA as they are, and highlight valid and rational motivations. In the core, we identify rational strategic elements in the wake of the sustainability crisis of the 21st century. The US as the sole superpower aims at saving or even strengthening her position during the crisis; and instead of a higher level of cooperation of optimistic (globally community-optimal) scenarios, highly competitive actions are trivially much safer and more beneficial for an individual (strong) actor in the crisis. There are similarly rational but unconventional elements of US global policy. The world order of the recent half century (the 'pax Americana'), may seem to be being destroyed by its definitive power; but these steps can be equally nothing else but taking unconventional countermeasures against losing power, as well as preparing for the hardly foreseeable (cataclysmic) movements in the onset of the new era after the sustainability breakdown.

Keywords: global sustainability, global politics, USA, unipolar world order, sustainability event horizon

1   Introduction

It is still desperately little what we know about the required actions for global sustainability, and it is even less what we know about how to manage it, but we now firmly know that humanity on its host planet, the Earth is in a sustainability crisis,[3]

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[3] When we are talking about *the present global sustainability crisis*, we can talk about multiple global crises too (of which climate change is by far the most severe and important),

and as a consequence, our society and economy will be radically reshaped until the second half of the 21st century. It can be taken with certainty that our global society, economy, and other human systems will not even resemble what we currently have. [1, 2] With this little knowledge about this huge change, we can even say that there is an *event horizon* at the climax of our middle-term (maybe even short-term) sustainability trajectory: the world coming afterwards will be so different, so unknown beforehand, and so intractable with our current scientific, logical, and cultural instruments, that currently available forecasts necessarily become irrelevant at some point on this way.

It is our, and everyone's, task however to study possible strategies for the present era (until the horizon), which will have an impact on what comes thereafter. There are policymakers, businesspeople, military leaders, scientists and many more types of actors who need to study and adapt to what is going to happen. But not only the information-shielding nature of the event horizon hinders our efforts to do so. The very nature of the present sustainability crisis implies that there are radically different possible answers to the big question, and therefore there are as many expectations towards (major) players about what courses of action they take. Moreover, morally expected (community-optimized) and rationally validated (individual) strategies can be completely opposite to each other.

In this situation, we try to evaluate the recent actions taken by the largest international player, the United States of America; not only because the United States itself is the most important actor on the global level, but because of the recent, largely unexpected shifts and changes in its global sustainability policy. [3] We also study the global geopolitical strategies in which sustainability policies are embedded, and which, by our opinion, originate in the relation of the US with global sustainability. We try to examine the aforementioned phenomena as they are; we want to give a fully descriptive study. We will use moral or ideological categorizations only in cases when they are themselves part of the description.

Thus, in our age when superficial observers may have the impression that the US is destroying "pax Americana", the global order lead by itself, our scope of study will encompass two main areas in which we are going to arrive at the contrary conclusion:

1. What is the United States doing about global sustainability efforts, why is this contrary to the mainstream expectations, and what is the rational strategy in which this fits well?
2. How and why is this parallelled in the global foreign policy of the US as the sole but challenged superpower; and how can this be again a part of a rational scenario? Last but not least, why are these two policy levels

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but from a political decision-theoretical point of view, we can remain at the general notation of a single crisis.

tightly connected, and what are the conclusions coming from this tight connection?

2 Review on the relation of global sustainability efforts and the role of the United States

Humanity's steadfast march into what we may call a "climate catastrophe" is not a recently originated and recognized process. Scientific results showing the depth of the problem [4] and its anthropogenic nature have been known for more than half a century. [5] It has been for long known therefore that avoiding a cataclysm needs human action. According to this, the first global sustainability summit took place back in 1972, in Stockholm, where 113 member states of the United Nations were present (among severe political discord and even a boycott of the eastern bloc), resulting in the *Stockholm Declaration* [6, 7] with 26 principles that can be identified as the roots of today's *Sustainable Development Goals*, [8] an action plan, and the creation of the *United Nations Environment Programme*. It was also there where the very first practical global action against exhaustion of global environmental resources originated: protection of oceans. [9] In the 1979 Geneva Conference, called retrospectively as the *first climate summit*, [10] climate change reached the status of the topmost important global sustainability question (which has been remained so), and among other results, this finally led to the foundation of the IPCC (Intergovernmental Panel on Climate Change) in 1988. The first (and so far only) efficient global sustainability cooperation started in 1987, when the *Montréal Protocol on Substances That Deplete the Ozone Layer* (the first universally ratified treaty in UN history) was accepted.

The first report of IPCC in 1990 [11] was focusing on the anthropogenic impact on climate change. In 1992, the United Nations Conference on Environment and Development (UNCED) was held in Rio de Janeiro; where the United Nations Framework Convention on Climate Change (UNFCCC) has been introduced, and the long series of conferences of parties (COP's) to it has begun. In 1997, COP3 established the Kyoto Protocol, the first legally binding climate target at 5% reduction of greenhouse gas emissions for 36 developed countries until 2008–2012 with respect to 1990. The United States signed the protocol, but has not ratified since then, due to a non-binding 1997 resolution of the senate (unanimously) that international agreements of this kind (containing no commitments of developing countries) should not ever be ratified, [12] rendering Kyoto Protocol's meticulously designed "principle of common but differentiated responsibilities" effectively failed. The next international major milestone, the Paris Agreement was achieved in 2015 (COP21), with an explicit and globally well-defined target of keeping global warming under 2, or 1.5 if possible, degrees above the pre-industrial level, coming into force in 2016. The emerging serious scientific consensus about the needed

global emission scenario (50% reduction of the peak emission until ca. 2030, and net climate neutrality before 2050 [13]) as well as the more and more unfavourable scientific results (gradually worsening prognoses) [14] have challenged the motivations of parties to adhere to Paris commitments. The European Parliament declared climate emergency, [15] and soon passed a law [16] requiring an 55% reduction of ghg emissions (with respect to 1990, not the global peak year), and net neutrality until 2050, but this all seems to be based on production carbon footprint figures, rather than consumption figures, giving way to carbon footprint outsourcing (largely disregarding embodied emissions in trade, EET [17]).

On the level of political declarations, there is an apparent swing between climate skepticism and activism depending on the party leading the USA. [18] Democrats seem to favour policies towards climate sustainability, while republicans oppose active participation in those efforts. Now the memories have already faded, but the bet was the highest, and a real breakthrough may have been the nearest when George W. Bush and Al Gore contended for the presidency; the latter campaigning with an environment conscious electoral programme of an unprecedented quality. No-one knows what would have followed after an eventual victory of Gore, but his steadfast activism both earlier as a vice president, and later as a civilian activist represents almost an alternative history. [19] The actual course of events had Bush win, and then, the Democrat Barack Obama elected in 2008, and subsequently in 2012. The Obama administration ratified the Paris Agreement, and in parallel strengthened sustainability-oriented industrial policies. [20] Donald Trump's election in 2016 radically changed the landscape; not only by swinging to the opposite direction, but by the deconstruction of several diplomatic norms, conventions and protocols. As for the global sustainability struggle and specifically the Paris Agreement, president Trump made an apparent U-turn by withdrawing from it (and industrial policies distancing the US from sustainability). His successor, Joe Biden once again ratified it, and now, the second Trump administration is currently preparing for the re-withdrawal, [21] thus rendering the mainstream theoretical scenario of global cooperative climate protection effectively void.

Despite the high contrast of the pictures based on the presidents and their administrative apparatus, some continuous rationality behind different US leaderships is useful to hypothesize behind all of the above turns and actions. First, independent of the personality and even the partisan position of the current president, the federal state of the United States is run by a strong and professional bureaucracy, which retains a large part of its momentum and behavioural patterns through changes of leadership. Second, as the smart-tuned strategic parameters of the European Union, the global climate champion also suggest (see above), the real difference between "climate friendly" and "climate skeptical" policies is marginal if we compare them to scientifically justifiable (really climate friendly) trajectories [22] towards sustainability. It is then not far from the truth that substantially strong cooperative climate friendly policies expected from e.g. the US are almost equally breached by Democrat and Republican governments so far (look at e.g. the

unanimous Byrd–Hagel resolution mentioned above, [12] or the skyrocketing carbohydrogen exports under Obama, the first Trump, and the Biden era [23], one of the last sellouts of a necessarily shrinking non-sustainable industry [24]).

3 Methods of identifying current motivations

Our analysis of the most recent geopolitical movements is based on identifying their relation to the global sustainability struggle as the most central and fundamental motivation of them, and then unfolding the consequences and effects on other layers of global politics. Therefore we will follow basically two threads of reasoning: 1. where are the origins of these history-forming processes, and 2. how is then the scene of global politics built up on these foundations.

As we will see, the most fundamental motivation identified behind the movements studied here is how the actors, and first of all, the United States, is related to the challenge of our age: global sustainability. And while the political behaviour of recent Democrat leaderships of the US have followed an (appropriately diluted) cooperative strategy in the global scene, the Republicans, and especially the two Trump administrations seem to do the opposite. And while the cooperative strategies are somehow "the most admissible for the global public" because they keep with the collective general goals of humanity, the highly competitive ('anticooperative') ones can be regarded as a game-theoretic imperative, a cold-rational optimum for the US itself.

Note the 'game-theoretic imperative' nature of the anticooperative behaviour. This statement suggests not only that this extremity of strategies can be rational, but something stronger: this rational choice is dictated by the current situation. Taking the highly competitive strategy under these circumstances may be then a direct consequence of not intending to change history (not taking the cooperative way for sustainability, and expecting all the other parties to do similarly), but simply optimizing to how it currently evolves (taking an individually optimized strategy, and handling the situation as unchangeable). For a cold-rational actor, the latter position can have further advantages in addition to the trivial game-theoretic choice of competition over cooperation (the Nash equilibrium of such games); e.g. one of its further advantages is that it requires no effort against the global trends which show a combination of competition against sustainability, and some signs of lukewarm sustainability efforts at most, setting an overall global tendence against sustainability anyway.

Built on top of the cold-rational answer to the sustainability challenge, we are able to analyze the most recent short-term movements in global politics. Why is the US taking unconventional steps against its closest allies, and favourizing an apparent enemy, Russia? What is the course of events in global politics for which the US

takes these steps as some kind of preparation? Of course, the final answer lies in the above cold-rational analysis of the global sustainability struggle.

4 Results: the rationale of current moves

4.1 The most harsh answer to the greatest-ever challenge

What happens when an actor in a situation which needs perfect cooperation as the collective optimum comes to the conclusion that there is no chance for that cooperative action? What if the leadership of the US analyses the global landscape of the sustainability struggle, and concludes there is no hope for global cooperation? And what if they, moreover, learn that even the hypothetical success of the cooperative scenario will have detrimental effects both on the US elite's internal power, and the power of the United States in its foreign relations? Even if they do not sympathize with competitive (and destructive) outcomes, they can easily come to the conclusion that adapting to them, or even stimulating them is the only optimum for them and the United States as a global power.

But why would the US elite come to such a grief conclusion about the near future of humanity? The competition vs. cooperation answer is the game-theoretic nature of the global sustainability struggle: while a collective optimum or merely a modest collective survival is only possible with full cooperation of all parties, these parties as individual actors can maximize their payoffs by letting the others do the job, while they not only enjoy the free ride, but also gain further advantage by not wearing down themselves in the struggle. This game-theoretical setting is known as the tragedy of the commons, [25, 26] and inevitably leads to a fully competitive, and as for the collective goals, destructive outcome. In addition to this, the internationally cooperative strategy, complete with ecological austerity which is unacceptable for the 21st-century consumer citizens even at its lowest satisfactory level (like everywhere else in the world, e.g. [27]), promises no popularity on the national level. And on top of these effects, there comes what we have touched in the introduction: the strategy in the great struggle (turmoil) during the sustainability crisis will be a preparation for life after the sustainability event horizon.

How will the United States be the fittest for the unknown new era, moreover, how can it retain or even strengthen its globally dominant position? As we have stated, no-one knows what the new world will look like, but most probably the more wealth an actor acquires at the expense of the others, the better choices it is going to have. When we talk about wealth, of course, there will be parts of it which will not persist into the new era, but the most durable physical wealth, e.g. gold, or the portion of the ecological treasury one has, i.e. controlled territory, or well-maintained military capabilities will certainly not be useless. This all gives an amplified version of the

tragedy of the commons, where competitive destruction of the common good is not only a consequence of the relation of players, but it emerges as a short-term goal (this is the game-theoretic structure of e.g. the 'fishbanks' game, [28] where the non-cooperative outcome is a rush for destroying the common resource). Therefore the chance (or even the imperative) for a rational actor to engage in competitive strategies is extremely high. This way is, in addition, the most profitable for strong actors: being a strong competitive participant, having the opportunities of a strong player, and retaining or increasing a strong position all improve both the viability and the payoff of the competitive strategy. And the United States is not merely a strong actor; it is by far the strongest; however, it feels challenged by China, [29] giving more motivation for the full competition.

One word too many, if ideological, moral considerations, fulfilment of expectations of international observers, or simply formal diplomatic frameworks of international action are set aside, the purely rational choice for the United States in the present sustainability crisis is not only breaching cooperation, but starting a competition in destroying all the available environmental (climate) resources of humanity which can be exploited until the sustainability event horizon arrives.

4.2   The necessary trends implied in shortest-term global politics

On top of the broken-down sustainability struggle, the most prominent natural short-term trend of global politics is a harsher global competition and in this competition, the increasing importance of international alliances. Because China has emerged as the US' sole competitor for global leadership, this will mean a more fluctuating landscape in which alliances around these two poles and their growing or shrinking sizes form the basis of power dynamics. There are solid cores around the global players, which we expect to be rather stable, while the instabilities will dominate the peripheries of the alliances and the terra nullius between them. The resulting new global geopolitics of the USA must then focus on the periphery of the Western alliance. While the US can be negligent or even conflict-seeking within the core of its own alliance (resources may not only be spared on these relations, but sometimes even extracted, and reassigned to others), the same US policy must be "irrationally friendly" to global second-tier (or lower-tier) partners whose alignment is not clear in advance.

The set of second-tier powers in this landscape is concentrated in Eurasia. Whether on an emerging or submerging path, it encompasses the European Union, Russia and India (inclusion of other powers, as well as their positioning on the second or the third tier of global politics can be the subject of further discussion, but these three are the most probable greatest powers behind the two first-tier ones). These three second-tier polities can clearly show how the periphery of the US-lead alliance

has to be managed during the upcoming hard years (leading up to the aforementioned sustainability event horizon).

First, the European Union is unquestionably at the hardest core of the alliance of the USA. [30] Because then there is no doubt, for cultural, historical, economical and other reasons, that the European Union will never end up as a Chinese ally, there is no reason for the US to invest in this alliance, when political, economical, military, etc. resources that can be invested into such an alliance become scarce. Second, the place of India seems to be not as solid in the alliance structure as the EU, but if we study it from the opposite direction, the picture is clearer: India and China as historical (geopolitical, cultural, economical, etc.) enemies are very unlikely to evolve as close allies in the future. [31] The slight ambiguities that come into consideration when we are discussing these relations come from the 20th-century cold war era: India was then rather a Soviet ally than a western one. This leads us to the third second-tier power in this story: Russia. The only (very slightly) ambiguous valence of India's network of alliances leads to Russia, which means that India's position in the two-pole structure of the middle and late 21st century can be slightly (if at all) influenced by the position of Russia. [32]

And this is where we arrive at the third member of our set of most probable second-tier players: Russia. As the events of the recent years show, [33, 34] Russia is prone to become a subordinate ally of China, because its global ambitions and the exhaustive Russo-Ukrainian war are simply not sustainable by its economic strength. Although many observers expect a collapse of the Russian state under this burden, [35] this may not happen. However, the slow decline in power from 1991 (the dissolution of the Soviet Union) is accelerating, and Russia's demise as a superpower is now evident. [36] Russia also has conflicting interests with China in parallel. Control over its vast Siberian territories can be challenged by China, and relations with India, as well as Russia's European cultural heritage, and of course its superpower identity can also lead to conflicts with China. This all puts Russia in the role of a peripheral ally of the USA; and thus the benefit-to-cost ratio of tying Russia to the US alliance (in a cultural-historical perspective: to the Western world) is by far the highest of its kind now.[4] Relatively strong ties of India to Russia and their possible consequences in such a dilemma are a plus in this cost-benefit analysis.

Conclusion

We have discussed the recent and past non-cooperative sustainability policy of the USA, the restructuring of international focus exhibited by the new government (an

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[4] An interesting process in the background is a possible EU–India rapprochement, [37] which can both serve as a short-term backup for these two when their ties to the US seem to loosen (its intended goal), and as an improvement of the US-led global alliance in the long run (not intended).

ongoing process when this paper is being written), and the connection between them. Given that the US government expects (or simply only does not rule out) a global sustainability collapse in the coming decades, its focus on its cooperations and alliances may get restructured, and its close allies may get not only less attention, but even unfamiliar treatment. This, regardless of its entirely intentional or partly unintentional nature, can then fit into a rational, though rather cold-minded, cynical global strategy of the US.

Will then pax Americana vanish? Does the current leadership of the US intend to do so? Based on our discussion, the situation is the opposite: the leaders of the USA are working on saving the role of the USA as the leading superpower (of course, with steps more or less faithful to the strategy). This strategic mainline is rational when it is embedded into an expected turmoil and the next, yet unknown age after the event horizon of global sustainability, simply building upon the most probably unfavourable outcome of the global sustainability crisis in the 21st century.

Disclaimer for the political content

This paper discusses its topic on an "as-is" basis; no expectations, ideological stances or other subjective relation of the authors to it is intended to appear in the text. Results can be used both for the validation and the criticism of the treated subject and its properties; the actual discussion is merely about their existence and logical, rational nature as observable political phenomena.

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Tracing the development of platform economy research: key trends and insights

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Abstract: In recent years, the platform economy has transformed how individuals share and conduct transactions in digital spaces. This phenomenon has attracted scholars from various diverse fields and disciplines into an emerging research area. This study aims to explore the trends and key insights in the literature on the platform economy through a bibliometric approach. The analysis includes research articles published between 2000 and 2024 on the platform economy. Using publications available on the Web of Science, this study identifies influential journals, institutions, landmark papers, and citation bursts. In addition to researchers in management, business, and economics, scholars from sociology, communication, law, and computer science are increasingly contributing to platform economy research. The findings reveal that the focus of platform research has evolved over time. This research will serve as a basis for future discussions on the crucial roles played by digital platforms in the platform economy.

