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ECONOMIC COMPETITIVENESS AND SUSTAINABILITY 2025

PROCEEDINGS

March 27th–28th, 2025, Brno

Editors:
Petr David
Hana Vránová

MENDELU
Faculty
of Business
and Economics

2025

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ABSTRACT

On March 27–28, 2025, the Faculty of Business and Economics at Mendel University in Brno hosted the 27th edition of the international conference Economic Competitiveness and Sustainability, which welcomed more than 100 participants from the Czech Republic, Germany, Hungary, India, Japan, Lithuania, Poland, Serbia, Slovakia, Sweden, Ukraine, and the United States. This conference proceedings volume includes 17 papers that were recommended by the conference discussants and selected through a peer-review process. The presented research contributions expand current knowledge and stimulate further discussion not only within the academic community but also across the public and private sectors. The selected papers address current interdisciplinary challenges in the fields of Economic Policy, Public Finance and Public Administration, Enterprise Information Systems and Technologies, Digital Transformation and Sustainability, Marketing and Management and Finance.

Keywords: Economic Policy, Public Finance and Public Administration, Enterprise Information Systems and Technologies, Digital Transformation and Sustainability, Marketing and Management and Finance

ABSTRAKT

Ve dnech 27. a 28. března 2025 uspořádala Provozně ekonomická fakulta Mendelovy univerzity v Brně již 27. ročník mezinárodní konference Economic Competitiveness and Sustainability, které se zúčastnilo více než 100 účastníků z České republiky, Německa, Maďarska, Indie, Japonska, Litvy, Polska, Srbska, Slovenska, Švédska, Ukrajiny a USA. V předloženém sborníku naleznete 17 příspěvků, které byly doporučeny diskutujícími na konferenci a vybrány na základě recenzního řízení. Prezentované výzkumné výstupy přispívají k rozšíření současného stavu poznání a podněcují další diskusi nejen v akademické sféře, ale také v prostředí veřejného a soukromého sektoru. Zveřejněné příspěvky reagují na aktuální interdisciplinární výzvy v oblasti hospodářské politiky, veřejných financí a veřejné správy, podnikových informačních systémů a technologií, digitální transformace a udržitelnosti, marketingu, managementu a financí.

Klíčová slova: hospodářská politika, veřejné finance a veřejná správa, podnikové informační systémy a technologie, digitální transformace a udržitelnost, marketing a management a finance

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FOREWORD

Dear readers,
We are honoured to present the Conference Proceedings, published as one of the key outcomes of the 27th International Conference on Economic Competitiveness and Sustainability (ECOS 2025), held on March 27–28, 2025.

We hosted two distinguished well-known speakers who contributed to the conference programme with their keynote speeches. Prof. Karsten Neuhoff (Head of the Climate Policy Department German Institute for Economic Research (DIW Berlin)) gave a speech " EU Industrial Deal – How to Create Reliability for Investments in a Volatile World?". Prof. Magdalena Daria Vaverková (Warsaw University of Life Sciences, Poland) contributed to the discussion on the topic of "Are we on Track with Sustainable Development Goals in Waste Management? The Role of University Education and Active Engagement".

We welcomed more than 100 researchers representing universities and research institutes from countries including Czech Republic, Germany, Hungary, India, Japan, Lithuania, Poland, Serbia, Slovakia, Sweden, Ukraine and the United States of America, who also served as the discussants of the papers and helped to improve the quality of the research results presented during both conference days.

Another useful opportunity to discuss the conference themes was a moderated Panel Discussion entitled "Beyond Green: ESG Strategies and Dilemmas for a Sustainable Future", with four invited experts: Karsten Neuhoff, Magdalena D. Vaverková, Anna Píchová (responsible for the investment agenda, One Family Office) and Theodor Christofi (ESG Reporting Manager, ČSOB Group).

The purpose of the conference is to enhance academic debate on current problems in the global socio-economic environment and dynamic technological development. Last but not least it is a chance to meet our research counterparts in person and critically review our perspectives on contemporary research problems.

In the presented Proceedings you can find 17 papers which were recommended by conference discussants and selected on the basis of a peer-review process. The presented research outputs contribute to and extend the current state of knowledge and will stimulate further debate not only in academia but also in other institutions of public and private sector.

The submitted papers react to the current interdisciplinary problems arising in the areas of Economic Policy, Public Finance and Public Administration, Enterprise Information Systems and Technologies, Digital Transformation and Sustainability, Marketing and Management and Finance.

We would like to thank all the participants in the conference for their inspiring contributions. Furthermore, we are grateful to all the reviewers and the members of the scientific committee for their contribution to the organisation of this high-level scientific conference.

ECONOMIC COMPETITIVENESS AND SUSTAINABILITY 2025

CONTRIBUTIONS

LEVERAGING HTTP/3 FOR EFFICIENT RESTFUL API COMMUNICATION

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ABSTRACT

The rise of IT systems automation required the shift of the management of network devices and servers to machine-oriented interfaces, such as REST APIs. It enables large-scale batch requests but also creates challenges such as latency and limited concurrency handling. This paper investigates the potential benefits of adopting HTTP/3 for REST-based network and server management, examining its impact on communication efficiency. Specifically, the research compares different versions of HTTP in terms of communication performance, latency, message count, and execution speed, while exploring the advantages and challenges of such solutions. The findings provide valuable information on the integration of HTTP/3 into modern network management practices, with the aim of optimising automation and improving performance across IT infrastructures.