Keywords: Platform economy, Scientific research, Bibliometric analysis

1 Introduction

The platform economy represents a distinct economic paradigm characterised by two-sided markets functioning within the broader context of traditional market economics. [1] examine the evolution of the platform economy, which is propelled by advancements in digital technologies, including the Internet, cloud computing, big data, and the Internet of Things [2]. Central to this transformation are platform enterprises that create and manage extensive digital ecosystems, facilitating connections between consumers and service providers while transforming industry dynamics.

The platform economy exerts a profound influence on both upstream and downstream enterprises, striving to lower transaction costs by optimising organisational structures and service mechanisms. This shift fosters a new model of economic integration, in which resource allocation becomes increasingly synchronised with traditional industries. Since the 1990s, the emergence of large-scale digital platforms employing data-driven business models has revolutionised global markets. Pioneering companies such as Google, eBay, Alibaba, Baidu, Tencent, and JD.com have played a pivotal role in shaping this economic transformation, redefining market structures, competitive behaviours, and industry landscapes [3].

Furthermore, the platform economy transcends national boundaries, facilitating cross-border and cross-regional business models that accelerate global economic integration. The exponential growth of platform enterprises has stimulated extensive academic inquiry, driving in-depth research into their economic, technological, and regulatory implications. As digital platforms continue to evolve, they present both opportunities and challenges, necessitating ongoing scholarly analysis to understand their long-term impact on economic structures and market dynamics.

Given the rapid expansion of the platform economy, a comprehensive and systematic review of its development over the past two decades is essential. This study employs a bibliometric approach to enhance the theoretical and empirical understanding of trends and insights in the platform economy by examining its evolution from 2000 to 2024. Furthermore, the findings will contribute to the growing body of literature by refining analytical frameworks and supporting the creation of more effective, data-driven decision-making strategies for academia and industry. Such an analysis will synthesise existing knowledge, map prevailing research trajectories, identify critical gaps, and provide insights to inform future scholarly inquiry and policy-making.

This study is structured into five sections. Introduction section highlights the significance of the platform economy, its evolution, and the objectives of this systematic review. Section 2 – Theoretical Overview of bibliometric analysis in platform economy. Section 3 - Methodology details the data sources (Web of

Science) and bibliometric tools (VOSviewer 1.6.20) employed for analysis. Section 4 - Results presents key findings, including keyword trends, number of publications, citation analysis, and collaboration patterns, using visual representations. Section 5 - Conclusion summarizes the main findings, provides recommendations for advancing platform economy research, and emphasizes the importance of interdisciplinary approaches and future research directions.

2 Literature review

Bibliometric analysis has become increasingly prominent in business research, primarily due to advances in accessible analytical tools such as Gephi and VOSviewer and comprehensive databases like Scopus, Web of Science, and Dimensions.ai [4-6]. Its growing adoption reflects not only methodological innovation transferred from information science but also its practical value in managing large datasets and generating high-impact insights. Bibliometric analysis is a useful resource for researchers seeking to uncover emerging trends, collaboration networks, and the intellectual framework of a research field [4]. Examining extensive amounts of objective data, like citation counts, publication metrics, and keyword frequencies, facilitates both quantitative performance assessments and qualitative thematic interpretations. Previous literature has documented certain publications that utilized bibliometric analysis within the platform economy and its applications in other scientific fields.

[7] identify the rise of digital platforms as one of the three defining events of the digital revolution, fundamentally reshaping production, daily life, and cognitive processes. The platform-based model has become a cornerstone of modern business, with many of the most successful enterprises exhibiting platform attributes [8]. Serving as intermediaries that facilitate interactions and value exchange among participants, platforms have transformed traditional market dynamics. Consequently, major technology companies are predominantly structured as platform-based enterprises, leveraging network effects to drive innovation, scalability, and competitive advantage [9]. [10] indicates that the sharing economy offers potential for economic growth and enhanced sustainable resource use.

According to [11] the sharing economy has garnered significant scholarly attention, prompting a need to systematically map its intellectual structure and research trends [21, 22]. Through a bibliometric analysis of 416 articles published between 2013 and 2018, the authors identify key thematic clusters, influential publications, and leading contributors in the field. Their findings reveal that research on the sharing economy is interdisciplinary in nature, with growing emphasis on sustainability, digital platforms, business models, and user behavior.

The sharing economy plays a growing role in promoting sustainable development, prompting [12] to conduct a bibliometric analysis to explore research trends in this area. By analyzing 975 publications from 2010 to 2020, the study identifies key research hotspots such as collaborative consumption, climate change, renewable resources, and the circular economy. The findings reveal a steady increase in academic interest, particularly in China, and point to underexplored areas like the bioeconomy and urban mobility. The authors emphasize the need for further research to better understand the sharing economy's impact on environmental, social, and economic sustainability. Analyzing 440 publications from 2009 to 2022, [13] identified major research themes in operations research, including pricing strategies, resource allocation, platform design, and demand forecasting, within the context of the sharing economy. Through a systematic review of 175 scientific articles, [14] examined drivers and barriers to participation in the sharing economy, focusing on environmental, economic, and social motivations. Their findings suggest that while environmental concerns play a role in driving participation, other factors such as trust, convenience, and financial incentives are also critical. [12] deal with the platform economy in the context of sustainable development, applying bibliometric analysis to explore how sharing economy research contributes to sustainability discourse. By examining 975 academic publications from 2010 to 2020, the authors identify major thematic areas such as collaborative consumption, climate change, renewable resources, and the circular economy.

3   Methodology

The bibliometric analysis uses literature from the publication database to create a scientific and coherent network and structural representation [15]. This method is essential and effective for illustrating, analyzing, and summarizing existing research in relevant fields. Through techniques such as cluster analysis, co-citation analysis, and visual analysis, bibliometrics evaluates the relationships among papers, authors, and keywords, providing credible research insights for scholars [16]. This paper applied bibliometric analysis to quantitatively evaluate the literature review concerning the platform economy.

3.1   Data collection

The data was collected from the Web of Science (WoS) webserver, a resource widely used by scholarly researchers in the field of bibliography [15-17]. „Web of Science Core Collection" database was used, which encompasses over 34000 journals, books, and conferences, totaling more than 134 million research materials [18]. Academics value the WoS database for its reliable archiving of high-quality sources and the rich collection of materials referenced in numerous prior studies.

WoS, maintained by Clarivate Analytics, is recognized as the most extensive scientific research platform and was previously known as ISI Web of Science.

This research utilizes a bibliometric analysis method to examine studies on the platform economy from 2000 to 2024. Data was obtained from Web of Science by using the search conditions were set as follows: the topic is „platform economy" and the document type is designated as "Article." A total of 10322 documents were retrieved. Using the export function of WoS, all records were exported to "txt" format, including the title, keywords, abstract, author, year, foundation programs, and source journal of each article. All articles were analyzed with VOSviewer to uncover publication trends, co-authorship networks, and thematic patterns [19]. Essential analyses included citation impact, keyword mapping, and collaboration clusters. Non-peer-reviewed papers and unrelated domains were excluded from consideration. The results offer valuable insights into trends, key contributors, and research gaps within the platform economy literature.

4 Results

The analysis of the top research categories highlights the diverse applications of the platform economy (Figure 1).
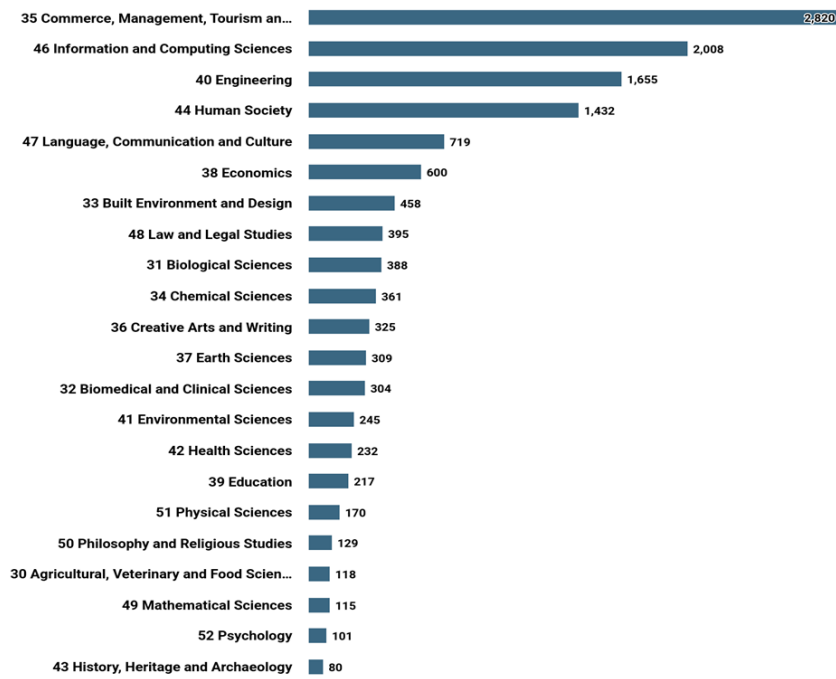
Figure 1
Flowchart of number of publications in the fields of (ANZSRC 2020)

Commerce, Management, Tourism, and Services lead with 2820 publications, emphasising how the platform economy leverages digital technologies to enhance efficiency, connectivity, and innovation in these sectors, thereby creating new opportunities and challenges. Information and Computing Sciences follow with 2008 research studies, serving as the backbone of the platform economy by developing technologies, enabling efficient data usage, and ensuring secure, innovative, and scalable digital ecosystems for platforms in operation. Engineering ranks third with 1655 publications, emphasizing its pivotal role in optimizing processes, advancing infrastructure development, and adapting to the demands of the platform economy, which drives innovation, fosters the integration of cutting-edge technologies, and reshapes traditional engineering practices to meet the needs of a rapidly evolving digital landscape. Other prominent categories include Human Society (1432), Language, Communication and Culture (719), Economics (600), and Built Environment and Desing (458) further demonstrate the applicability of the platform economy across domains such as community and cultural development, management, economic policy, and urban planning. This diversity underscores the importance of the platform economy in modern society.
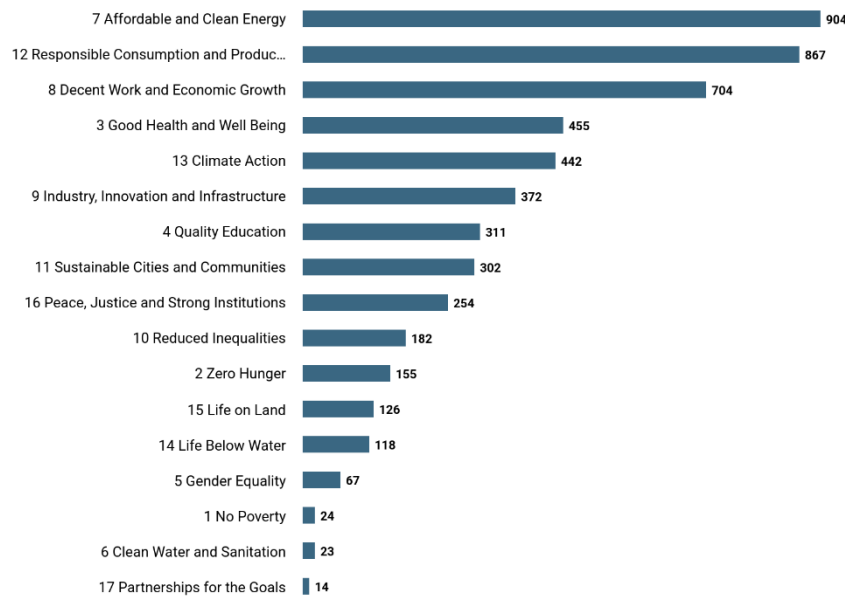
Figure 2

Flowchart of number of publication in the fields of Sustainable Development Goals

The analysis categorizes platform economy research contributions based on alignment with the United Nations Sustainable Development Goals (SDGs), highlighting a significant focus on environmental sustainability and responsible consumption (Figure 2). The most addressed SDG is Affordable and Clean Energy (SDG 7), with 904 studies emphasizing renewable energy and optimization. Responsible Consumption and Production (SDG 12) follows with 867 studies, while Decent Work and Economic Growth (SDG 8) has 704. Contributions to Good Health and Well Being (SDG 3) and Climate Action (SDG 13) include 455 and 442 studies, respectively. Lesser-researched SDGs include Industry, Innovation and Infrastructure (SDG 9), Quality Education (SDG 4), and Sustainable Cities and Communities (SDG 11), highlighting gaps and future opportunities for research.

During the initial phase (Figure 3) from 2000 to 2010, the research landscape was nascent, with annual publications remaining small, ranging from 16 to 91 (Table 1). This reflects the early exploration of the platform economy, with limited academic and industrial adoption. However, a modest increase in the period 2011-2014 marked the beginning of growing interest in the platform economy. Digital platforms like Uber, Airbnb, and Amazon became dominant in the global economy during that period. The development of the Internet, mobile technologies and cloud computing have enabled the growth of business models based on digital platforms. The period from 2015 to 2019 witnessed gradual but consistent growth, as annual publications rose from 215 in 2015 to 848 in 2020. From 2021 to 2024, the field entered a maturity phase and sustained high productivity, with annual publications

exceeding 1000. A slight plateau was observed in 2023, and this stability reflects the field's saturation in certain domains, accompanied by continuous expansion into emerging areas like generative artificial intelligence, Web3, and blockchain economies. 2024 saw the highest number of publications, reaching 1504, underscoring platform economies' critical role in interdisciplinary research areas like digital law, digital communication, and circular economy.

Figure 3

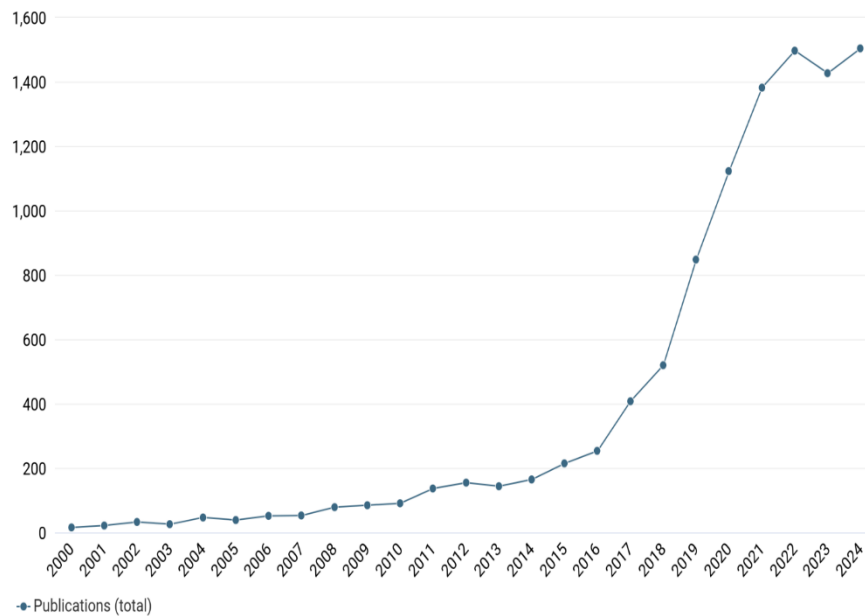The number of publications published in each year (2000 - 2024)

Keywords reveal the primary message of the related paper. Based on the analysis of the keyword findings reveal four unique clusters (Figure 4), each depicted in a different color. The most frequently used topic word is „platform economy. Other most frequent keywords are "gig economy", „sharing economy", „digital platforms" and „colaborative consumption".

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Publications	16	22	33	26	47	39	52	53	79	85	91	137	155
Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Publications	144	165	215	254	408	520	848	1123	1382	1497	1427	1504	/

Table 1

Publications trend analysis (2000 - 2024)

Figure 4

Word cloud map of the keywords on platform economy with network visualization mode

Co-author analysis examines the collaboration among researchers by studying the publications they co-authored. Tools like VOSviewer create visual networks where nodes represent authors and edges demonstrate their collaborative connections. This method highlights key researchers, collaboration patterns, and clusters of academic partnerships. Additionally, it evaluates collaboration at various levels, including

between nations and organizations, providing valuable insights into research dynamics and strengthening academic ties [5, 20].
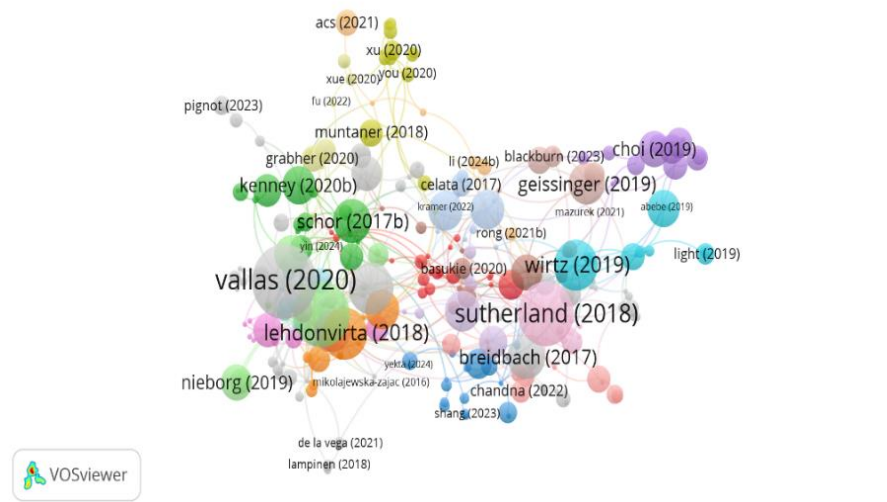

Figure 5

Bibliometric map on co-authorship unit of authors with network visualization mode

The analysis of the leading authors (Figure 5) in platform economy research highlights their crucial roles in shaping the field through significant contributions, influential citations, and academic impact. Notable scholars include Vallas (2020), Wirtz (2019), Wood (2019), Lehdonvirta (2018), Sutherland (2018), and Graham (2017).
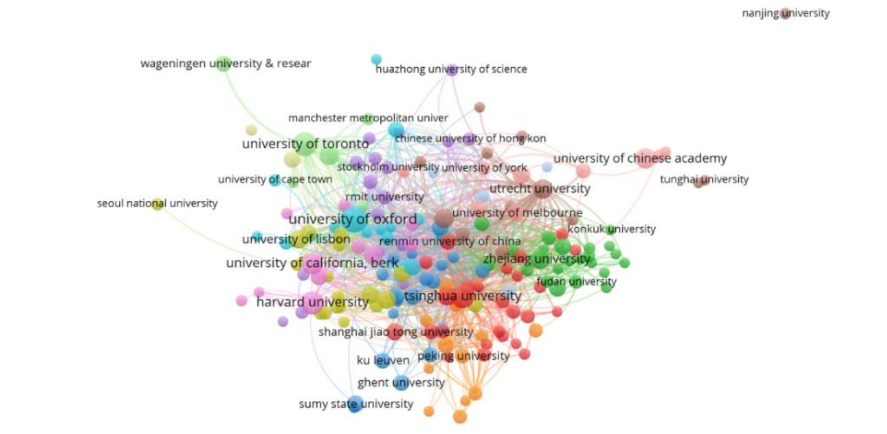

Figure 6

Bibliometric map on organization with network visualization mode

The analysis of leading organizations in platform economy research underscores their substantial contributions to scholarly productivity, citation impact, and collaborative networks. The findings identify 11 distinct research clusters, each represented by a different color (Figure 6), highlighting the diverse institutional engagement in this field. Several organizations stand out as key contributors to platform economy research. Among the most prominent are Tsinghua University, Harvard University, the University of Oxford, Sichuan University, the University of Toronto, and Stockholm University, each playing a pivotal role in advancing knowledge, fostering interdisciplinary collaboration, and shaping the academic discourse on digital platforms.
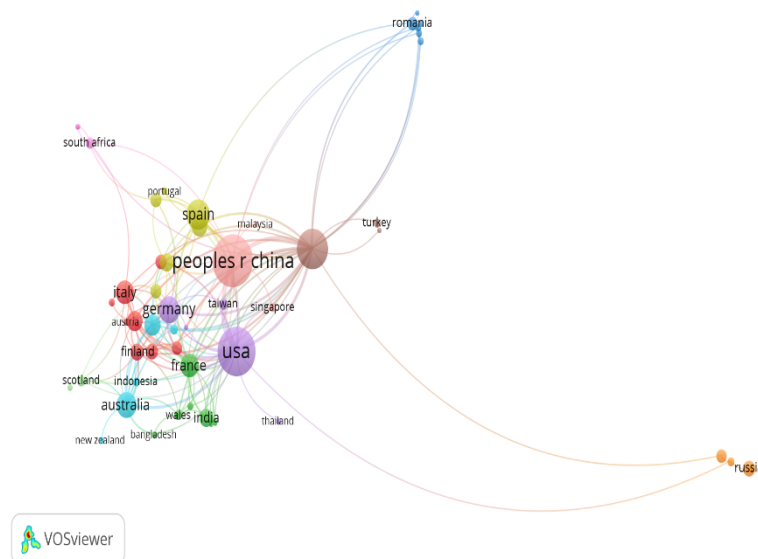

Figure 7
Bibliometric map on county with network visualization mode

The bibliometric analysis of leading countries in platform economy research (Figure 7) highlights the significant contributions of specific nations in terms of publication output. China stands out as the clear leader with 3,214 publications, reflecting a strong research focus and investment in digital platforms and data-driven economies. Spain follows closely with 3,031 publications, indicating a high level of academic engagement and interest in platform-based business models within the European context. The United States ranks third with 2059 publications, underscoring its long-standing role in the development of digital platforms, technological innovation, and regulatory frameworks in this field. England is in fourth place with 1557 publications, reaffirming its substantial contribution to

research on digital economies, including analyses of platform labor and socioeconomic implications. South Korea, with 970 publications, ranks fifth, emphasizing its focus on technological advancements and the rapidly growing platform economy in the Asia-Pacific region.

Conclusion

The paper reveals that the platform economy is a research hotspot of growing popularity, as demonstrated by bibliometric and visual analyses of the academic references sourced from the Web of Science between 2000 and 2024. It aims to identify the research hotspots and trends in this domain by examining major fields, the number of publications, authors, keywords, countries, and organizations. This research not only maps the current academic landscape but also provides a strategic foundation for guiding future scholarly and policy-oriented efforts in this increasingly relevant field.

The contribution of this study is reflected in the unification of recent scientific publications on the platform economy, providing a comprehensive overview of key research trends, influential authors, and institutional collaborations.

While this study has yielded valuable information and significant findings, it is important to acknowledge certain limitations. Firstly, the academic articles pertaining to the platform economy included in this research are not comprehensive, possibly omitting valuable references from journals not indexed in the Web of Science. Secondly, there may be an unavoidable linguistic bias since all retrieved articles are in English. To address these limitations, future research on the bibliometric analysis of the platform economy should consider several key improvements. First, expanding the dataset by incorporating articles from additional databases such as Scopus, Dimension.ai, and regional indexing services could provide a more comprehensive overview of the field. This would help capture relevant studies published in journals not indexed in the Web of Science, thereby reducing potential publication bias.

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Applying the COPRAS method for metaheuristic algorithm selection: The case of the economic dispatch problem

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Abstract: In recent literature, an increasing number of metaheuristic algorithms have been proposed for solving individual optimization problems. One such complex problem, widely studied and addressed with various algorithms, is the economic dispatch problem. Hence, this paper aims to establish a systematic approach for selecting the most suitable metaheuristic algorithm by employing the COPRAS (COmplex PRoportional ASsessment) method, a multi-criteria decision-making (MCDM) technique. The proposed methodology is applied to evaluate and rank five metaheuristic algorithms (MSA, FA, PSO, PSOGSA, and PSOCGSA) across four variants of the economic dispatch problem. The assessment considers multiple performance metrics, including best-obtained results, standard deviation, mean values, error rates, computation time, and convergence behaviour. To ensure the reliability of the ranking, the results were further validated using the EDAS method, confirming the robustness of the selection process. This study provides a structured framework for algorithm recommendation, aiding researchers and practitioners in choosing the most effective optimization approach for similar complex problems.

Keywords: metaheuristics, economic dispatch, MCDM, COPRAS method, EDAS method

1 Introduction

A wide range of metaheuristic algorithms has been proposed in the literature to address complex optimisation problems. These problems often have multiple subproblems, each characterised by distinct objective functions and constraints. According to the „No free lunch" theorem [1], a single algorithm for resolving a multifaceted problem cannot be the optimal solution for each subproblem. Consequently, there has recently been growing interest in developing

methodologies for selecting the most suitable algorithm from several proposed solutions to a specific multifaceted problem [2]. One such optimisation challenge is the Economic dispatch problem, which has received considerable attention in the literature due to its significance in power system operations [3]. In this study, we employ the COmplex PROportional Assessment (COPRAS) multi-criteria decision-making (MCDM) method [4] to identify the most appropriate metaheuristic algorithm for solving the economic dispatch problem. The algorithms under consideration include the Moth Swarm Algorithm (MSA) [5], Firefly Algorithm (FA) [6], Particle Swarm Optimisation (PSO) [7], PSOGSA [8], and PSOCGSA [2]. Given the comparable performance of these metaheuristic algorithms, a more detailed evaluation was conducted using a multi-criteria decision-making approach to establish a ranking based on their effectiveness across different functions. To ensure a comprehensive assessment, multiple performance metrics were considered, including the Best-obtained results (B), Standard Deviation (SD), Mean values (Mv), Error rates (Er), Computation time (Ct), and Convergence (C) for each algorithm. The most suitable algorithm for solving the Economic dispatch problem was identified by integrating these criteria according to four different functions. The COPRAS method enables a structured comparison and selection of the optimal algorithm. This methodology ensured that the ranking process accounted for the accuracy and robustness of the algorithms and their efficiency and stability across various problem variants.

2   Testing the algorithms

We test the selected algorithms on a standard IEEE 30-bus 6-generator system with a total load demand of 283.4 MW. Economic dispatch is the adjustment of the output power of several-generators in a thermal power plant to minimize fuel cost by satisfying the constraints in the system. In this optimization process, the four most commonly used objective functions (f_1, f_2, f_3, and f_4) are as follows:

$$f_1 = \sum_{g \in G} \left(a_g + b_g P_g + c_g P_g^2 \right), \ \ g = \ 1, \ 2, \ldots, G$$
$$P_{loss} = 0 \tag{1}$$

where, f_1 (\$/h) is the fuel cost function of all generator units in the thermal power plant that should be minimized; P_g is the output power of generator g (MW); G is the total number of generators; a_g, b_g and c_g are the cost coefficients. In this case, power losses P_{loss} in the power system to which the generators are connected are neglected ($P_{loss}= 0$).

$$f_2 = \sum_{g \in G} \left(a_g + b_g P_g + c_g P_g^2 \right), \ \ g = \ 1, \ 2, \ldots, G$$
$$P_{loss} = \sum_{g \in G} \sum_{j \in G} P_g B_{gj} P_j + \sum_{g \in G} B_{0g} P_g + B_{00} \tag{2}$$

In this case, the objective function is the same as in the previous one, but the power losses P_{loss} in the system are taken into account. B_{gj} and B_{0g} are the coefficients of the **B**-loss matrix, and B_{00} is a constant.

$$f_3 = \sum_{g \in G} \left(a_g + b_g P_g + c_g P_g^2 \right) + \sum_{g \in G} \left| d_g \sin \left(e_g \left(P_g^{\min} - P_g \right) \right) \right|, \quad g = 1, 2, \ldots, G$$
$$P_{loss} = 0 \tag{3}$$

In this case, the fuel cost function (f_3) takes into account the valve point effect in the thermal power plant. $P_g^{\min}$ (MW) is the minimum power of the generator g; d_g and e_g are coefficients for valve point effect. P_{loss} are neglected.

$$f_4 = \sum_{g \in G} \left(a_g + b_g P_g + c_g P_g^2 \right) + \sum_{g \in G} \left| d_g \sin \left(e_g \left(P_g^{\min} - P_g \right) \right) \right|, \quad g = 1, 2, \ldots, G$$
$$P_{loss} = \sum_{g \in G} \sum_{j \in G} P_g B_{gj} P_j + \sum_{g \in G} B_{0g} P_g + B_{00} \tag{4}$$

Function f_4 represents the fuel cost function, which accounts for both power loss and the valve-point effect. The constraint on generator power output remains consistent across all four optimization processes and is defined as follows:

$$P_g^{\min} \leq P_g \leq P_g^{\max} \tag{5}$$

where, $P_g^{\min}$ and $P_g^{\max}$ are the minimum and maximum power of generator g, respectively. During the optimization process the power balance in the system must be satisfied, i.e.:

$$\sum_{g \in G} P_g - P_D - P_{loss} = 0 \tag{6}$$

where, P_D is the total power of the consumer. Coefficients of fuel cost, emission and B-loss matrices are taken in this paper from [9]. The algorithms are implemented in MATLAB R2017a computational environment and run on 1.3 GHz, with 8.0 GB RAM. The best results of the simulations are obtained after 30 runs. The coefficients of the algorithms are shown in Table 1.

FA					MSA			PSOGSA and PSOCGSA						PSO			
N	t_{max}	α	$\beta_{\min}$	γ	N	t_{max}	N_c	N	t_{max}	G_0	α	C_1	C_2	N	t_{max}	C_1	C_2
50	200	0.25	0.20	1	50	200	6	50	200	1	20	0.5	1.5	50	200	0.5	1.5

Table 1.
Coefficients of the algorithms applied to the test system

The testing results indicate that the optimal fuel cost values are either identical or highly similar across all five algorithms. However, other performance metrics exhibit varying degrees of similarity or significant differences among the tested algorithms. In the next section, algorithms are ranked based on multiple evaluation metrics, overused functions of Economic dispatch problem.

3 COPRAS method in Multi-Criteria Decision-Making

The Complex Proportional Assessment (COPRAS) method is a widely used multi-criteria decision-making (MCDM) approach that facilitates the ranking and selecting alternatives based on multiple conflicting criteria. Introduced by Zavadskas, Kaklauskas, and Sarka in 1994, COPRAS is particularly effective in situations where decision-makers must evaluate alternatives by considering both beneficial and non-beneficial criteria while maintaining proportionality between the alternatives [10], [11]. This method follows a systematic process for ranking and evaluating options based on their relative importance and utility. By analysing best-case and worst-case scenarios, COPRAS ensures a well-balanced decision-making approach that effectively accounts for trade-offs between competing criteria. Key characteristics of the COPRAS method include its compensatory nature, which allows weaker criteria to be offset by stronger ones, its ability to maintain independence among attributes, and its capability to convert qualitative attributes into quantitative measures, making it a versatile tool for multi-criteria decision-making applications [12].

Step 1. Formulation of Decision Matrix

$$X = \begin{bmatrix} x_{ij} \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & ... & x_{1n} \\ x_{21} & x_{22} & ... & x_{2n} \\ ... & ... & ... & ... \\ x_{m1} & x_{m2} & ... & x_{mn} \end{bmatrix} \tag{7}$$

Where x_{ij} is the estimated value of the *i*-th in relation to the *j*-th criterion, *m* is the number of alternatives and *n* is the number criteria.

Step 2. The Normalized Decision Matrix. Normalization of the initial decision matrix using the linear normalization procedure. The equation (8) is used for normalization in the COPRAS method:

$$R = \begin{bmatrix} r_{ij} \end{bmatrix} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{8}$$

Step 3. The Weighted Normalized Decision Matrix. Equation (9) is used to calculates the values for the weighted normalized decision matrix.

$$D = \begin{bmatrix} x_{ij} \end{bmatrix} = r_{ij} \cdot w_j \qquad i = 1, \dots, m; \quad j = 1, \dots, n \tag{9}$$

Where w_j is the normalized value of the i-th alternative in relation to the j-th criterion and w_j is the weight or importance of the j-th criterion. The sum of weighted normalized values for each criterion is always equal to the value of that criterion:

$$\sum_{i=1}^{m} y_{ij} = w_j \tag{10}$$

Step 4. The Maximizing and Minimizing Indexes

The indices for maximising and minimising each attribute are determined by whether the attributes are negative or positive, utilizing equations (11) and (12):

$$S_{+i} = \sum_{i=1}^{n} y_{+ij} \tag{11}$$

$$S_{-i} = \sum_{i=1}^{n} y_{-ij} \tag{12}$$

Where y_{+ij} and y_{-ij} are weighted normalized values for positive or negative criteria, respectively.

Step 5. The relative significance value. Determining the relative importance of each alternative. Relative weight Q_i for the i-th alternative is calculated using the equation (13) or equation (14):

$$Q_i = S_{+i} + \frac{\min_i s_{-1} - i \sum_{i=1}^{m} s_{-i}}{s_{-i} \sum_{i=1}^{m} \dfrac{\min_i s_i}{s_{-i}}} \tag{13}$$

$$Q_i = S_{+i} + \frac{\sum_{i=1}^{m} s_{-i}}{s_{-i} \sum_{i=1}^{m} \dfrac{1}{s_{-i}}} \tag{14}$$

Step 6. Final Ranking of Alternatives. The alternatives are arranged in descending order according to their relative importance values, with the highest final value ranked first.

The COPRAS method has been extensively applied across various fields due to its efficiency in handling multi-criteria decision-making problems. It has been widely utilized in engineering optimization [4], transportation planning [13], energy sector

analysis [14], supply chain management [15], in risk assessment [16], [17], [18], investment project selection [19], manufacturing environments [20], logistics performance evaluation [21], public health and occupational safety [22], aerospace engineering [23]. These diverse applications underscore the robustness and adaptability of the COPRAS method, making it a powerful tool for tackling complex decision-making challenges across multiple industries. Compared to other MCDM methods, such as TOPSIS and VIKOR, COPRAS offers a straightforward computational process and ensures that the final ranking reflects the relative importance of each criterion while maintaining consistency in decision-making [14]. Therefore, in this research COPRAS method is used to rank algorithms according to different performance measures to solve mentioned Economic dispatch problem variants.

4 Results of ranking algorithms

Based on the findings from the previous research phase, the five algorithms tested, MSA, FA, PSO, PSOGSA, and PSOCGSA, were ranked using the COPRAS method. The initial decision matrix, presented in Table 2, displays key performance metrics for each algorithm, including the best (minimum) obtained values, mean values, standard deviation, error rate, convergence rate, and computation time.

After performing the linear normalization explained in step 2 equation (8) and weighting the normalized matrix equation (9), the weight-normalized decision matrix is obtained (Table 3).