Keywords: HTTP/3, QUIC, REST API, RESTCONF, server, network, management

JEL Code: L86, C88, O31

1 INTRODUCTION

Traditionally, servers, services, and network devices have been managed through SSH or web interfaces. However, with the growing adoption of IT systems management automation, machine-oriented interfaces have gained significant importance. These interfaces enable rapid, large-scale batch requests to devices, improving efficiency in the management of IT infrastructure. However, this approach introduces challenges related to response times and the ability of managed devices to handle large volumes of concurrent requests effectively.

Although SSH (Secure Shell) remains one of the primary protocols for network automation, its usage is typically limited to executing standard command-line instructions through automation tools such as Ansible, Chef, or Puppet. Legacy protocols such as SNMP (Simple Network Management Protocol) and TR-069 (Technical Report 069), once popular for device configuration, have become largely outdated due to their limited scalability and security. On the contrary, modern automation interfaces increasingly utilise NETCONF (Network Configuration Protocol), RESTCONF (RESTful Configuration Protocol), and general REST APIs (Representational State Transfer Application Programming Interfaces). Both the RESTCONF and REST APIs rely on HTTPS as their underlying communication layer.

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The evolution of the HTTP protocol raises the question whether adopting the modern HTTP/3 version could improve communication efficiency for REST-based management services. In the case of network devices, the HTTP version is typically fixed, with HTTP/1.1 remaining the most widely used. However, for servers and service interfaces, it is essential to evaluate which HTTP version is best suited to optimise request-response performance in management operations. The benefits of HTTP/2 and HTTP/3 over traditional HTTP/1.1 in terms of speed, parallelism, and latency can be crucial factor in enhancing automation efficiency in modern IT environments.

Therefore, this paper explores how the adoption of HTTP/3 can improve REST API communication and its impact on communication latency. Specifically, the research addresses the following questions:

- Research Question 1 (RQ1): Can HTTP/3 reduce latency and enhance performance for large-scale network management operations?
- Research Question 2 (RQ2): How does the performance of network and server management differ between HTTP/1.1, HTTP/2, and HTTP/3 in terms of message count and execution speed?
- Research Question 3 (RQ3): What challenges might arise when migrating existing network management tools to HTTP/3?

These questions aim to provide insights into the benefits and potential limitations of adopting HTTP/3 for network management tasks.

2 RELATED WORKS

The current principles of network device automation are primarily based on the NETCONF and RESTCONF protocols, utilising JSON and XML as the primary data formats (Abuelanain, 2021). While RESTCONF is specifically designed for network management, REST APIs are widely used beyond this scope, serving as interfaces for data exchange between various systems and services. Consequently, this chapter will first explore the foundational principles of REST APIs and methodologies for their testing. The second part will focus on recent research advancements related to the HTTP protocol.

2.1 REST API

The systematic review of the literature on current methodologies and challenges in RESTful API testing was carried out by Ehsan (2022) and Golmohammadi (2023). Wu (2022) provided an in-depth analysis of the number of operations required in specific scenarios and the interaction of various parameters in each operation.

Kim (2023) reviewed existing REST API testing tools and proposed an adaptive testing technique using reinforcement learning. Gowda (2024) compared response times across different REST APIs, applying a developer-focused method to assess both performance and security. Most recent studies on REST API testing treat APIs as black boxes, with one of the latest works by Poth (2024) focusing on contemporary performance evaluation.

2.2 HTTP protocol

The use of HTTP/3 as a communication protocol for infrastructure and management tasks was proposed and validated by Saif (2021) through the MQTT protocol. Michel (2023) explored the concept of SSH over HTTP/3, highlighting key advantages such as faster session establishment and reduced response times. These two studies demonstrate the potential of HTTP/3 to improve device management protocols.

Perna (2022) conducted one of the first comprehensive evaluations of HTTP/3 performance. Gahtan (2024) performed extensive testing of HTTP/3 responses on the open Internet, analysing approximately 7 million images to estimate response times. Ravuri (2023) provided a practical example by implementing an interactive service using HTTP/3. Gupta (2024) investigated content delivery prioritisation in HTTP/3, focusing on minimizing head-of-line blocking and evaluating Quality of Experience (QoE) across various websites.

The security issues in networks were evaluated by Kashtalian (2023), where the problem of their detection was investigated. Attacks on HTTP/3 were comprehensively reviewed by Chatzoglou (2023), where all current QUIC libraries and applications were tested.

3 REST API MANAGEMENT OVER HTTP/3

To effectively compare the efficiency, responsiveness, latency, and security of REST API communication across various HTTP versions, it is essential to dive deeper into the structure and principles of REST APIs.

3.1 REST API management

Representational State Transfer (REST) has become a standard interface not only for application data exchange but also for device management. Originally proposed by Fielding (2000), but the structure of REST APIs are now primarily standardized by OpenAPI (2024).