Criteria → Alternatives ↓	Best (B) min				Standard Deviation (SD) min			
	B (f1)	B (f2)	B (f3)	B (f4)	f1 (SD)	f2 (SD)	f3 (SD)	f4 (SD)
MSA	600.11140866	605.99836998	631.34826554	635.82880914	4.42645122E-06	6.81784E-06	7.8239730665	6.627336699
FA	600.11140820	605.99836950	631.34937828	635.82395070	5.103360307E-04	0.030611058	4.6155303303	0.255825779
PSO	600.11140819	605.99836946	631.90736059	635.90446527	5.893239936E+00	6.858534642	6.3725351986	8.401397207
PSOGSA	600.11140819	605.99836946	631.33121085	635.82011047	3.468910298E-13	11.12599965	6.6175988664	15.576524660
PSOCGSA	600.11140819	605.99836946	631.33122939	635.82041383	2.701100444E-08	7.285294731	4.9459138782	8.722792025
Criteria →	Mean value (Mv) min				Error rate (Er) min			
	f1 (Mv)	f2 (Mv)	f3 (Mv)	f4 (Mv)	f1 (Er)	f2 (Er)	f3 (Er)	f4 (Er)

Alternatives↓								
MSA	600.11141342	605.99837820	639.59170422	639.62799639	8.713818E-07	1.44223E-06	1.3085116005	0.59889359 6
FA	600.11153488	606.00395852	633.36741788	636.03929498	2.111228E-05	0.000922291	0.3226120308	0.03447272 3
PSO	606.06077310	611.09555167	642.59481029	648.73761871	9.913767E-01	0.84112144	1.7841903904	2.03162939 1
PSOGSA	600.11140819	616.65200830	636.37489520	661.44054499	5.683287E-14	1.758030943	0.7989832102	4.02950993 4
PSOCGSA	600.11140823	607.90362553	633.28208453	637.91709308	7.313727E-09	0.314399539	0.3090956101	0.32980753 1
Criteria →	**Computation time (Ct)** *min*				**Convergence (C)** *min*			
Alternatives↓	*f1 (Ct)*	*f2 (Ct)*	*f3 (Ct)*	*f4 (Ct)*	*f1 (C)*	*f2 (C)*	*f3 (C)*	*f4 (C)*
MSA	0.74757034	3.579557657	1.836055390	4.970300697	106	97	750	471
FA	1.79574585	3.931430443	4.551615297	6.506888597	66	68	252	334
PSO	1.08263050	3.162463743	1.304519950	3.054587227	43	38	98	156
PSOGSA	0.7845	1.6958	1.9987	1.5170	18	28	71	85
PSOCGSA	0.7856	2.3182	2.0949	4.7472	20	17	129	166

Table 2
The initial matrix for ranking tested algorithms

Criteria→	**Best (B)**				**Standard Deviation (SD)**			
Alternatives ↓	*B (f1)*	*B (f2)*	*B (f3)*	*B (f4)*	*f1 (SD)*	*f2 (SD)*	*f3 (SD)*	*f4 (SD)*
MSA	0.0083	0.0083	0.0083	0.0083	0.0000	0.0011	0.0107	0.0070
FA	0.0083	0.0083	0.0083	0.0083	0.0000	0.0000	0.0063	0.0003
PSO	0.0083	0.0083	0.0083	0.0083	0.0417	0.0110	0.0087	0.0088
PSOGSA	0.0083	0.0083	0.0083	0.0083	0.0000	0.0178	0.0091	0.0164
PSOCGSA	0.0083	0.0083	0.0083	0.0083	0.0000	0.0117	0.0068	0.0092
Criteria→	**Mean value (Mv)**				**Error rate (Er)**			
Alternatives↓	*f1 (Mv)*	*f2 (Mv)*	*f3 (Mv)*	*f4 (Mv)*	*f1 (Er)*	*f2 (Er)*	*f3 (Er)*	*f4 (Er)*

	f1	f2	f3	f4	f1	f2	f3	f4
MSA	0.0083	0.0083	0.0084	0.0083	0.0000	0.0020	0.0121	0.0036
FA	0.0083	0.0083	0.0083	0.0082	0.0000	0.0000	0.0030	0.0002
PSO	0.0084	0.0084	0.0084	0.0084	0.0417	0.0115	0.0164	0.0121
PSOGSA	0.0083	0.0084	0.0083	0.0085	0.0000	0.0239	0.0074	0.0239
PSOCGSA	0.0083	0.0083	0.0083	0.0082	0.0000	0.0043	0.0028	0.0020
Criteria→ Alternatives↓	**Computation time (Ct)**				**Convergence (C)**			
	f1 (Ct)	*f2 (Ct)*	*f3 (Ct)*	*f4 (Ct)*	*f1 (C)*	*f2 (C)*	*f3 (C)*	*f4 (C)*
MSA	0.0060	0.0102	0.0065	0.0100	0.0175	0.0163	0.0240	0.0162
FA	0.0144	0.0112	0.0161	0.0130	0.0109	0.0114	0.0081	0.0115
PSO	0.0087	0.0090	0.0046	0.0061	0.0071	0.0064	0.0031	0.0054
PSOGSA	0.0063	0.0048	0.0071	0.0030	0.0030	0.0047	0.0023	0.0029
PSOCGSA	0.0063	0.0066	0.0074	0.0095	0.0033	0.0029	0.0041	0.0057

Table 3

Weight-normalized decision matrix

All criteria must be minimised. Employing equation (12) in step 4, the resulting matrix is obtained, which reveals the calculated total of the cost criteria. The obtained results from this step is present in Table 4.

Alternatives	S_{-i} (min)
MSA	0.2095
FA	0.1728
PSO	0.2691
PSOGSA	0.1996
PSOCGSA	0.1490

Table 4.

Presentation of gained values S_{-i}

Applying equation (13), a matrix with the following values is obtained based on which alternatives are ranked. The obtained results is present in Table 5.

Alternatives	Q_i	Rank
MSA	0.1839	4
FA	0.2226	2
PSO	0.1429	5
PSOGSA	0.1928	3
PSOCGSA	0.2581	**1**

Table 5.

Ranking list of algorithm using COPRAS method

The best-ranked algorithm applied in four different functions according to the best results, standard deviation, computation time and convergence is PSOCGSA, followed by the FA, PSOGSA, MSA and PSO algorithm.

5 Validation of results using EDAS method

To further validate the results obtained through the COPRAS method and ensure the accuracy of the ranking, the EDAS (Evaluation Based on Distance from Average Solution) method was employed [24]. EDAS is a multi-criteria decision-making technique that evaluates alternatives based on their distances from an ideal or average solution [25], providing a complementary perspective to the COPRAS method. In this approach, the alternatives are assessed by calculating their positive (S_i^+) and negative (S_i^-) distances from the average solution, which represents a reference point in the decision space. These distances are then used to rank the alternatives, with the smallest positive distance indicating the best-performing alternative [26]. Table 6 displays the final rankings of the analyzed algorithms based on the EDAS method.

Alternatives	S_i^+	S_i^-	S_i	Rank
MSA	0.7107	0.4184	0.565	4
FA	1	0.6513	0.826	2
PSO	0.3018	0	0.151	5
PSOGSA	0.8770	0.4234	0.650	3
PSOCGSA	0.9836	0.9378	0.961	**1**

Table 6

Ranking list of algorithm using EDAS method

The results obtained by the ranked algorithms using the EDAS method showed consistency in the ranks obtained for different performance measures compared to the COPRAS method results. Namely, the application of the EDAS method indicates that the best-ranked algorithm is PSOCGSA (according to the best results, standard deviation, computation time, and convergence), which points out that the validity of the obtained results was achieved.

The application of the EDAS method allowed for the cross-validation of the results derived from COPRAS method, providing additional confidence in the robustness and consistency of the obtained ranking. By comparing the rankings from both methods, a more comprehensive and reliable assessment of the alternatives was achieved, enhancing the overall decision-making process.

Conclusion

This study applied the COPRAS multi-criteria decision-making method to rank and evaluate metaheuristic algorithms for solving the multi-objective Economic dispatch problem. The ranking criteria were based on multiple performance measures, assessing each algorithm's effectiveness in addressing different subproblems of the optimization task. By integrating these criteria, the PSOCGSA algorithm was identified as the most suitable solution for the Economic dispatch problem. The COPRAS method facilitated a structured and systematic comparison, ensuring that the final ranking considered the accuracy and robustness of the algorithms and their computational efficiency and stability across various problem variants. The EDAS method was employed to validate these findings, confirming our ranking procedure's reliability. The results of this study demonstrate that the proposed methodology is effective and can be extended to other optimization problems requiring the selection of the most appropriate metaheuristic algorithm.

Acknowledgement

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Unlocking food security: the power of labelling in consumer trust and safety

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Abstract: Food safety and food security are critical to public health, economic stability, and national security. This study explores the role of food labelling in strengthening food safety by enhancing consumer trust. To investigate this relationship, we conducted a literature review, selecting studies based on predefined inclusion and exclusion criteria. The review focused on peer-reviewed studies published in English between 2014 and 2024 that investigated the association between food labelling and food safety and security. Improved food labelling can ensure that consumers have access to reliable and accurate product information, thereby mitigating food insecurity. In addition, the adoption of digital food labelling systems and certification mechanisms can improve food safety outcomes and enhance consumer trust.

1 Introduction

Food security has evolved from a narrow concept of food supply and availability to a multidimensional concept that encompasses economic, social and cultural aspects[1]. Ensuring food security requires not only adequate supply but also safe, nutritious and accessible food. Food safety is a fundamental component of food security, ensuring that food is free from contamination and fit for consumption, providing nutritional value[2]. Without food safety, the broader goal of food security cannot be fully achieved, as hunger causes anxiety and fear, or contaminated, unsafe food undermines health and well-being[3-8].

Food labels are a direct channel of communication between manufacturers, retailers, regulators, third-party certification bodies and consumers[9]. This study examines the interaction between food safety, food safety and food labelling, analysing mandatory information (such as nutritional content, production date and expiration date) and voluntary labelling (such as organic certification and GMO-free claims). In addition, we assess how emerging technologies, including blockchain and AI-based traceability systems, can improve the transparency and credibility of food labels. Given the increasing complexity of food systems and the growing need for transparency, this study focuses on the role of food labels in strengthening food safety, particularly by increasing consumer trust. Furthermore, food insecurity can

exacerbate conflict and undermine regional stability. Integrating food systems into national security frameworks can enhance the resilience of food systems and reduce vulnerabilities that can be exploited in times of crisis by focusing on the intersection of food safety, security and technology.

2 Methodology

For studies on food labelling with safety and security, we developed research questions and inclusion and exclusion criteria. The inclusion criteria used in this systematic review were (i) focusing on the relationship between food labelling and food safety and security (ii) academic peer-reviewed journals and research articles, (iii) publications written in English, and (iv) papers published within the research timeline (2014-2024). Exclusion criteria were those that (i) were not relevant to the topic of interest.

3 Results

3.1 The relationship of food security and food safety

Food security has evolved constantly since its initial definition in the 1970s by World Food Conference(1974), defined food security as food supply - assuring the availability and price stability of basic foodstuffs at the international and national level [10]. According to World food summit in 1996, they state that food security is "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life [11]". FAO divides food security into four parts: Food availability(supply and resource); food Access(affordability or social safety; utilization(sustain health and well-being) and stability(development and sustainability) [1],which improved food security in terms of availability and access, market development, natural resource management and access to basic services. The focus of food security has shifted from food supply, food availability to a broader definition. This shift reflects an increasing understanding that food security involves multiple dimensions that includes economic (economic access to food), social, and cultural aspects associated with well-being (food preferences, quality, safety, and nutrition) [2]. Food insecurity impacts well-being especially in less developed country [4, 12]. Food insecurity well-being includes three factors: (i) sensory experiences(hunger) [3, 4]; (ii) affective experiences(such as anxiety and

fear, mental health is found to be strongly associated with food insecurity [5-8]); and (iii) evaluative experiences(relative deprivation) [13].

Food safety is a foundational aspect of food security. Food safety involves foodborne illness and includes the handling, preparation and storage of food [14]. Food safety is an essential component of food security, particularly in the context of food utilization [1]. Food safety refers to the entire process from food production to consumption, ensuring that food is safe when eaten and does not cause harm to consumers' health [15]. It includes: pollution prevention and control: preventing food from being contaminated by biological (such as bacteria, viruses), chemical (such as pesticides, heavy metals) and physical (such as foreign matter) [16-18]; handling and storage: ensuring that food remains hygienic and safe during production, processing, transportation and storage [19, 20]; and regulations and standards: complying with relevant food safety regulations to ensure food traceability and controllability [15, 21, 22].

Figure 1
The relationship between food security and food safety

Among them, the standards and systems commonly used in food safety assessment are: HACCP (Hazard Analysis and Critical Control Points; ISO 22000 (Food Safety Management System); GFSI (Global Food Safety Initiative; IFS (International Featured Standards; FSSC 22000 (Food Safety System Certification 22000, Food Safety System Certification); Codex Alimentarius (Food Code); FSMA (Food Safety Modernization Act) of the United States; Regulations of the European Food Safety Authority (EFSA); China's national food safety standards (GB standards), etc., as shown in Table 1. These standards and systems mainly include international, regional and national food safety standards to ensure that all links in the production, processing, transportation and sales of food meet the requirements.

As mentioned above, food security focuses on whether food can be effectively obtained and continuously supplied, including four key elements: availability, accessibility, utilization and stability. The utilization part is closely related to food safety, ensuring that the food obtained is safe, nutritious and suitable for consumption. Without food safety, the other dimensions of food security—particularly access and utilization—cannot be fully realized, as unsafe food undermines the very goal of providing nutritious and reliable sustenance. Thus, food safety acts as a foundation for achieving broader food security.

In the situation of resource constraints, food security prioritizes concerns about persistent food shortages and hunger when hunger is more urgent to be addressed than food safety [23]. However, generally food security always prioritizes food safety over healthy nutrition [24]. To establish healthy and sustainable food production and food systems, food safety is also very important, and food safety and food security must be combined to meet the food security challenges facing humanity.

Standard	Description	Application	Aera
HACCP	Hazard Analysis and Critical Control Points	Food manufacturing, processing, catering, etc.	Global
ISO 22000	ISO 22000 helps Food Safety Management System	Food supply chain	Global
GFSI	Global Food Safety Initiative	Retail, food manufacturing, supply chain, etc.	Global
IFS	International Featured Standards	Food Manufacturing (retailers and suppliers)	Europe
FSSC 22000	Food Safety System Certification 22000 based on ISO 22000, recognized by GFSI.	Food production, processing and manufacturing enterprises	Global
Codex Alimentarius (Food Code);	It developed by the United Nations and the World Health Organization	All types of food	Global
Regulations of the European Food Safety Authority	It covers standards for food additives, residues and other aspects.	All types of food	Europe
China's national food safety standards (GB standards)	It issued by the Chinese government stipulate requirements for food additives, pesticide residues, etc.	All types of food	China

Table 2
The standards and systems commonly used in food safety assessment

3.2 Food labelling: a way to enhance food security

3.2.1 Food labelling guidelines

Food labels refer to information on prepackaged food [25]. "Prepackaged" means packed or prepared in advance in a container and ready to be provided to consumers or for catering purposes. The internationally recognized definition of food labelling is any label, brand, mark, picture or other descriptive material, etc. In modern society, food systems are often made up of long supply chains, which results in a large degree of separation between consumers and growers, reducing consumers' understanding and involvement in food production [26]. Food labels are the main way for consumers to obtain food-related information, also seen as a policy tool to help transition to healthier, more sustainable food systems. At the same time, food producers are very interested in using product labels to inform consumers about the quality of their products and brands at the point of purchase, and to connect with consumers [25]. Food labels refer to information on pre-packaged food, "Pre-packaged" means packaged or made up in advance in a container, ready for offer to the consumer, or for catering purposes. The internationally recognized definition of food label is any tag, brand, mark, pictorial or other descriptive matter, written, printed, stencilled, marked, embossed or impressed on, or attached to, a container of food [27]. According to the General standard for the labelling of prepackaged foods by Codex Alimentarius Commission, the following information is mandatory labelling content: the name of food; list of ingredients; net content and drained weight; name and address of the manufacturer, exporter, importer, packer, distributor or vendor; country of origin; lot identification; date marking and storage instructions; instructions for use; The Codex Alimentarius Commission also provides for the following eight foods and ingredients known to cause allergies should always be declared on the label as table 2 showed. (wheat, crustacean shellfish, egg, fish, peanuts, and soy, milk, tree nuts and sulfurizing agents when Sulphite in concentrations of 10 mg/kg or more) need to be labelled [27-29]. If the food has been treated with ionizing radiation, a written statement must be attached [27]. In some cases, quantitative labelling of ingredients is also required. According to Codex general standard for the labelling of pre-packaged foods must not be described or presented on any label in a manner that is false, misleading or deceptive or as this could create an erroneous impression in any respect as to their characteristics [27]. Since consumer trust is an important driver of consumer food choices [30, 31]. It follows that, food labels play a vital role in build customer trust. Therefore, ensuring accurate and transparent food labels helps consumers make healthier and safer food choices [32].

Currently, although the pre-packaged food labelling guidelines around the world are based on the Food Codex Alimentarius of the Food and Agriculture Organization of the United Nations(FAO) and World Health Organization(WHO) , there are great differences in specific regulatory requirements among countries [25].
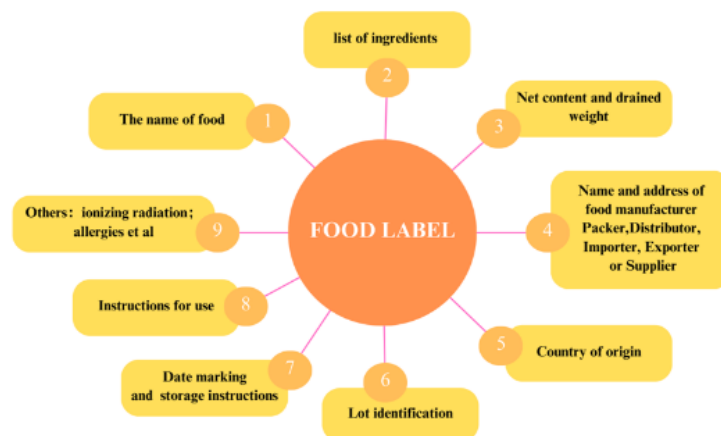
Figure 2

Content of food label

	Type of foods and ingredients known to cause hypersensitivity
1	Cereals containing gluten; i.e., wheat, rye, barley, oats, spelt or their hybridized strains and products of these
2	Crustacea and products of these;
3	Eggs and egg products
4	Fish and fish products
5	Peanuts, soybeans and products of these;
6	Milk and milk products (lactose included)
7	Tree nuts and nut products
8	Sulphite in concentrations of 10 mg/kg or more

Table 3

Mandatory labelling - foods and ingredients known to cause allergies

3.3 Food labelling with food security and consumer trust

Food labels are a direct communication channel between manufacturers, retailers, regulators and third-party certification bodies and consumers[9]. Research on the credibility of food labels plays a key role in food security research[33]. When consumers doubt label information, it may affect their trust in product quality, which in turn has a negative impact on their purchasing decisions. In addition, inaccurate or ambiguous label information (such as unclear expiration dates and

opaque ingredients) may cause consumers to refuse to buy and even cause food waste[34]. With the development of emerging technologies (such as blockchain, food traceability systems, artificial intelligence), the transparency of the food supply chain has been significantly improved[35, 36]. These technologies help enhance the authenticity of food labels and increase consumer trust in labels[37, 38].

Given the increasing complexity of food systems and the growing need for transparency, this study focuses on the role of food labelling in strengthening food safety, particularly by increasing consumer trust.

By analyzing mandatory information on labels (such as nutritional content, production date, shelf life, etc.) and voluntary information (such as organic certification, GMO-free, etc.), we can explore the differences in consumers' perception and trust in labels. In particular, how emerging technologies such as blockchain and AI-based traceability systems can enhance the transparency of the food supply chain, improve consumers' trust in food labels, and provide a reference for optimizing the safety of food label design.

4 Discussion

Food labels are a bridge between food safety policies and consumer behavior. Accurate and transparent labels are essential to foster consumer trust and reduce food-related health risks. In addition, emerging technologies have a positive impact on food labelling transparency. Blockchain technology enables safe, tamper-proof traceability in the food supply chain, providing consumers with verifiable information about product origins and safety standards. Similarly, AI-driven certification systems can improve labelling accuracy and prevent fraudulent misrepresentations. By integrating these technologies into food labelling systems, regulators and industry stakeholders can improve food safety and minimize the risks associated with mislabeled or contaminated products.

Another aspect is the psychological and behavioral response of consumers to food labels. Clear and easy-to-understand labels have a positive impact on purchasing decisions, reduce uncertainty and improve product safety. Distrust in food labels, especially in regions with a history of food safety scandals, can lead to people being reluctant to consume products and even cause food waste. Therefore, enhanced public education on food labelling and improved regulatory enforcement can enhance consumer confidence.

In addition, this study highlights the broader safety impact of food labelling. In crisis situations such as conflict or natural disasters, ensuring the authenticity and traceability of food sources is critical. A robust food labelling framework can serve as a national security tool to prevent food fraud, mitigate economic disruptions and promote stability in the food supply chain.

Conclusion

This study highlights the critical role of food labelling in improving food safety and consumer trust. Blockchain and AI-driven labelling systems offer promising solutions to improve traceability, prevent food fraud, and ensure compliance with safety standards. Future research should explore the long-term impact of digital food labelling on consumer behavior, especially in different cultural contexts. Policymakers should also consider harmonizing food labelling regulations to facilitate international trade and enhance global food security, so that food labelling can become an important tool to achieve a safer and more transparent food system.

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Blockchain-Based Transportation IT Solutions in Supply Management

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Abstract The Intelligent Transport System has made transportation more efficient. With available traffic information and 5G technology, cars can effectively transmit relevant information to other road users, such as congestion, environmental forecasting, and accidents. This information is vital to designing a fast and efficient means of transport. However, many people do not participate in the sharing of information, even depending on the possibility, because this means that a lot of personal information about the car and its owner must be provided. The information systems used so far could not solve these problems. However, in the case of vehicles authenticated in the blockchain, the personal data of the car owner will remain secret and will not be made public. Due to decentralization, trust is based on blockchain technology and not on personal and sensitive data. To this end, the research goal is to create a blockchain where ITS data can be safely stored. Since the registration data can be efficiently saved in the blockchain, a smart contract is created without any special knowledge of its use by the end user. A smart contract always requires a simple registration, which is recorded in the contract. The data specified in the contract are automatically saved in the blockchain, avoiding all "traditional" centralized data storage solutions, thereby increasing the safe storage of data.

Keywords: Blockchain technology, Smart contract, Data security, Ethereum sidechain

1 Introduction

The 21st Century has been continuously digitalized, which gradually helped to introduce new and innovative technologies [1]. The rapid and dramatic development of information technology, over the recent decade, cannot be denied [2], which has seen many good and bad solutions in the past [3]. Blockchain technology and distributed ledgers are attracting massive attention and triggering multiple projects in different industries [4]. Traffic management and passenger safety are important domains where ubiquitous connectivity between vehicles can play a vital role [5]. This crucial and imperative need in our transportation system is not only important but also extremely essential for the present and future of road networks, vehicles, and user sustenance. Improvement in road and vehicle transport

technology has continued to redefine the current expectations and, subsequently prospects of sustainable transport and traffic management [6].

The application of blockchain technology makes it possible to transfer the ITS solution to a decentralized environment. Due to the structure of the blockchain called ITSB, the blocks are closely connected and form a high level of security suitable for data storage. Blocks of the blockchain contain all ITS-related data important for road users. The structure of the ITSB blocks is shown in the Fig. 1 below.
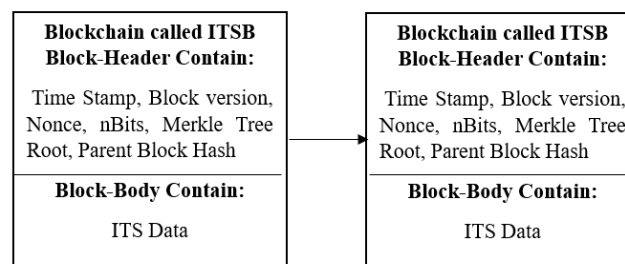

Figure 1
Building the structure of the blocks of the blockchain called ITSB

The research questions that guided this study were as follows:

Research Question 1:

Is it possible to create a blockchain with private access to securely store data generated by smart intelligent transport systems?

Achieving this research goal is a big challenge because decentralized peer-to-peer data storage systems are much more complex than the centralized data storage solutions that have been frequently used and accepted up to now.

Research Question 2:

Can the data generated by intelligent transport systems be automatically uploaded to the private access blockchain by using a smart contract?

The motivational goal is to write a smart contract that can automatically upload data to the ITSB blockchain for supply chain management. Until now, such a solution has not been created in scientific life.

Trends are the results of economic processes that can even change development trends [7]. Centralized data storage solutions are widely accepted these days, but this is also a trend that will presumably change since newer and safer data storage can be implemented in a decentralized environment, which is one of the important motivational points of this research. It is typical of this research that it presents so many new solutions, the acceptance of which is not uniform even in the IT sector.

The research is structured according to the following structure:

- Modern solutions between ITS and blockchain technology,

- Creation of a blockchain called ITSB,

- Creating a smart contract for the automated storage of data for the ITS system.

2 Building a Model of the Relationship Between itsb Blockchain and the its Smart Contract for Intelligent Transportation Systems

With the authentication of information on vehicular network events, it is important to authenticate the sender and forwarder of this information. The authentication is more critical with moving vehicles. As we know, the vehicular network is composed of different regions. Vehicles move continuously across these regions and lose their connectivity with previously visited regions. Because in every region, another data center is installed, and there are fewer chances of registration of nodes with this. So, it becomes more difficult for moving vehicles to authenticate in real time. The authors proposed a system model in which volatile vehicles move from one data center to another. Each data center has a specific service manager who is responsible for managing the vehicular fog service. The data of vehicular fog service is stored in fog, and the hash of this data is stored in the blockchain. The service managers are also responsible for storing the ledger with which the vehicles are authenticated. As the same ledger is present at each service manager's database, the service manager of the different regions is now able to authenticate the vehicle easily. This will prominently reduce the time of authentication [8]. Fig. 2 below shows the more important steps in building a blockchain-based ITS system.
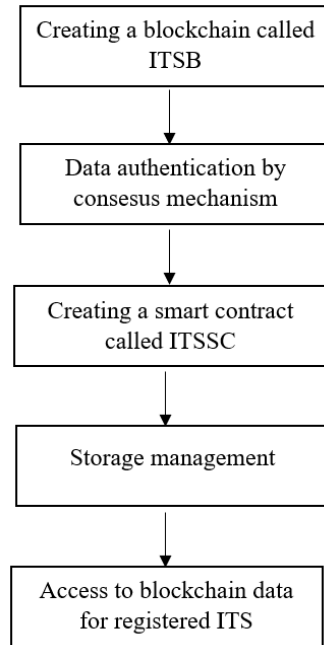
```
┌─────────────────────────┐
│  Creating a blockchain called │
│           ITSB           │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│   Data authentication by   │
│    consesus mechanism    │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│   Creating a smart contract  │
│       called ITSSC        │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│     Storage management     │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│   Access to blockchain data  │
│     for registered ITS     │
└─────────────────────────┘
```

Figure 2

More important steps in building a blockchain-based ITS system

To build the system, 3 layers are needed, which are closely connected. In the first step, the data is entered, the communication layer is connected to this, and then the layer responsible for security. Security is of paramount importance in this case, as this necessitates the use of blockchain technology. Without modern database security solutions, the available ITS information loses its relevance. According to my formulation, database security can be defined as follows:

Database security is defined as the ability to resist threats and attacks, and the totality of defending resources, which will avert all unauthorized natural and legal entities, as well as malicious computer programs' intentions in influencing the database's operation, as well as their causing any type of damage to database's rightful owners, or users. The security requisites are confidentiality, integrity, and accessibility, as well as undeniability and authenticity [9].

Fig. 3 below presents the layered architecture of the ITS and blockchain system.
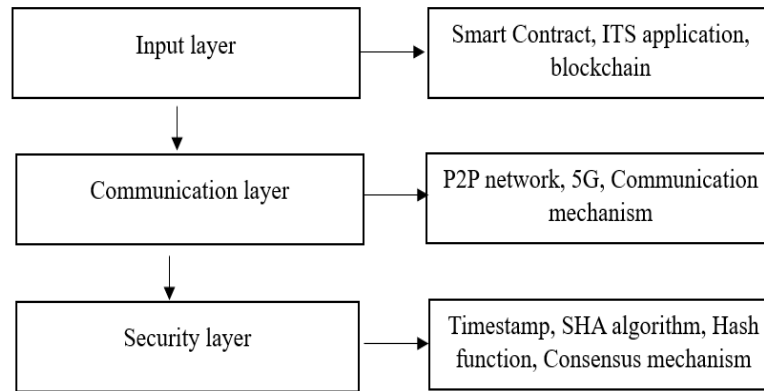
Figure 3

The layered architecture of the ITS and blockchain system

3 Creation and Configuration of ITSB Blockchain Genesis Block

The first and most important step in creating a blockchain is to create a Genesis block. The Genesis block is essentially the first block in the blockchain. Fig. 4 below presents the close relationship between the genesis block and subsequent blocks.
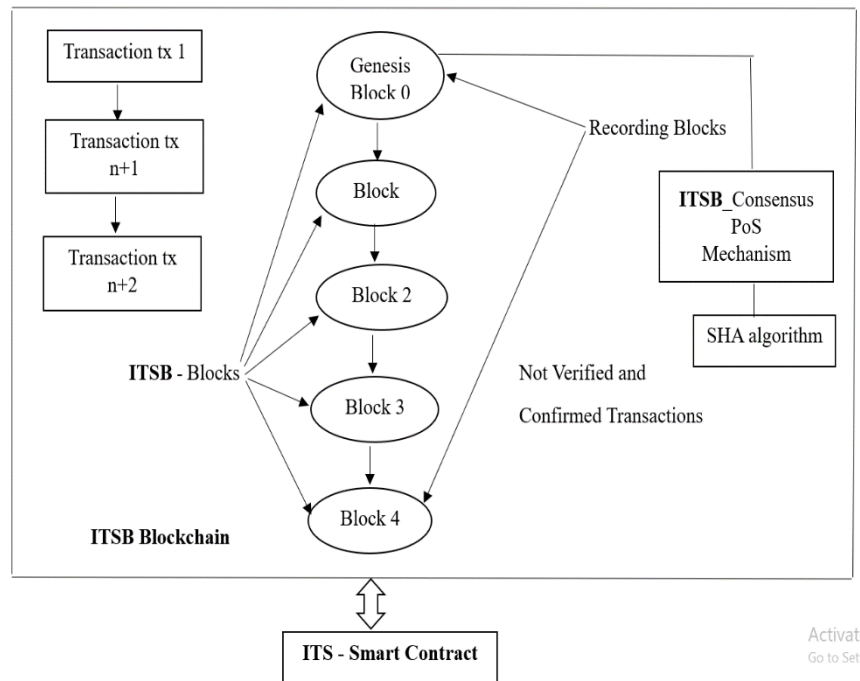
Figure 4

Schematic block diagram of the blockchain base mode

The source code of the first block of the ITSB blockchain is demonstrated in Fig. 5 below.

```
{

 "config": {

  "chainId": ITS_100,

  "homesteadBlock":1,

  "ERC20Block": 1,

  "byzantiumBlock": 1

 },

 "difficulty": "200",

 "gasLimit": "50",

 "extraData": "0x00",

 "alloc": {

  "56c5kza8obv0097562220872534698hjdsjcyq94n": {

  "balance": "2"

  },

  "hol84dpmv82554kpcneqfwwjm00054867596knz": {

  "balance": "2"

  }

 }
```

Figure 5

Creation of ITSB blockchain Genesis block

The following are the most important commands used during the creation of the ITSB blockchain:

- Config: It defines the blockchain configuration and determines how the network will work.

- ChainId: This is the chain number used by several blockchains. The Ethereum main chain number is "1". Any random number can be used if it does not match with another blockchain number.

- HomesteadBlock: It is the first official stable version of the Ethereum protocol, and its attribute value is "0". One can connect other protocols such as Byzantium, eip155B, and eip158. To do this, under the homesteadBlock add the protocol name with the Block prefix (for example, eip158Block) and set the parameter "0" to them.

- Difficulty: It determines the difficulty of generating blocks.

- GasLimit: Gas is the "fuel" that is used to pay transaction fees on the Ethereum network. The more gas a user is willing to spend, the higher will be the priority of his transaction in the queue. It is recommended to set this value to a high enough level to avoid limitations.

- Alloc: It is used to create a cryptocurrency wallet for the private blockchain and fill it with "fake" ether [10].

4 Creating a Smart Contract for Automatic Data Storage in the Blockchain Database

Writing a smart contract requires not only legal knowledge but also IT knowledge. Broken down into skills, hard skills (textbook knowledge) are necessary for programming, as well as soft skills to understand how the system works [11].

In terms of Blockchain, a smart contract automatically enforces agreements between two or more parties without a trusted intermediary. These smart contracts are implanted as computer programs in Blockchain software like Ethereum and Hyperledger. Participants join the network depending upon the type of Blockchain and can request the execution of a particular contract for a transaction in the Blockchain P2P network. The history of these transactions is stored in blockchain is similar to digital currencies. The state of the contract and participants' assets are determined by the sequence of transactions in the blockchain [12].

The correct execution of smart contracts does not rely on a trusted third party similar to cryptocurrencies. Consensus protocols are there to resolve any potential conflict between contractual parties. There are different solutions available for conflict resolution depending on the platform [13].

Ethereum supports smart contracts. Blockchain platforms that support smart contracts are often referred to as programmable blockchains [14]. An Ethereum-based smart contract is a cryptographic box that stores information, processes inputs writes outputs, and is only accessible to the outside if certain predefined conditions are met [15].

Benefits of Smart Contract:

- Autonomy: Smart contracts remove the need for trusted intermediaries, enabling a higher degree of autonomy when it comes to transactions and other processes.

- Trust & Transparency: Since there's no third-party involvement and because transaction records are shared across the blockchain network, there's no need to question whether the information has been altered for personal gain.

- Efficiency: As soon as a condition is met, the contract wastes no time and executes immediately. Moreover, since smart contracts are digital and automated, they minimize the potential for human error.

- Savings: With smart contracts, intermediaries don't need to handle transactions, which removes associated time delays and unnecessary fees [16].

The smart contract conditions are called triggers. The following 4 conditions are required when concluding a smart contract:

- For the subject of the contract, which is the subject of the contract,

- To define conditions precisely. The provisions of the contract can only be implemented if they are fulfilled,

- For authentication. The subject of the contract and its conditions must be authenticated with a digital signature,

- Finally, a blockchain is also needed where the contract can be created [17].

Fig. 6 below presents the connection between the ITS Smart Contract and the ITS blockchain.
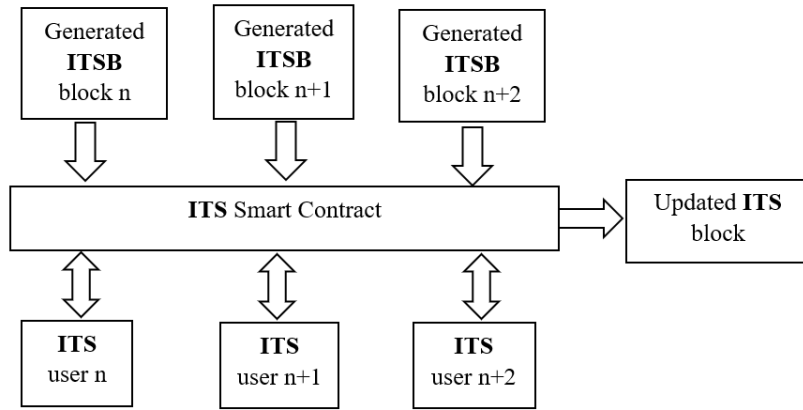
Figure 6
ITS Smart Contract

4.1 Platforms for Smart Contract

In the case of the ITS system, it is advisable to choose from 3 different Smart Contract platforms. These are the following:

- Bitcoin is a public blockchain platform that can be used to process cryptocurrency transactions but with a very limited computing capability. Bitcoin uses a stack-based bytecode scripting language.

- NXT is a public blockchain platform that includes built-in smart contracts as templates NXT only allows developing smart contracts using those templates. It does not, however, allow customized smart contracts due to the lack of Turing completeness in its scripting language.

- Ethereum is a public blockchain platform that can support advanced and customized smart contracts with the help of Turing-complete programming language. Ethereum platform can support withdrawal limits, loops, financial contracts, and gambling markets. The code of Ethereum smart contracts is written in a stack-based bytecode language and executed in Ethereum Virtual Machine (EVM). Several high-level languages (e.g., Solidity, Serpent, and LLL) can be used to write Ethereum smart contracts. The code of those languages can then be compiled into EVM bytecodes to be run [18].

In the case of the ITS system, it is recommended to choose the Ethereum-based smart contract platform. The ETH blockchain is a stable blockchain on which the smart contract platform is built. In addition to security, reliable operation and continuous availability are very important aspects, that the ETH Smart Contract meets.

4.2 Creating a Smart Contract

The attitude towards innovation is a key factor, as it is through innovation that new solutions can be created. Such is the application of the smart contract in the intelligent transport system [19].

One of the most important steps when writing a smart contract is connecting to the ITS system. In the smart contract, it is necessary to enter the registration data, which the system stores in the private ITSB blockchain. This means that personal data is protected and can be stored safely.