Communication with REST APIs is carried out using the standard HTTP protocol, predominantly through its secure variant, which utilizes SSL/TLS layer. REST APIs support all CRUD operations (Create, Read, Update, Delete) through the standard HTTP methods such as POST, GET, PUT, and DELETE. One of these methods is specified in the initial part of the request, followed by the resource identification via a unique URL and the used HTTP version. When creating or updating a resource, the message body contains the relevant data, typically in JSON or YAML format.

The server‘s response includes the HTTP version, a three-digit status code, and a status message. In the case of data retrieval, the requested content is also included in the message body. Both the request and response may contain additional headers, such as client/server versions, timestamps, accepted content types, and more. The fundamental structure of the mandatory components is illustrated in Figure 1.

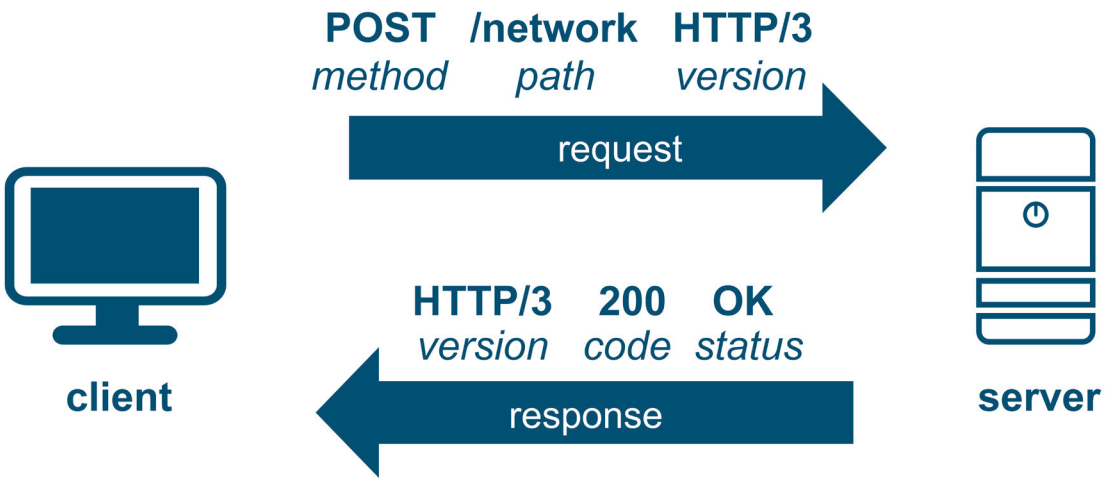

Fig. 1: REST API request and response structure

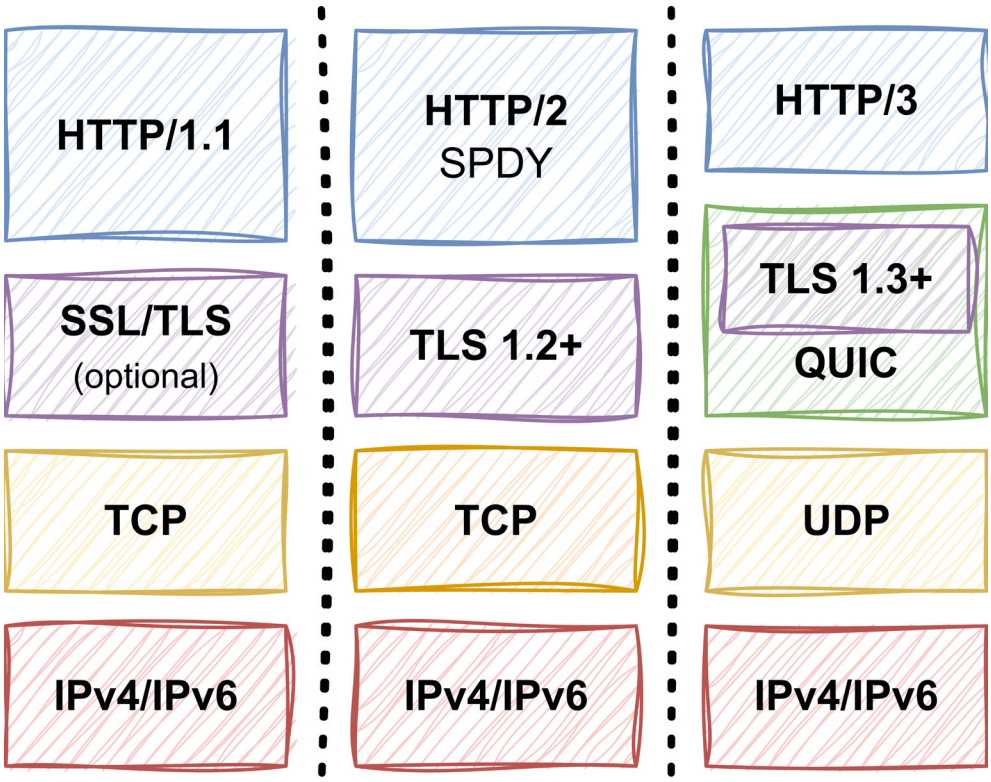

Fig. 2: Protocols stack by OSI layers for various versions of HTTP

3.2 HTTP development

Over the past decade, significant progress has been made in the evolution of HTTP protocols. The widely adopted HTTP/1.1, which dominated the web for over 20 years, has become less efficient in meeting the demands of modern services and networks.