Fig. 7 below presents the source code of the smart contract called ITSSC, which enables users to register in the system.

```
pragma solidity ^0.8.0;

        contract name ITS Smart Contract {

  // Storage

  string firstName_Krisztan;

  string lastName_Balint;

  constructor(string memory _firstName, string memory _lastName) {

     mapping (address => vehicle1 address) balances;

   }

     function fullname (Krisztian Balint) private view returns (string  memory) {

        return string(abi.encodePacked(lastName_Balint;
firstName_Krisztian));

     }

   }

   functions send ITS data (ITSB blockchain address)

   }
```

Figure 7
ITS Smart Contract

Conclusions

The application of blockchain technology provides the opportunity to expand Intelligent Transport Systems and make them more efficient. Safe storage of data is a key issue in this sector. The efficient and safe identification of road users has been an unsolved problem until now, as many people did not want to provide their sensitive personal data during identification. As a result, building and expanding the system was an unsolved problem.

The ITSB blockchain ensures the safe and long-term storage of ITS system data. Due to the structure and consensus mechanism of the blockchain called ITSB, data can be stored more securely than in the case of their centralized counterparts.

The smart contract called ITSCC provides an additional opportunity in the development of the ITS system since the personal data of the registered ITS parties will never be made public, and they will not be known to the other participants, despite this, all smart contract members trust each other, since everyone must meet the same smart contract conditions based on a strict mathematical solution.

It can be concluded that the connection of the created ITSB blockchain with the smart contract may be an important part of the ITS system in the future, thus providing new opportunities in the field of further development.

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The Role of Corporate Social Responsibility in Achieving Economic and Social Sustainability

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Abstract: Corporate Social Responsibility (CSR) has become a pivotal strategy for businesses to address global challenges and promote sustainable development. This study examines the role of CSR in achieving economic and social sustainability by analyzing its impact on corporate performance, social equity, and environmental preservation. Through a literature review and qualitative analysis, the research finds that CSR initiatives align well with the United Nations Sustainable Development Goals (SDGs). The results indicate that CSR not only enhances corporate reputation and stakeholder trust but also fosters long-term economic growth while addressing social and environmental issues. However, the effectiveness of CSR depends on its integration into core business strategies and genuine commitment to sustainability. This study concludes that CSR is a vital tool for balancing economic and social sustainability, but its implementation requires robust governance and stakeholder engagement.

Keywords: Corporate Social Responsibility; Economic Sustainability; Social Sustainability; Sustainable Development Goals; Stakeholder Engagement; Environmental Preservation

1 Introduction

In latest years, as the global organisation surroundings keeps to evolve, Corporate Social Responsibility (CSR) has end up a key method for addressing essential worldwide challenges, together with weather exchange, social inequality, and financial uncertainty. CSR refers to the integration of social, environmental, and ethical worries into business operations and stakeholder relationships. [1], [2]With growing worldwide attention to sustainable development, CSR has progressively

shifted from being a peripheral pastime to turning into a critical method for lengthy-term commercial enterprise fulfillment and the introduction of social cost [1], [2].Despite the great adoption of CSR, there stays an ongoing debate about its real impact on selling financial and social sustainability. Some research shows that CSR can enhance organization performance and contribute positively to social welfare [3], whilst others argue that many CSR practices are symbolic and shortage sizable consequences[4]. To address these troubles, modern frameworks emphasize the need to integrate CSR into middle enterprise strategies and implement it correctly [5]. The scope of CSR has additionally advanced—from fundamental compliance to proactive company obligation and leadership improvement—calling for extra comprehensive processes to prepare destiny business leaders to tackle complicated social and environmental challenges[6], [7].

Further research explores CSR's role in diverse contexts. For example, subsidiaries in emerging markets regularly alter CSR techniques to match nearby socio-financial situations even as aligning with global goals [8]. Innovation is likewise found to mediate the connection between CSR and organization overall performance, improving competitiveness and sustainable growth [9]. A meta-evaluation also confirms the positive impact of CSR on financial performance, displaying that CSR is each a social responsibility and a strategic device [10]. However, current literature reveals several gaps. Many research consciousness on specific industries or regions and absence a holistic evaluation of CSR's overall impact across various socio-economic settings. This is specially evident in growing countries, wherein CSR practices are formed by means of informal establishments and unique cultural elements. Scholars argue that CSR techniques need to stability standardization and nearby model, as one-length-fits-all models may not be powerful globally [11], [12]. Furthermore, the mechanisms via which CSR contributes to attaining the United Nations Sustainable Development Goals (SDGs), mainly through its effect on company techniques and governance systems, stay underexplored.

This study aims to explore how CSR contributes to both financial and social sustainability by examining its impact on corporate performance, social equity, and environmental stewardship. The research also seeks to assess CSR's role in advancing the SDGs and to provide practical guidance for organizations in designing effective CSR strategies.

To fulfill this purpose, the look at addresses the following key questions:

(1) How does CSR effect corporate overall performance and stakeholder believe?
(2) To what extent does CSR make a contribution to selling social justice and environmental protection?
(3) What are the critical success elements of CSR in supporting the realization of the SDGs?

By exploring those questions, this take a look at seeks to offer new insights and actionable suggestions for reinforcing the function of CSR in sustainable improvement throughout numerous monetary and cultural contexts.

2 Literature Review

CSR is broadly diagnosed as a key issue in promoting social fairness and environmental sustainability. It supports tasks which includes truthful wages, team of workers range, and neighborhood network improvement, which now not most effective improve corporate reputation however also have significant impacts on societal properly-being [13]. These social contributions reflect how groups can have an impact on broader public pursuits via both inner practices and outside engagement. Before similarly discussing its influences, it is essential to distinguish CSR from company sustainability. Although those phrases are now and again used interchangeably, they range of their underlying functions and strategic strategies. CSR emphasizes pleasurable a employer's social and moral responsibilities, at the same time as company sustainability specializes in achieving lengthy-time period, balanced development throughout environmental, social, and economic dimensions [2]. Understanding this distinction offers a foundation for analyzing how CSR contributes to sustainable improvement and informs enterprise selection-making.

In addition to its social dimension, CSR movements together with lowering carbon emissions and adopting sustainable sourcing practices assist address pressing environmental challenges [14]. These projects help ecological desires and align with international efforts closer to responsible manufacturing and intake. However, in practice, many CSR activities fall quick of expectations. Without clean integration into commercial enterprise techniques, CSR regularly remains symbolic or quick-term in nature, missing the potential to generate lasting, significant trade [4]. This disconnect limits both social and environmental consequences and restricts companies from knowing the full capability of CSR. One tremendous barrier to effectiveness is the absence of a standardized method for measuring CSR performance. Indicators vary extensively across businesses, industries, and areas, which makes comparative evaluation tough and hinders the development of effective benchmarking structures [15]. Therefore, organising a standardized assessment framework is important for agencies to screen consequences, improve implementation, and disseminate first-rate practices.

Despite these challenges, there is significant scholarly agreement that CSR can be a effective strategic tool while aligned with long-term commercial enterprise targets. When integrated into the middle corporate approach, CSR can create each monetary and social cost [13]. A complete framework that aligns CSR tasks with a organisation's vision, strategic priorities, and execution mechanisms offers a clean

route to convert CSR intentions into realistic and powerful movement [5]. Such a strategic approach no longer simplest enhances the enterprise's capability to reply to global social and environmental demanding situations but also reinforces its competitiveness and resilience in a rapidly converting international. Taken together, previous studies shows that CSR holds full-size potential in improving company performance, promoting equity, and assisting environmental sustainability. However, the fulfillment of CSR practices in large part depends on how nicely they're embedded within company approach and whether their outcomes are systematically evaluated. This observe builds in this foundation through exploring how groups can higher layout and put in force CSR practices to develop long-time period sustainability throughout monetary, social, and environmental domain names.

3 Methodology

To cope with the studies questions mentioned on this look at, a comprehensive technique became hired, utilizing a number statistics resources and analytical techniques. Data became collected from diverse credible sources, inclusive of peer-reviewed magazine articles, enterprise reviews, and case studies published in the beyond 5 years. This choice ensures the inclusion of updated and relevant statistics, reflecting contemporary developments and practices in CSR.The evaluation ordinarily makes a speciality of exploring the effect of CSR on company performance and stakeholder agree with, investigating how CSR tasks make contributions to social equity and environmental protection, and identifying the key factors influencing the success and effectiveness of CSR implementation. By very well analyzing those areas, this examine objectives to advantage a deeper expertise of CSR's role in selling sustainable development and guiding agencies towards extra impactful and long-term techniques.Previous research has emphasised the imperative connection between CSR and sustainable development goals (SDGs), underscoring CSR's potential to make a contribution to each corporate overall performance and broader societal welfare [1].Furthermore, studies highlight the differentiation between company obligation and sustainability, stressing how each contributes uniquely to long-time period business success and societal improvement[2].

4 Results

The The outcomes of this have a look at demonstrate substantial and superb results of Corporate Social Responsibility (CSR) on numerous factors of commercial

enterprise performance. Notably, CSR practices related to inexperienced supply chain control have a marked fine impact on corporate overall performance. Companies that include sustainability projects into their operations are capable of lessen manufacturing charges whilst concurrently enhancing their environmental photo. This, in turn, attracts environmentally-conscious clients, contributing to both elevated emblem recognition and improved financial performance.

These findings are constant with previous studies that highlighted the high quality courting between CSR and innovation, as well as the monetary benefits of CSR throughout a couple of industries[10], [16].Moreover, CSR initiatives specializing in fairness—consisting of equitable wage regulations and the promotion of diversity—serve to build greater public accept as true with, foster patron loyalty, and guide marketplace enlargement. These efforts, in flip, lead to greater long-time period profitability. The effects confirm that CSR isn't always merely a ethical duty but a strategic enterprise device that can significantly make contributions to both social fee and financial performance.

4.1   CSR and Social Equity

In phrases of social fairness, CSR projects play a vital function in decreasing disparities and fostering inclusive increase. Companies that undertake fair salary regulations, endorse for gender equality, and put money into community development projects are definitely impacting the lives of their personnel and surrounding communities. A key instance is Starbucks' "Global Farmer Fund," which promotes sustainable farming practices and helps coffee farmers growth productivity and earnings. This initiative aligns with the findings of previous studies, which demonstrate how CSR investments in sectors like schooling, healthcare, and infrastructure make a contribution to greater equitable societies [14].These efforts no longer handiest paintings to reduce inequality but additionally contribute to long-time period social stability via assisting structural enhancements within communities. Therefore, CSR plays a key position in advancing social fairness through bridging gaps within and among groups, in the end contributing to a extra inclusive and sustainable future.

4.2   CSR and Environmental Sustainability

CSR also performs a considerable role in selling environmental sustainability. Many organizations have taken proactive steps to limit their environmental impact by means of adopting renewable strength sources and lowering emissions. A wonderful example is Tesla, whose commitment to inexperienced technologies, including electric automobiles and smooth electricity answers, showcases how CSR can lead to both carbon discount and management in the inexperienced innovation sector. This locating aligns with previous studies, which indicates that CSR can

power sustainable innovation and create long-time period economic cost [14].However, challenges remain in fully realizing the capacity of environmental CSR efforts. Although many organizations have launched environmental protection initiatives, research suggests that the dearth of cohesive, systematic techniques regularly prevents these efforts from reaching their full potential. Companies that correctly integrate environmental sustainability into their center enterprise techniques, but, now not handiest generate tremendous ecological outcomes however also enhance their aggressive positioning. This emphasizes the need for a greater strategic, incorporated method to environmental CSR.

4.3   Challenges in CSR Implementation

Despite the high-quality affects observed, the examine also highlights several demanding situations that businesses stumble upon in enforcing CSR projects efficiently. One main issue is the mixing of CSR into a company's common commercial enterprise strategy. Many agencies conflict to align their CSR efforts with lengthy-time period strategic goals, leading to fragmented and quick-term actions which have restrained lengthy-term impact.

Another giant undertaking is the absence of standardized CSR assessment frameworks. Without a unified gadget for measuring CSR consequences, it will become hard to evaluate outcomes across unique industries and regions. For instance, some businesses determine CSR achievement primarily based on social effect metrics, whilst others consciousness on environmental signs like carbon emissions, main to inconsistent and non-similar results. This lack of standardization hinders the potential to share high-quality practices across sectors and impedes the wider adoption of a success CSR techniques.

Therefore, the findings recommend the want for a extra standardized technique to measuring CSR outcomes, which might facilitate the effectiveness and scalability of CSR projects throughout industries. A unified framework ought to permit for greater meaningful comparisons and higher understanding-sharing, in the long run enhancing the impact of CSR efforts international.

5   Discussion

This study shows that Corporate Social Responsibility (CSR) is essential for each financial and social sustainability, improving company performance, promoting social fairness, and supporting environmental safety. The findings affirm current research whilst emphasizing CSR's interconnected impact on economic, social, and environmental effects.

5.1 Concluding remarks

CSR positively influences corporate overall performance. Companies implementing sustainable practices, like green supply chain management, lessen expenses and entice environmentally-aware customers, aligning with preceding research displaying CSR drives economic performance via innovation and stronger emblem reputation [10], [16].CSR tasks promoting fairness, which includes truthful wages and gender equality, additionally beautify public believe, consumer loyalty, and marketplace increase [13].

CSR also advances social fairness. Companies adopting honest regulations and investing in community development enhance residing situations. Starbucks' "Global Farmer Fund," as an example, supports sustainable agriculture and boosts farmer income, reflecting CSR's position in fostering greater equitable societies [14].

In environmental sustainability, CSR drives wonderful alternate. Companies prioritizing renewable electricity and waste discount, like Tesla, no longer most effective reduce their environmental effect however advantage a competitive part. Despite many efforts, the shortage of cohesive strategies frequently limits their fulfillment [4]. However, integrating sustainability into core business strategies can lead to long-time period ecological and economic advantages [14].

Despite its blessings, CSR faces demanding situations, in particular in aligning it with broader business techniques. Many agencies struggle with integration, proscribing lengthy-term effectiveness [4]. Additionally, the shortage of standardized CSR assessment frameworks hampers steady dimension and the sharing of satisfactory practices throughout industries [15].

5.2 Future Research Directions

While this examine highlights the tremendous impact of CSR on corporate performance, social equity, and environmental sustainability, several regions continue to be underexplored. Future research ought to cognizance on the following key areas:

1.Developing a unified CSR assessment standard to quantify the social and environmental benefits of CSR. This would improve the comparison of CSR practices across industries and regions, addressing the current gap regarding the lack of standardized assessment criteria **[4]**.

2.Exploring the role of technology in CSR, particularly the use of blockchain to enhance supply chain transparency and artificial intelligence to optimize resource utilization. These technologies can improve the efficiency of CSR practices, ensuring companies meet sustainability standards while also enhancing business operations.

3.Investigating CSR implementation across different industries and cultural contexts to understand the variations in CSR practices and their impact. This will help develop more tailored strategies for different sectors and regions **[14]**.

Conclusion

This study concludes that Corporate Social Responsibility (CSR) performs a important role in achieving a balance between financial growth and social sustainability. CSR practices make a contribution notably to each long-term monetary blessings and high-quality social and environmental influences. By addressing international demanding situations which includes social inequality and climate change, CSR facilitates companies now not handiest thrive financially however also force broader societal change, fostering fairer and extra sustainable development.The a hit implementation of CSR is contingent upon its integration into the core strategies of companies and alignment with common enterprise objectives. Transparency, responsibility, and lively engagement with stakeholders are important additives that permit CSR to absolutely recognise its capacity and help lengthy-term sustainable improvement.In conclusion, despite the fact that challenges remain inside the implementation of CSR practices, their ability to make a contribution to sustainable improvement is sizable. With improvements in era and the development of more sophisticated evaluation systems, the affect of CSR is poised to make bigger, fostering worldwide sustainable changes.

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The Impact of AI-Driven Demand Forecasting Technologies on Enterprises

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Abstract: With the rapid development of Artificial Intelligence (AI) technology, significant technological changes have been introduced into enterprise supply chain management. This study examines the transformative potential of AI-driven demand forecasting techniques in enterprise supply chain management. Using qualitative assessment method, the study compares traditional statistical methods with advanced AI-driven forecasting models and analyses internationally renowned companies that have applied AI for demand forecasting, aiming to reveal how AI can enhance the competitive advantage of enterprises and the impact of AI on supply chain management, and the results of the study are expected to provide valuable insights for the strategic integration of AI technologies. The results are expected to provide valuable insights into the strategic integration of AI technologies, which can provide companies with more reliable forecasts to help optimize inventory management, reduce stock-outs, and avoid overstocking, thus improving the decision-making process and operational efficiency in supply chain management.

Keywords: AI-Driven Demand Forecasting, Supply Chain Management, Traditional Statistical Methods, Enterprise Efficiency

1   Introduction

According to a report by Fortune Business Insights, the global artificial intelligence market grew from $81.4 billion in 2019 and is projected to reach $695.16 billion by 2032, with a compound annual growth rate (CAGR) of 37.7% during the forecast period. This significant growth indicates the increasing adoption of AI technologies across various industries, including demand forecasting [1]. In today's rapidly

changing market environment, businesses face unprecedented challenges such as shifting consumer preferences, economic uncertainty, and supply chain disruptions, which, coupled with increasing consumer demand for personalized experiences and faster deliveries, make accurate demand forecasting more important than ever. Demand forecasting is one of the most critical aspects of supply chain management, as it drives decisions related to supply chain management. Chain management, as it drives decisions related to procurement, production planning, and inventory management [2] .

Traditional demand forecasting methods rely on historical data and linear models, such as time series analysis, regression models, and so on. Analysis, regression models. However, traditional demand forecasting methods have major limitations. On the one hand, when traditional forecasting models deal with changing data and complex market environments, they may have problems such as low accuracy and poor adaptability, and therefore often fail to effectively reflect the dynamic changes in the market. On the other hand, traditional methods rely more on historical data, so changes in external markets are difficult to take into account. Artificial Intelligence, on the other hand, excels in the processing of changing and large amounts of data, so the adoption of Artificial Intelligence (AI)-based forecasting methods that utilize machine learning and real-time data processing can provide a more accurate and flexible solution to help companies better cope with market fluctuations and improve their market efficiency. In recent years, companies such as Coca-Cola, for example, have begun to use AI-based forecasting models to optimize inventory levels and accurately predict customer demand, so that they can provide customers with better service.