The first major advancement was HTTP/2, developed based on the SPDY protocol draft. This version introduced several significant improvements, including mandatory TLS use, header compression, binary encoding, enhanced prioritization, and server push mechanisms. However, HTTP/2 still relies on TCP as its transport layer protocol and typically uses TLS 1.2 or TLS 1.3.

HTTP/3, the latest version, made a significant shift by replacing TCP with UDP as the transport protocol and using new protocol QUIC responsible for connection handling and TLS security layer. This change addresses the limitations of TCP's congestion control algorithms, which can slow down data exchange in cases of packet loss. HTTP/3 also mandates the use of TLS, specifically version 1.3. Although HTTP/3 was officially standardized only recently (Iyengar, 2021; Bishop, 2022), it has been in practical use for more than five years and currently it is adopted by approximately 30–40% of servers, according to W3Tech statistics. Figure 2 illustrates the protocol structures used for HTTP communication across different versions.

3.3 HTTP message exchange

The performance of communication is directly influenced by the number of exchanged message pairs (request-response), as each subsequent pair must wait for the previous one to complete. The delay caused by a single exchange is referred to as Round Trip Time (RTT), which includes the time taken to deliver a message, generate a response, and transfer it back. The request-response message pairs are illustrated in Figure 3 (Marx, 2021).

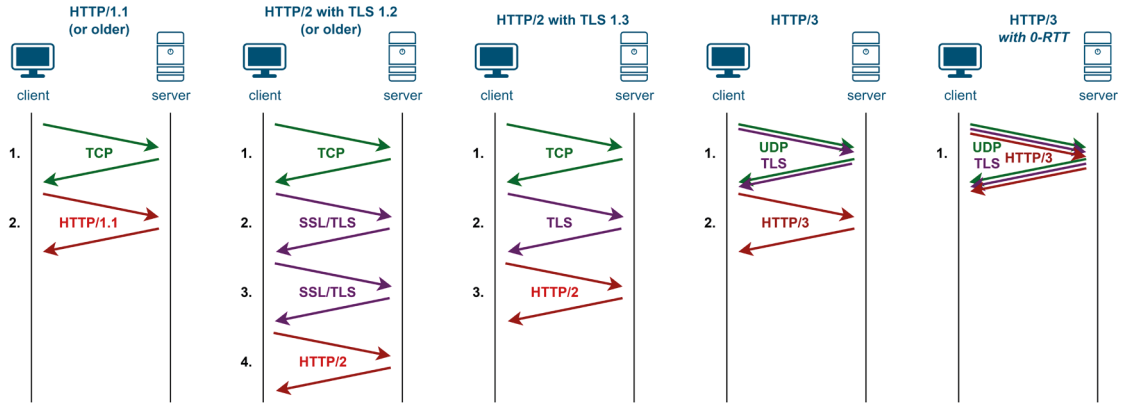

Fig. 3: HTTP versions session establishment communication
Source: Marx, 2021)

In the first versions of HTTP (as shown in the first example in Figure 3), establishing a TCP session required one RTT, while an additional RTT was necessary for the actual data transfer. This exchange did not include a security layer (TLS/SSL), which is now essential for modern communication.

The introduction of HTTPS added two additional message exchanges to the process, increasing the total RTTs to four (second example in Figure 3). However, with the advent of TLS version 1.3, only one message exchange is needed to establish a secure channel, reducing the total number of RTTs to three (third example in Figure 3).

HTTP/3 eliminates the use of the TCP protocol, which required the first RTT for connection establishment. Instead, channel establishment and TLS negotiation are completed in a single exchange (fourth example in Figure 3). Additionally, HTTP/3 supports a method called 0-RTT, which enables session resumption based on a previously established secure connection. However, 0-RTT introduces vulnerabilities, such as replay attacks, and is considered less secure.

1.1 HTTP communication experiment

The theoretical concepts described above were tested in a real-world environment. To validate our hypotheses, we conducted experiments using different HTTP versions and evaluated their security aspects.

We used the curl client, with supports of all current HTTP versions. As the target was used cloudflare-quic.com, which also supports all current HTTP versions. To minimize the size of request and response we used method HEAD, which grabs only website header. All communication finished with status code 200 OK, but with plain HTTP (non-secure), the server responds with a 301 (Moved Permanently) status code. This response does not affect the validity of our results.

HTTP version negotiation and communication details were verified through the verbose output of the curl command. Additionally, all exchanged messages were captured using Wireshark and analyzed with various tools.

Figure 4 shows the resulting flow graph. We highlighted the key differences in total communication time and message direction. Rather than counting individual packets, we focused on communication directions, as the primary delays sources from message transmission between communication partners.

To maintain relevance to data retrieval performance, we limited the analysis to the point of receiving the HTTP response status code, excluding the additional 3–4 message exchanges typically involved in closing a TCP session—since those steps do not impact the retrieval of data itself.

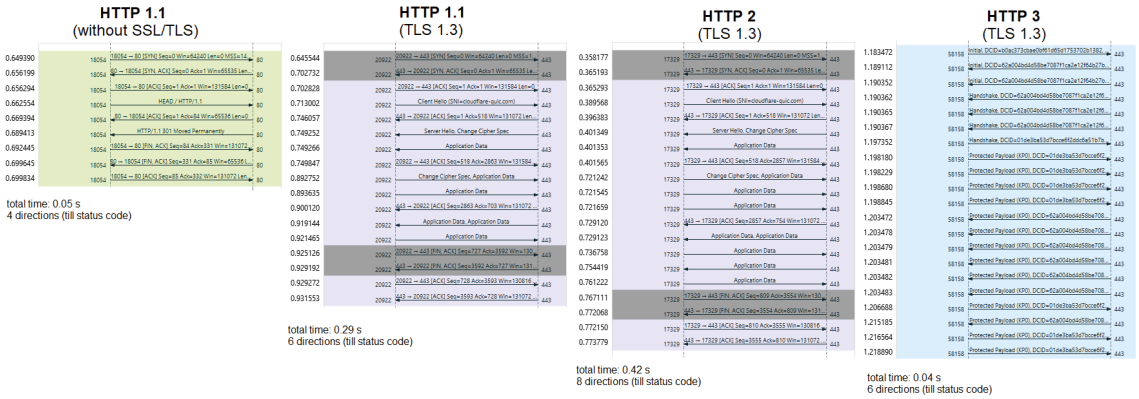

Fig. 4: Retrieving website header (method HEAD) using various HTTP versions

Data in Figure 4 clearly shows that HTTP/1.1 without TLS and HTTP/3 with TLS are comparable in terms of total communication time. While the non-secure HTTP required fewer message exchanges overall, HTTP/3—despite having the highest number of individual messages—achieved communication in just six directional exchanges. In our assessment, HTTP/3 outperforms the other secure HTTP variants in this experiment, offering better efficiency in terms of both speed and message flow structure.

4 RESULTS

4.1 Research Question 1

- Can HTTP/3 reduce latency and enhance performance for large-scale network management operations?

HTTP/3 can reduce latency by eliminating the need for the TCP protocol and enabling 0-RTT (Zero Round-Trip Time) connections. It also offers improved concurrency handling compared to HTTP/2 and older versions. Furthermore, the use of the UDP protocol allows faster recovery from packet loss than TCP, contributing to enhanced overall performance.

4.2 Research Question 2

- How does the performance of network and server management differ between HTTP/1.1, HTTP/2, and HTTP/3 in terms of message count and execution speed?

Modern HTTP versions, such as HTTP/2 and HTTP/3, enable multiplexing, which enhances performance by addressing the issue of head-of-line blocking. HTTP/3, in particular, reduces the number of exchange messages compared to older versions, further improving both performance and execution speed.

Our experimental results confirm that HTTP/3 outperforms both secure HTTP/1.1 and HTTP/2 in terms of total required time. Interestingly, HTTP/2 was observed to be slower than HTTP/1.1 in our test scenarios, which may be attributed to its more complex connection management and dependency handling.

4.3 Research Question 3

- What challenges might arise when migrating existing network management tools to HTTP/3 or QUIC?

One of the main challenges with network devices and systems is the lack of support and willingness from vendors to adopt newer technologies. However, HTTP/3 is now well-established, widely used and there are available many public libraries to facilitate integration. Despite its growing adoption, issues may still arise during implementation. Additionally, the use of UDP instead of TCP in HTTP/3 remains relatively untested in some environments, which may pose challenges for stability and performance in certain network conditions.

5 CONCLUSIONS

RESTful APIs are widely applied in various domains, including IoT, cloud applications, services and device management, where efficient, scalable, and loosely coupled communication is necessary. These APIs have also become a foundation for popular web frameworks and technologies, enabling seamless integration of third-party services, and enhancing interoperability in modern software ecosystems.

The findings of the paper highlight the potential of HTTP/3 for REST APIs, offering benefits such as reduced latency and enhanced performance. By leveraging UDP protocol and introducing features such as 0-RTT connections, HTTP/3 addresses limitations of previous HTTP versions, particularly in handling packet loss and reducing exchange overhead. Comparisons of HTTP version reveal that modern ones like HTTP/2 and HTTP/3 benefit from advancements such as multiplexing and binary format, which improve execution speed and efficiency and at the same time secure the communication.

While HTTP/3 presents promising performance improvements for network and server management, transitioning existing tools to these protocols involves challenges such as compatibility issues, devices updates, and new security considerations (Kuhlewind, 2022). Additional testing and evaluation is necessary before implementing the protocol for device management.