This study examines how artificial intelligence (AI) and data analytics can improve the accuracy of demand forecasting in supply chain management, and what advantages AI-driven demand forecasting models have over traditional statistical methods in supply chain management. In addition, the study not only aims to provide new insights into theoretical frameworks in the field of supply chain will also provide practical guidance on how companies can effectively integrate AI technology in their real-world operations, analysing the technology's potential, implementation challenges and future trends. The research results are expected to provide valuable references for enterprises to improve supply chain efficiency, reduce costs, and enhance market competitiveness.

2   Literature review

Traditional demand forecasting models such as time series models (e.g. ARIMA) and Exponential Smoothing Techniques (ETS), etc., these modeling approaches rely on historical data and have more stringent data requirements such as stable linear patterns. For example, Zhang suggest that traditional methods fail to address

complex demand fluctuations in highly volatile environments, making them less effective in meeting the needs of modern businesses [3].

In recent years, with the advent of big data, AI and machine learning techniques have become increasingly popular for demand forecasting. AI-driven models, particularly deep learning technologies such as Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNN), excel in capturing complex and non-linear patterns in demand. LSTM models, in particular, are highly effective for time-series forecasting due to their ability to retain long-term dependencies. Li found that LSTM outperformed traditional models in e-commerce sales forecasting, demonstrating superior accuracy [4].

AI-based forecasting models offer several advantages over traditional statistical methods. While traditional models are limited by their linear assumptions, AI models can handle complex, non-linear data relationships, improving the accuracy of forecasts. Wang compared the performance of ARIMA and LSTM in retail demand forecasting and found that LSTM outperformed ARIMA in dealing with demand fluctuations, seasonality, and unexpected events [5]. Additionally, hybrid AI models, which combine AI with traditional methods, have been shown to achieve even better forecasting accuracy, as they capitalize on the strengths of both approaches [6].

Future research in demand forecasting may focus on improving the transparency and interpretability of AI models. This would help decision-makers trust AI-generated forecasts. Moreover, hybrid models that integrate both AI and traditional forecasting techniques are expected to gain more attention, as they combine the flexibility of AI with the robustness of traditional methods. The integration of AI with emerging technologies, such as blockchain and the Internet of Things (IoT), could further improve forecasting accuracy and real-time decision-making. Khan explored the combination of AI and blockchain for demand forecasting in supply chains, demonstrating the potential for increased transparency and efficiency in supply chain operations [7].

3   Methodology

An empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not evident; and in which multiple sources of evidence are used [8]. The case study method in qualitative research can help discover cause and effect relationships by analyzing the characteristics of the research object and examining the relationship between the object and the research context based on selecting an appropriate research object. The method can effectively integrate multiple data sources, increase the credibility

and authenticity of the study, and make the results of the study have practical guidance value.

This study adopts a combination of case study and literature analysis to explore the impact of AI demand on enterprises from representative enterprise or industry cases in the current market, and also extracts relevant information and the development trend of AI prediction models from existing industry reports and academic papers through literature analysis. The combination of quantitative and qualitative analyses allows for a better understanding of the impact of AI-driven demand forecasting models based on AI on enterprise supply chains. The potential, implementation challenges and future trends of the technology are analysed in their actual operations. The results of the study are expected to provide valuable references for enterprises to improve supply chain efficiency, reduce costs, and enhance market competitiveness.

4 Results

4.1 Amazon

Amazon, as the world's leading e-commerce giant, has always had stringent requirements for its supply chain management.

In the early days before AI became commonplace, Amazon relied heavily on traditional forecasting methods for inventory planning and customer demand prediction. While these methods performed reasonably well in predicting best-selling products, for long-tail products with sparse data and irregular purchasing behaviours, the prediction error often exceeded 30%, leading to frequent stock-outs or backlogs, and also reducing the efficiency of logistics scheduling [9].

To improve supply chain efficiency, Amazon has widely adopted AI prediction models, especially in inventory management and demand forecasting [10]. Due to the large and variable amount of data that Amazon needs to deal with, it has an extreme amount of variability. Therefore, traditional prediction models cannot satisfy Amazon's prediction needs well. Amazon uses deep learning and machine learning models to predict customer demand in real time. These models can analyze large amounts of historical and real-time sales data to help Amazon accurately forecast product demand fluctuations and automatically adjust inventory levels [11]. Amazon's AI forecasting model, Amazon can make good predictions of product demand for the next six hours, automatically making adjustments to inventory levels, using historical and real-time sales data for more than 10 million products. Through AI prediction models, Amazon can achieve precise inventory management, reduce overstocking and stockouts, lower storage costs, and improve

customer satisfaction. Research shows that Amazon reduced inventory costs by 15% and shortened order processing times by 25% through AI prediction models [12]. This advantage has not only improved Amazon's operational efficiency but also enhanced its competitiveness in the global market. This transformation not only enhances operational flexibility and customer satisfaction, but also improves its overall competitiveness in the highly competitive global marketplace.The application of AI technology enables Amazon to quickly adapt to market fluctuations and accurately respond to customer needs, thereby steadily expanding its market share.

4.2   Coca-Cola

As a global leader in beverage manufacturing, Coca-Cola faces complex supply chain challenges. Coca-Cola relied on regression and econometric models to estimate product demand based on factors such as seasonal trends, advertising expenditures, and macroeconomic indicators. Despite incorporating multiple variables, these traditional models frequently experienced mean absolute percentage errors (MAPE) of around 20%, especially during season transitions where demand became harder to model. Moreover, the reliance on human judgment and domain experience introduced additional subjectivity, reducing forecast robustness [13].To address inventory management issues caused by demand fluctuations, Coca-Cola introduced AI-driven prediction models to optimize its supply chain operations [14]. Demand for Coca-Cola as a beverage is typically a seasonally varying figure and there are also more promotional activities that make for a variable sales environment. Research shows that Coca-Cola reduced production costs by 5% and shortened supply chain response times by 30% through AI prediction models [15].

4.3   Walmart

Walmart combines AI prediction models with big data analytics to accurately forecast product demand in different regions and periods by analyzing historical sales data from over 5,000 SKUs, seasonal changes, geographic locations, and other factors. By adopting AI models, Walmart reduced demand forecasting error rates by 30% and increased inventory turnover by 20% [16]. This application demonstrates how Walmart leverages AI technology to improve operational efficiency in the complex retail environment, achieving significant advantages over traditional methods.

4.4 Summary of results

Overall, these cases show that the application of AI predictive models in the supply chain can significantly improve forecast accuracy, optimize inventory management, and reduce operational costs. Despite the challenges of technology adaptation and data quality in the implementation process, the advantages of AI have gradually emerged, helping companies achieve greater competitiveness in the global competition. As technology continues to advance, the role of AI in supply chain management will become more and more significant, and it is expected to provide more enterprises with smarter and more efficient operation modes in the future.

5 Discussion

5.1 Concluding remarks

The results of this study show that AI-based demand forecasting models offer clear advantages over traditional statistical methods in complex and rapidly changing supply chain environments. In the cases of Amazon, Coca-Cola, and Walmart, AI systems improved forecasting accuracy, reduced inventory costs, and enhanced responsiveness to market changes. These findings support existing research advocating the use of AI in supply chain management.

For example, Amazon replaced its traditional models—which had over 30% error rates for less common products—with real-time AI systems that improved forecast accuracy. This aligns with Wang et al. [5], who found that LSTM models handle nonlinear demand patterns better than ARIMA. Similarly, Coca-Cola experienced seasonal forecast errors using traditional methods, reflecting Zhang et al.'s [6] conclusion that such models perform poorly in volatile conditions. The 15–30% efficiency improvements seen across these companies also support Li et al. [4], who highlighted the benefits of deep learning in dynamic markets. Walmart's use of AI and big data echoes Khan et al. [7], who emphasized the value of combining AI with IoT to improve transparency and efficiency.

In short, this study confirms that AI-powered forecasting tools give businesses greater flexibility and accuracy in supply chain planning. While traditional methods remain useful in stable settings, AI is becoming essential for dealing with today's complex supply chain demands.

5.2   Limitation and suggestion

Although this paper has some value in demand for ecasting for AI-driven supply chain management, it still has some limitations.

Firstly, this paper adopts a qualitative research approach and selects three famous enterprises as case studies. Amazon, Coca-Cola and Walmart are large enterprises with strong technological base and data resources, which can hardly represent the actual situation of SMEs. Secondly, this paper mainly relies on existing industry reports and literature as data sources, which may have the problem of information lag or publication bias. Finally, the research focuses on the positive impact of AI prediction, but potential issues regarding model interpretability, data privacy, and high implementation costs still need to be further explored in future research.

In subsequent studies, more research cases with different representativeness should be selected for the study, which can represent small, medium and large enterprises respectively, and data analysis method should be used to be able to reflect the impact of AI on demand forecasting more objectively.

Conclusion

This study explores the performance of AI technology in enterprise demand forecasting by analysing the case studies of several typical companies. From the actual cases of Amazon, Coca-Cola and Walmart, the introduction of AI not only improves the accuracy of forecasting, but also reduces the inventory cost to a certain extent, while allowing the supply chain to respond faster. Combined with previous research, AI models are clearly superior to traditional forecasting methods when faced with complex and variable data.

As AI continues to evolve and gradually merge with new technologies like big data, IoT and blockchain, its value in optimising the supply chain is growing. For companies that want to stay competitive in a rapidly changing market, using AI forecasting tools is no longer just a technological update, it's part of a strategy for the future. Of course, subsequent research will need to consider real-world issues such as the interpretability of the models, the quality of the data, and how to ensure that AI technology is used wisely and in a compliant manner, in order for it to play a more sustainable role in practice.

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Speech Identification for Remote Assessments: Age and Gender Recognition in Distance Learning

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Abstract: Ensuring the authenticity of student identity in online education remains a topic of research to date. With the rapid development of Internet-based distance learning system, the demand for learner identity verification methods is increasing day by day. This study explores how voice-based age and gender recognition technologies can be applied to improve the authority of online learning and examination platforms. We use deep speaker embedding technology to extract and analyze speaker identity attributes using advanced speaker verification models such as x-vector, ECAPA-TDNN and ResNet. We employ deep speaker embedding techniques to extract and analyse speaker identity attributes using state-of-the-art speaker verification models (e.g., x-vector, ECAPA-TDNN and ResNet). Using the collected speaker dataset, we evaluate the effectiveness of these models for age and gender classification, demonstrating their potential to reduce the risk of impersonation and improve the security of exam proctoring. Our findings highlight that integrating automatic speech recognition can enhance identity verification in digital educational environments while maintaining the student learning experience. This study contributes to improving biometric security in distance learning by evaluating the feasibility of voice-based authentication in distance learning.

Keywords: deep learning, distance learning, speaker identification, biometric security.。

1 Introduction

With the rapid development of digital education platforms and the continuous evolution of the global distance learning environment, distance teaching and online examination systems have gradually become popular. However, there are still severe challenges in ensuring the authenticity of students' identities during the remote assessment process. Traditional identity verification methods (such as account and password login) are difficult to effectively prevent cheating behaviors such as proxy examination and disguise. Therefore, an increasing number of studies have begun to focus on biometric identity-based solutions to enhance the security and credibility of online evaluation systems [1].

Among numerous biometric technologies, voice is regarded as an identity recognition method with broad application prospects due to its advantages of convenient collection and low hardware threshold. Speech signals naturally carry the individual characteristics of the speaker, such as gender and age, making them of great value in the tasks of speaker verification and classification. In recent years, the development of deep learning technology, especially the introduction of embedded modeling methods such as x-vector and ECAPA-TDNN, has significantly improved the accuracy and robustness of speech identity recognition systems.

This study aims to explore the utilization of gender and age recognition results in speech to assist the student identity verification mechanism in remote examination scenarios. Specifically, this paper attempts to evaluate the mainstream speaker embedding extraction model on the Hungarian speech dataset, and uses classifiers such as MLP, Logistic Regression and Random Forest to automatically identify the gender and age of speakers. So as to analyze its feasibility and application value in identity-assisted verification.

Although methods such as face recognition [2] have been used for remote identity verification, the identity attributes contained in the voice (such as gender and age) have not been fully utilized in the online education scenario. Most of the existing studies focus on speaker verification [3], while attempts to integrate speech recognition into examination systems are still relatively limited.

Therefore, this paper focuses on the automatic classification ability of age and gender in speech recognition, and attempts to introduce an auxiliary verification system in the remote examination and assessment mechanism, thereby enhancing the security and discrimination of identity verification.

2 Literature Review

Speaker Verification is a technology that uses the characteristics of an individual's voice for identity confirmation and is widely applied in fields such as security and distance learning. In recent years, deep learning technology has greatly promoted the development of this field. Traditional manual features such as MFCC (Mel-Frequency Cepstral Coefficients) have gradually been replaced by more representational deep embedding models, such as x-vector and ECAPA-TDNN [4]. The x-vector model proposed by Snyder et al. converts variable-length speech sequences into fixed-dimensional vectors through time-averaged pooling, becoming an important baseline in the speaker verification task [5].

In the speech recognition system, age and gender recognition, as auxiliary identity information, can significantly improve the accuracy and robustness of the system. Existing studies have shown that there are statistical differences in acoustic characteristics among different gender and age groups, which provides distinguishable features for classifiers [6]. Furthermore, embedding gender and age as prior features into the recognition process also helps to reduce the search space, improve the efficiency of speaker clustering and matching, and is particularly suitable for the fields of remote evaluation and forensic medicine [1].

The current mainstream speech embedding models include x-vector, ECAPA-TDNN and ResNet based on residual structure. Most of these models are trained with the goal of speaker verification, but they are also widely used to be transferred to age estimation and gender recognition tasks, forming the so-called Multi-task Learning framework. Some of the works adopted the joint loss function and trained the three subtasks of gender, age and identity simultaneously, achieving better performance [7]. However, most of the existing studies rely on controlled corpora or English speech, and seldom explore the generalization ability on multilingual and real-world data.

Although existing studies have achieved certain results in the task of speech gender and age classification, in real application scenarios such as distance learning, they still face challenges such as noise interference, changes in speech rate, and short speech segments. Therefore, this paper takes speaker recognition in remote evaluation as the background, uses the pre-trained x-vector model to extract embeddings, and builds gender and age classification models on Hungarian speech data to further compare the performance differences of methods such as MLP, Logistic Regression and Random Forest. To explore the relationship between embedding stability and recognition accuracy and provide a reference for actual deployment.

In recent years, identity verification systems in distance learning scenarios have mostly relied on face recognition. However, face recognition still has deficiencies in aspects such as privacy protection, lighting adaptability and device requirements [2]. Therefore, this study attempts to introduce a voice-based identity recognition

method, using the gender and age characteristics of the speaker as supplementary information to enhance the robustness, interpretability and user privacy security of the identity verification system.

3 Methodology

This research aims to explore and evaluate age- and gender-based speech recognition methods for authentication in the contexts of distance learning and online examinations. In order to achieve these objectives, five specific research processes are outlined in this paper: the preparation of a dataset, the extraction of speech embedding, Speaker Identification System in Distance Learning , the training and evaluation of a model.

3.1 DataSets

At the current stage of this study, the speech data set provide by the Dr. Abed. The data comes from real distance learning or experimental scenes, and has certain speaker diversity and real speech environment characteristics, which is suitable for the verification set of the preliminary experiment. The dataset is manually segmented, processed, and labelled by speaker. Further public data sets such as VoxCeleb are planned for subsequent experimental phases [8]. Public data sets have wider adaptability, which helps to improve the generalization ability of the model.A comparison of these public datasets is shown in Table 1.

Name	Env.	Free	#of Speaker	#of Utter.
AESDD	Acted Emotion	✓	>5	~500
ANAD	Acted Emotion	✓	Multiple	1384
ANDOSL	Clean speech	-	204	33,900
Forensic Comparison	Telephony	✓	552	1264
SITW	Multi-media	✓	299	2800
Common Voice	Multi-media	✓	40	>2500hs
NIST SRE	Clean speech	-	>2000	*
TIMIT	Clean speech	-	630	6300
VoxCeleb1	Multi-media	✓	1251	>100,000
VoxCeleb2	Multi-media	✓	6112	>1100,000

Table 1

Comparison of existing speaker identification datasets. (Env.: Recording Environment; Of Utter.:

Approximate number of utterances. *Varies by year.)

Source: based on literature [8]

3.2 Speech pre-processing for Speaker Identification

In the process of speech identification, the quality of speech data has a very important impact on the performance of the model. Therefore, it is necessary to preprocess the collected voice data. In this study, the original audio is systematically preprocessed to ensure the stability and validity of the model input. Preprocessing includes the following steps:

Convert all speech samples to a single-channel.wav file with a sampling rate of 16kHz, and complete the format conversion using the Librosa library.

Using the TextGrid annotation file matching with the voice file (including the start and end time and content label of each voice), accurate extraction of effective voice fragments [6].

By parsing the TextGrid file, the time periods marked as empty strings ("") or silent marks ("sil") are eliminated to preserve valid speech segments.

3.3 Embedding and Extracting

Speaker Embedding is extracted from the pre-trained depth model.It mainly uses X-Vector and ECAPA-TDNN models based on the SpeechBrain framework to extract the speaker 512-dimensional vector for each sample.These vectors contain key information such as the speaker's identity, physical charecteric [9]. By analogy to the classification method in face recognition, if the original voice file is compared to a face photo. Then the speaker embedding is equivalent to face embedding. Comparing with each other after extraction of the embedding is like comparing whether two faces are similar with FaceNet. Classifying with the embedding is similar to identifying age and gender with FaceNet [10].

The extracting of the Speaker embedding is to encode the processed audio through the pre-trained depth model and obtain a high-dimensional vector that can represent the identity of the speaker. This process is the basis for speech recognition, gender and age classification.

Compared with traditional handcrafted features (such as Mel-frequency cepstral coefficients, MFCC), **x-vector**-based speaker embeddings demonstrate stronger robustness and discriminability under complex acoustic conditions. In this study, a pretrained x-vector model is employed to extract speaker embeddings, which serve as the input features for subsequent **gender and age classification** tasks.