A logical extension of this research involves testing the reliability of REST APIs over HTTP/3 under a variety of conditions. Future work will focus on evaluating performance across different network scenarios, including varying levels of delay, bandwidth, and packet loss, to assess how HTTP/3 handles adverse environments. The impact of concurrent client requests on API responsiveness and throughput will also be measured, providing insights into scalability. Additionally, we plan to investigate how the size of HTTP requests—particularly in Create and Update operations—affects performance. Another important aspect will be verifying the current level of support for REST APIs over HTTP/3 and HTTP/2 in existing network devices and server platforms. Finally, special attention will be given to cybersecurity, specifically through testing the security implications of the 0-RTT (zero round-trip time) feature when used in RESTful API communications.

REFERENCES

ABUELANAIN, K., DOYLE, J., KARNELIUK, A., JAIN, V. 2021. *Network Programmability and Automation Fundamentals.* Cisco Press, New Jersey, USA, 800 pages. ISBN: 978-1-58714-514-8

BISHOP, M. 2022. RFC 9114. HTTP/3. Jun. 2022. RFC *Editor*. https://www.rfc-editor.org/info/rfc9114

EHSAN, A., ABUHALIQA, M. A. M. E., CATAL, C., MISHRA, D. 2022. RESTful API Testing Methodologies: Rationale, Challenges, and Solution Directions. *Applied Sciences.* 12(9), 4369. https://doi.org/10.3390/app12094369

FIELDING, R. T. 2000. *Architectural Styles and the Design of Network-based Software Architectures.* Ph.D. Dissertation. University of California, Irvine.

GATHAN, B., SHAHLA, R. J., COHEN, R., BRONSTEIN, A. M. 2024. Estimating the Number of HTTP/3 Responses in QUIC Using Deep Learning. *arXiv*:2410.06140. https://doi.org/10.48550/arXiv.2410.06140

GOLMOHAMMADI, A., ZHANG, M., ARCURI, A. 2023. Testing RESTful APIs: A Survey. *ACM Transactions on Software. Engineering and Methodology.* 33(1), 27. https://doi.org/10.1145/3617175

GOWDA, P., GOWDA, A. N. 2024. Best Practices in REST API Design for Enhanced Scalability and Security. *Journal of Artificial Intelligence, Machine Learning and Data Science*. 2(1), 827–830. https://doi.org/10.1145/3617175 doi.org/10.51219/JAIMLD/priyanka-gowda/202

GUPTA, A., BARTOS, R. 2024. Improving Web Content Delivery with HTTP/3 and Non-Incremental EPS. In: *2024 33rd International Conference on Computer Communications and Networks (ICCCN)*. Kailua-Kona, HI, USA, pp. 1–9. https://doi.org/10.1109/ICCCN61486.2024.10637641

IYENGAR, J., THOMSON, M. 2021. RFC 9000, QUIC: A UDP-Based Multiplexed and Secure Transport, May 2021. *RFC Editor*. https://www.rfc-editor.org/info/rfc9000

KASHTALIAN, A., LYSENKO, S., SAVENKO, B., SOCHOR, T., KYSIL, T. 2023. Principle and Method of Deception Systems Synthesizing for Malware and Computer Attack Detection. *Radioelectronic and Computer Systems*. 4, 112–151. https://doi.org/10.32620/REKS.2023.4.10

KIM, M., SINHA, S., ORSO, A. 2024. Adaptive REST API Testing with Reinforcement Learning. *ACM International Conference on Automated Software Engineering.* IEEE Press, pp. 446–458. https://doi.org/10.1109/ASE56229.2023.00218

KUHLEWIND, M., TRAMMELL, B. 2022. RFC 9308, Applicability of the QUIC Transport Protocol, Sep. 2022. *RFC Editor*. https://www.rfc-editor.org/info/rfc9308

MARX, R. 2021. HTTP/3 From A To Z: Core Concepts. *Smashing magazine: For Web Designers And Developers*. Aug. 9, 2021. https://www.smashingmagazine.com/2021/08/http3-core-concepts-part1/

MICHEL, F., BONAVENTURE, O. 2023. Towards SSH3: how HTTP/3 improves secure shells. *arXiv*:2312.08396. https://doi.org/10.48550/arXiv.2312.08396

OPENAPI. 2024. OpenAPI pecification v3.1.1. *OpenAPI Initiative*. https://spec.openapis.org/oas/latest.html

PERNA, G., TREVISAN, M., GIORDANO, D., DRAGO, I. 2022. A first look at HTTP/3 adoption and performance. *Computer Communications*. 187, 115–124. ISSN 0140-3664. https://doi.org/10.1016/j.comcom.2022.02.005

POTH, A., RRJOLLI, O., ARCURI, A. 2024. Technology adoption performance evaluation applied to testing industrial REST APIs. A*utomated Software Engineering.* 32, 5. https://doi.org/10.1007/s10515-024-00477-2

RAVURI, H. K., VEGA, M. T., VAN HOOFT, J. D., WAUTERS, T., DE TURCK, F. 2023. Adaptive Partially Reliable Delivery of Immersive Media Over QUIC-HTTP/3. *IEEE Access.* 11, 38094–38111. https://doi.org/10.1109/ACCESS.2023.3268008.

SAIF, D., MATRAWY, A. 2021. A Pure HTTP/3 Alternative to MQTT-over-QUIC in Resource-Constrained IoT. In: *2021 IEEE Conference on Standards for Communications and Networking (CSCN)*. Thessaloniki, Greece, pp. 36–39. https://doi.org/10.1109/CSCN53733.2021.9686113

WU, H., XU, L., NIU, W., NIE, C. 2022. Combinatorial Testing of RESTful APIs. In: *ACM 44th International Conference on Software Engineering (ICSE)*. Pittsburgh, USA, pp. 426–437. https://doi.org/10.1145/3510003.3510151

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EU MERGER CONTROL: HEALTHCARE MARKET ISSUES

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ABSTRACT

This article analyses the laws and practices regarding the control of mergers in the healthcare sector at the EU level and in several EU member states. It compares the legal frameworks of the EU and its member countries to establish the legal basis for controlling the mergers (concentrations) of the undertakings. Additionally, the article indicates interconnections between the jurisdictions of the European Commission and EU member states national competition regulatory authorities. It also provides an analysis of the European Commission's merger assessment practices in the healthcare sector since the adoption of EU Merger Regulation 139/2004 on 1 May 2004 till the end of 2024 in comparison with the practice of the Lithuanian competition regulatory authority.

Keywords: merger control, concentration control, healthcare sector, EU merger regulation

JEL Code: O17, L84

1 INTRODUCTION

Policymakers' perspectives on competition significantly influence how each country regulates market concentrations. The EU competition policy also plays a key role in this regulation. The EU Merger Regulation 139/2004 aims to strengthen the internal market, enhance competitiveness, protect effective competition, and improve living standards within the EU. Improving living standards includes various social objectives, such as ensuring the well-being of individuals (Simanavičienė *et al.*, 2024, p. 780). This well-being encompasses aspects like high-quality healthcare, among others.

Under the EU health policy, member states are responsible for organising and delivering health services and medical care. EU health policy complements national policies (Commission, 2025a). Consequently, EU merger regulations support these objectives.

Merger analysis in the healthcare sector, excluding pharmaceuticals, is often overlooked in academic and Commission research. This study is the first to investigate the specifics of merger regulation in the healthcare industry.

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The article presents the merger regulatory framework in the healthcare sector at both the EU and national levels.

Methodology: In section 2, the article analyses and compares legal acts regulating mergers on EU and national levels in eight countries: France, Greece, Finland, Germany, the UK, Spain, and Lithuania. All countries, except Lithuania, were selected considering European Commission case practice in the healthcare sector, which primarily covers the assessment of mergers in these states.

Section 3 presents an analysis of the European Commission's merger assessment practices in the healthcare sector, covering the period from May 1, 2004, when EU Merger Regulation 139/2004 was adopted, to December 30, 2024 (Commission, 2025). The focus was on cases classified under economic activity: Q.86 Human Health Activities and related subsections. During this period, 120 merger cases were identified within the healthcare sector that met the selected criteria. Additionally, the analysis includes a comparison of merger cases handled by the Lithuanian Competition Council in the healthcare sector during the same timeframe with the practices of the European Commission. It is important to clarify that this analysis does not include cases related to the health sector that do not involve patient care. Such cases include purchasing medicines, medical supplies, equipment, accommodations, meals for patients, patient transportation, home care services, etc.

2 LEGAL FRAMEWORK

Following the EU principles of subsidiarity and proportionality, the jurisdiction for regulating concentrations or mergers (hereinafter both referred to as the merger) in the EU is shared between the EU institutions and EU member states. Mergers with the EU dimension are regulated under EU law, whereas mergers not considered within the EU dimension are regulated under the laws of EU member states.

However, even in cases where the European Commission performs the merger assessment, the Commission communicates closely and continuously with the relevant authorities of the member states to gather comments and information during the merger assessment procedure (Council, 2004, §13).

Considering that, this paper analyses the key elements of merger regulation at the EU and national levels.

2.1 EU Dimension

The main document regulating mergers at the EU level is *EU Council Regulation No 139/2004 On the control of concentrations between undertakings* (Merger Regulation).

Art. 3 of the Merger Regulation indicates that the merger arises where there is "a change of control on a lasting basis". Such changes can occur in two ways: (a) through the merger of two or more previously independent undertakings or parts of undertakings or (b) through the acquisition of direct or indirect control over undertaking by an individual controlling at least one undertaking or by another undertaking. The form under which the control can be acquired is defined broadly. This can happen via purchasing securities or assets, contracts, or other means.

The Merger Regulation shows that the merger with the EU dimension exists where the aggregate turnover of the undertakings concerned exceeds given thresholds. According to Art. 1 of the Merger Regulation, the merger is considered to have EU dimensions if:

1. the combined worldwide turnover of all participants of the merger exceeds EUR 5000 million, and at least two of them have turnovers exceeding EUR 250 million in the EU market (Art. 1 (2)) or;

2. the combined worldwide turnover of all merger participants exceeds EUR 2.500 million; at least two have turnovers exceeding EUR 100 million in the EU market. Furthermore, the combined turnover of all undertakings should exceed EUR 100 million, and at least two should have a turnover of more than EUR 25 million in at least three EU member states (Art. 1 (3)).