As illustrated in **Figure 1**, the embedding extraction pipeline consists of four main stages: loading the pretrained model, audio loading and preprocessing, embedding extraction, and feature saving. During the preprocessing phase, raw audio files are

first standardized to a uniform format (e.g., 16kHz mono) and undergo basic processing such as **denoising and amplitude normalization**. Then, the 512 feature embeddings corresponding to each audio segment are extracted through the x-vector model.
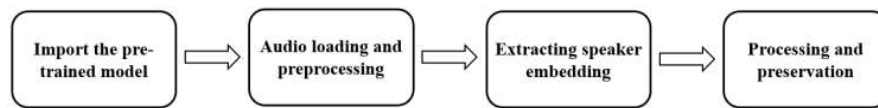

Figure 1

Speaker Embedding Extraction Workflow

Source: author' own construction

All the extracted embedding vectors and their corresponding labels (i.e., gender and age group) are uniformly saved the.csv file, and these vectors are directly used as input features for the subsequent training of the classification model. These embeddings effectively capture the speaker's acoustic and behavioral traits, and are used as the core input features for downstream classification models such as MLP, Logistic Regression, and Random Forest. The entire embedding extraction process provides fundamental support for constructing gender and age classification models in our system.

3.4   Age and Gender Classification Method

The extracted speech embeddings are input into two independent classification models, which are respectively used for gender recognition (male/female) and age group prediction (young/middle-aged/old). Each classifier consists of two layers of fully connected neural networks (MLP) and is trained using the cross-entropy loss function. In the task of gender recognition, we further introduce multiple traditional machine learning models (such as MLP, Logistic Regression, and Random Forest) for comparative experiments, all using the extracted x-vector embeddings as input features. On real distance learning datasets, the MLP model demonstrated the best performance, verifying the feasibility of integrating gender and age classification as auxiliary signals in the identity recognition task.

3.5   System frame workflow

This system aims at the identity verification problem of online examinations in the remote learning environment and designs a speaker verification system based on the

speech embedding and auxiliary classification module. The system mainly consists of the following five modules. The overall structure is illustrated in Figure 2.
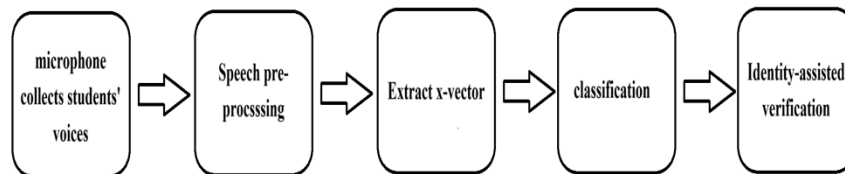

Figure 2
System structure
Source: authors' own construction

1. Voice Collection

The system is deployed at the back end of the online examination platform. Users upload voice clips (2-3 seconds of daily voice) through a computer or device microphone as the basic input for identity verification..

2. Speech Pre-processing

The sampling rate conversion (uniformly to 16kHz single channel), denoising and format standardization operations of the original audio were carried out through the Librosa tool. Further, effective speech segment extraction was conducted in combination with the TextGrid file to remove silent and non-target speech segments, ensuring the accuracy and robustness of subsequent feature extraction.

3. Speaker Embedding

Using the pre-trained x-vector model provided by SpeechBrain, each processed audio segment is transformed into a 512-dimensional speaker embedding vector, capturing its acoustic features and using them as a unified classification input.

4. Classification

The embedded vectors are input into various classification models such as MLP, Logistic Regression, and Random Forest for gender (male/female) and age group (young/middle-aged/old) identification respectively. The model demonstrated a relatively high accuracy rate (up to 99.6% at most) in the experiment and had good generalization ability.

5. Identification

This system is deployed at the back end of the online examination platform. During the examination process, it receives the candidates' voices in real time and completes the recognition of their identity features. When there are discrepancies between the classification results of gender or age and the registration information, the invigilators can be reminded to conduct further verification, thereby providing

a secure and convenient auxiliary identity verification mechanism for the distance education platform.

3.6   Experiment

This study adopted the same experimental setup in the two subtasks of gender recognition and age recognition. All experiments were based on the pre-extracted x-vector embedding vectors as input features, and comparative experiments were conducted respectively using three classification models: multi-layer perceptron (MLP), Logistic Regression, and Random Forest.

The training set and the test set are divided in a ratio of 8:2. The model training and evaluation were accomplished using the Scikit-learn framework, and the input features were uniformly standardized (StandardScaler). During the training process, end-to-end neural network training is not involved, and only shallow classifiers are constructed based on the embedding layer.

The model evaluation metrics include Accuracy, Precision, Recall, F1-score and Confusion Matrix.

4   Results

4.1   Analysis of Silent Elimination Effect

Figure 3 shows a comparison of the original language and the waveform after silent clipping. The green highlighted waveform area represents the valid speech segment retained after the silence is removed. This preprocessing step indicates that the silent detection algorithm can effectively eliminate non-speech intervals and provide clearer speech input for subsequent model training.
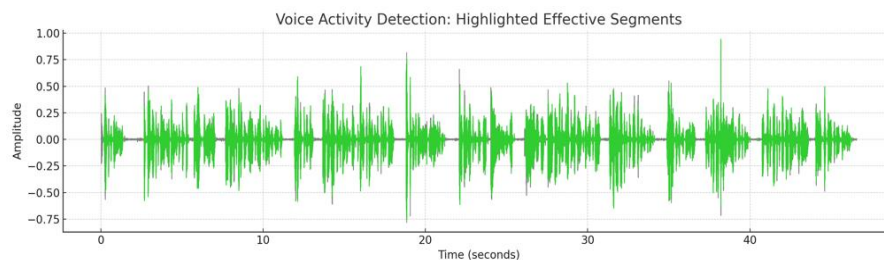

Figure 3

Data visualization of silent segment removal in speech preprocessing

Source: authors' own construction

4.2   Statistics of audio length distribution

As shown in Figure 4, we have plotted the histogram of the length distribution of the segmented speech segments from three speech datasets (PD, Dep, Pato). The results show that the speech segments in the two datasets of Dep and Pato are mainly concentrated between 2.0 and 2.5 seconds, which meets the preset input duration requirements of this study. While the PD dataset has a wider duration distribution and provides more diverse training samples.
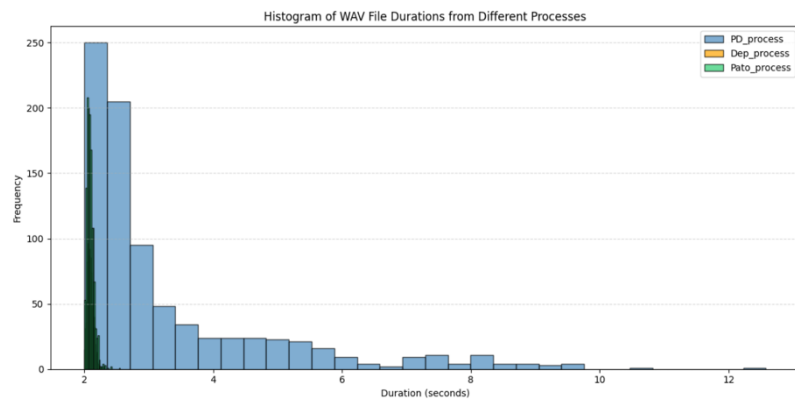

Figure 4

Histogram of Processed Speech Segment Durations

Source: authors' own construction

4.3   Embedded extraction process display

Figure 5 shows the process of extracting speaker embeddings from the pre-trained model (ECAPA-TDNN or x-vector), including audio loading, preprocessing, embedding generation and saving. The extracted 512-dimensional feature vector is used for the subsequent gender and age classification tasks and is the core basis of the system construction.
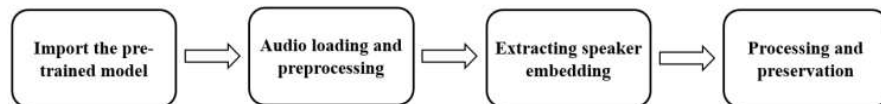

Figure 5

Speaker Embedding Extraction Workflow

Source: authors' own construction

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4.4　Gender Classification Performance Analysis

In the gender classification experiment, multiple classification models were constructed based on the extracted x-vector speaker embedding. Among them, the MLP model shows extremely high classification performance. As shown in Figure 6, among the 230 female samples in the test set, 229 were correctly identified, and only 1 was misjudged as male. Among the 216 male samples, 213 were correctly classified, and only 3 were wrongly identified as female. The overall accuracy rate of the model reached 99.0%, and both Precision and Recall reached 0.99, indicating that the model has a high discriminative ability on samples of different genders. It is notable that the recall of the MLP model for females (1.00) is slightly higher than that for males (0.99), which may be related to the distribution differences of gender characteristics in the speech data. Overall, this model shows good generalization ability in distinguishing the gender of speakers in the assisted distance learning scenario, providing reliable support for the subsequent multimodal identity recognition system.
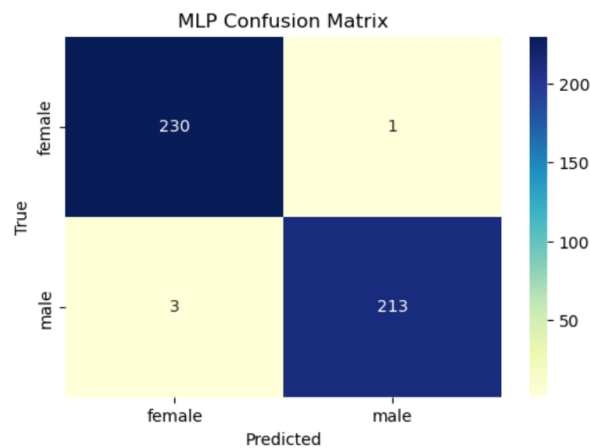

Figure 6

Result of MLP Confusion Matrix

Source: authors' own construction

To evaluate the effectiveness of deep speaker embeddings in supporting speaker identity verification, we conducted a series of gender classification experiments using x-vector features extracted from the speech dataset. Three different classifiers were implemented and compared: Multi-Layer Perceptron (MLP), Logistic Regression, and Random Forest.

The experimental results are summarized in Table X. The MLP model achieved the best overall performance, with an accuracy, precision, recall, and F1-score all reaching 99.6%. Logistic Regression followed closely, attaining a performance of 99.5% across all metrics. Although Random Forest showed slightly lower

performance compared to the other two models, it still yielded competitive results with a 98.6% accuracy.

These results suggest that x-vector embeddings are highly effective in capturing speaker-specific information for binary gender classification tasks. The consistently high accuracy across models demonstrates the reliability of these embeddings in distinguishing between male and female speakers, which is crucial for downstream tasks such as speaker verification in remote learning scenarios. As shown in Table 2 and Figure 6, all three classifiers exhibit strong performance in distinguishing speaker gender. The MLP model achieves the highest F1-score of 0.996. These findings confirm that gender recognition can be reliably integrated into remote assessment systems as an auxiliary signal for speaker identity verification, thus improving the robustness and security of distance learning environments.

Moel	Accuracy	Precision	Recall	F1-score
MLP	99.6%	99.6%	99.6%	99.6%
Logistic Regression	99.5%	99.5%	99.5%	99.5%
Random Forest	98.6%	98.6%	98.6%	98.6%

Table 2

Performance Comparison of Gender Classification Models

Source: authors' own construction

4.5 Age Classification Performance Analysis

In the age identification task, we divided the samples into five groups by age: teenagers (≤18 years old), young adults (19-29 years old), middle-aged adults (30-44 years old), middle-aged and elderly adults (45-59 years old), and elderly adults (≥60 years old). Based on the extracted x-vector embedding features, we conducted multi-classification recognition experiments for age groups using three mainstream classification models, namely Logistic Regression, MLP and Random Forest respectively. The experimental results show that the MLP model has the best comprehensive performance among the five age groups, with an accuracy rate of 76%. It has high Precision (0.81, 0.53) and Recall (0.94, 0.88) in the young and middle-aged groups, demonstrating a strong ability to distinguish age segments. In contrast, the overall performance of Logistic Regression was slightly weaker, with an accuracy rate of 71%. Although it had certain advantages in the adolescent group (Precision 0.74) and the middle-aged group (Recall 0.87), there were certain deviations in the identification of the middle-aged and elderly and the elderly segments. The overall performance of the Random Forest model was the worst, with an accuracy rate of only 57%. Especially on the samples of middle-aged and elderly people and the elderly, there was a lot of confusion, indicating that its ability to

distinguish age groups with blurred boundaries is weak. It can be seen from the model comparison that deep neural networks (such as MLP) have a stronger nonlinear modeling ability when dealing with high-dimensional embedding features, and can better depict the potential relationship between speech and age(Table 3). Therefore, they are more suitable for age recognition tasks. This experiment verified the feasibility and practicability of the speech-based age estimation method in assisting identity verification in the distance learning scenario. The detailed confusion matrix is presented in Figure 7.

Model	Accuracy	Macro F1	Weighted F1
LogisticRegression	0.71	0.71	0.71
MLP	0.76	0.80	0.77
Random Forest	0.57	0.64	0.58

Table 3

Performance Comparison of Age Classification Models
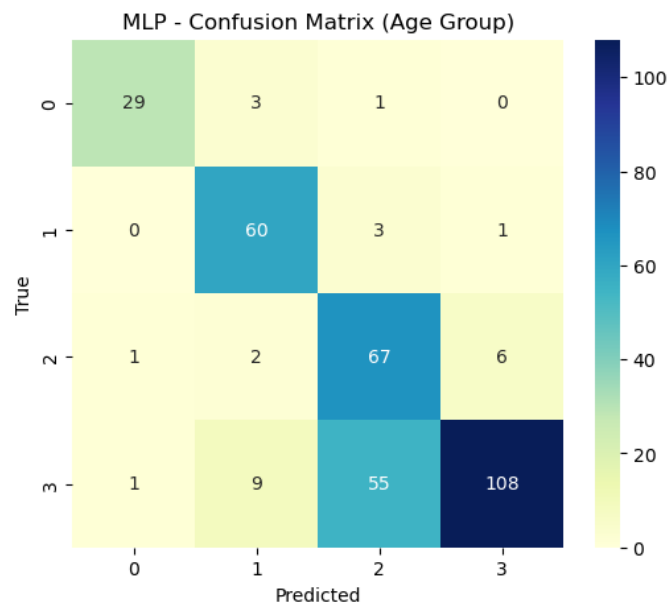
Source: authors' own construction

Figure 7

Result of MLP Confusion matrix

Source: authors' own construction

5 Discussion

5.1 Concluding Remarks

In recent years, with the application of deep learning in the field of speaker recognition, methods based on speaker embedding have gradually become mainstream. The x-vector method proposed by Snyder et al. (2018) [11] has demonstrated excellent performance on various tasks, proving its effectiveness in modeling speaker features.

In this study, the pre-trained x-vector model was adopted as the embedding feature extraction method, achieving good results in both gender recognition and age classification tasks, which is consistent with the related research trends mentioned in the Literature Review.

In the gender recognition task, the MLP model in this study achieves an accuracy of 99.6%, which is higher than the accuracy of about 95% in the literature [12] based on the traditional i-vector+PLDA method, showing that the deep learning model has a stronger ability to fit the speaker's gender features.

In the age recognition task, this study divided age into five intervals for classification, and MLP achieved an accuracy rate of approximately 76%, which is similar to the 74.2% accuracy rate result obtained based on CNN feature extraction and multi-category SVM classifier in reference [13].

It can be seen from this that the system in this study can also maintain high performance in a small-sample distance learning environment, further verifying the feasibility and practicability of the authentication scheme based on speaker embedding features.

5.2 Limitation and Suggestions

This study specifically compared three models, namely MLP, Logistic Regression and Random Forest:

MLP achieved the optimal performance in both tasks (gender and age), verifying the advantages of deep neural networks when dealing with high-dimensional and complex embedding vectors [3].

Although Logistic Regression and Random Forest have also reached a relatively high level in gender recognition, their performance has significantly declined in age classification, indicating that there are limitations in the ability of linear models and tree models to capture continuity and minor differences.

5.3 Implications for the Application of Identity Verification in Distance learning

In the Literature Review, a study [2] proposed the use of facial recognition and keystroke behavior as remote examination authentication methods, while the utilization of voice biometric features is still in its infancy.

This study verified the feasibility of assisted identity verification through voice embedding features from the perspectives of gender and age, providing a new technical option for future online education platforms.

Especially during the remote examination process, the system can infer the gender and age of the examinees in real time and verify them with the registration information. When a discrepancy in gender or age is detected, an alarm can be triggered, further reducing the risk of cheating.

By integrating gender classification into speaker verification frameworks, we propose a lightweight, privacy-friendly auxiliary check for distance learning authentication. For example, if a student's registered gender is "female" but the voice classification consistently predicts "male," the system could trigger an alert for potential impersonation.

Conclusion

This study proposes an identity verification framework based on speech recognition, aiming to enhance the authenticity and security of identity verification in the distance learning environment. This framework relies on the individual biological attribute characteristics contained in the speech, combined with the current mainstream deep embedding technology and classification algorithms, providing a lightweight and scalable auxiliary authentication method for remote examination and online education scenarios.

In terms of system construction, this paper has completed the complete process of speech data collection, preprocessing and embedding extraction, and adopted the pre-trained model based on x-vector for speaker feature extraction. Subsequently, by inputting the embedding vectors into various classifiers (such as MLP, Logistic Regression, and Random Forest), the experimental verification of the two core tasks of gender and age recognition was achieved.

The experimental results show that the MLP model has an accuracy rate as high as 99.6% in the gender recognition task and achieves an overall accuracy rate of 76% in the age recognition task. Especially in the young and middle-aged groups, the recognition effect is remarkable. Compared with the existing research results, this paper achieves a relatively high performance in speaker attribute recognition, verifying the feasibility and effectiveness of introducing gender and age as auxiliary features into the remote identity verification process.

The future work can consider the following directions: (1) Introduce more individual attribute labels (such as emotional state, language ability, etc.) to enhance the discrimination dimension of the model. (2) Introduce more languages to enhance the model's generalization ability. (3) Attempt more complex model structures to optimize the performance of age group recognition. (2) Attempt a multimodal joint modeling approach that integrates facial, voice and behavioral features

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