Art. 4 (1) of the Merger Regulation requires the participants to notify the Commission about the EU dimension merger before its implementation. However, the Commission is not obligated to assess each notified merger. If each participant in the merger achieves more than two-thirds of its aggregate Community-wide turnover within the same member state, the Commission can refer to that member state notified merger following the principles of subsidiarity and proportionality and considering competition interests of the member states (Council, 2004, Art. 1 (2) & 1 (3), §§ 6 & 11).

Participants in the merger can also ask the Commission to transfer the case to the competition regulating authority of a particular member state when the merger may significantly affect competition in that state's market, which has all the characteristics of a distinct market. They can submit the request to the Commission before officially notifying it about the merger (Council, 2004, Art. 4(4)).

Discussing the Commission assessment, it could be noted that the Commission does not authorise a merger that "would significantly impede effective competition in the common market or a substantial part of it", particularly if it leads to the establishment or reinforcement of a dominant position (Council, 2004, Art. 2 (3)). If the Commission finds that the merger does not raise serious doubts about its compatibility with the common market, it declares that the concentration is compatible with the common market and decides not to oppose it following Art. 6 (1)(b) of the Merger Regulation. If the merger requires more scrutinised analysis, its compatibility with the common market can be declared through the procedure defined under Art. 8 of the Merger Regulation.

To speed up the merger authorisation process, the EC applies a simplified procedure for mergers, which, under EC practice, are "generally not likely to raise competition concerns" (Commission, 2023, § 1).

2.2 National Dimension

Five analysed countries: France (2000, Art. L430-1), Greece (2011, Art. 5), Finland (2011, Sec. 21), Spain (2007, Art. 7 (1) (2)), and Lithuania (1999, Art. 3), define concentration similarly to the one described in the EU Merger Regulation. Concentration is a transaction where two or more independent undertakings or their parts merge. It also includes situations where an undertaking or one or more individuals who already control at least one undertaking acquire lasting control, directly or indirectly, over all or part of one or more other undertakings.

In all five countries, control refers to the ability to have a decisive influence on the undertaking's activities. Control can be acquired by purchasing securities or assets, contracts, or other means. Decisive influence refers to a situation where a controlling person or undertaking can implement decisions related to economic activities, the decisions of governing bodies, or the composition of personnel. Additionally, Finland (1997, Sec. 5) provides a more precise definition of control. Under the law, the person or undertaking is considered to have control when it has more than half of the votes in the target company based on ownership, membership, articles of association, partnership agreement or comparable rules or other agreement; has the right to appoint or dismiss a majority of the members of the board of directors of the target company or a comparable body or otherwise actually exercises control over the target company.

In Germany, the Competition Act (2013, Sec. 37) outlines two additional forms of concentration not covered by the previously discussed countries. These forms include acquiring 50 or 25 percent of shares or voting rights in another company. Additionally, it encompasses any

Tab. 1 Thresholds for notifying the merger to national competition regulatory authorities.

Country	Threshold tests			GDP in millions of US$; population; Per capita in thousands of US$; (2023)
UK	**The turnover test:** → turnover of acquired undertaking in the UK exceeds £100 m.	**The share of supply test:** → turnover of one involved undertaking in the UK exceeds £10 m., → and merger group will have 25% of the supply or acquire market in UK, → and increment to the share of supply or acquisition	**The hybrid test:** → 33% of supply or acquire market in UK by person(s) that carry on an enterprise, → and UK turnover of the same enterprise exceeds £350 m., and other enterprise has a UK nexus	GDP: 3,380,854.52 Population: 68,350,000 Per capita: 49.46
France	**I turnover test:** → total worldwide turnover exceeds 150 m. EUR, → and total turnover in France by at least two participants exceeds 50 m. EUR	**II turnover test, when two of the participants operate retail stores:** → total worldwide turnover of all participants exceeds 75 m. EUR, → and total turnover in the retail sector in France by at least two participants exceeds 15 m. EUR	**III turnover test, when at least one has activity in overseas departments:** → total worldwide turnover exceeds 75 m. EUR, and → total turnover of the two participants individually in any overseas department exceeds 15 m. EUR or 5 m. EUR in the retail market.	GDP: 3,051,831.61 Population: 68,287,487 Per capita: 44.69
Greece	**The turnover test:** → total worldwide turnover exceeds 150 m. EUR, → and total turnover in Greece by at least two participants exceeds 50 m. EUR			GDP: 243,498.33 Population: 10,405,588 Per capita: 23.40
Finland	**The turnover test:** → total worldwide turnover exceeds 350 m. EUR, and total turnover in Finland by at least two participants exceeds 20 m. EUR			GDP: 295,532.34 Population: 5,583,911 Per capita: 52.93
Spain	**The turnover test:** → total turnover of the merger group in Spain exceeds 240 m. EUR, and → total turnover in Spain by at least two participants exceeds 60 m. EUR	**The share of supply test:** → Merger group market share reaches 30% of the product or service market in Spain or a geographical market		GDP: 1,620,090.73 Population: 48,347,910 Per capita: 33.51
Germany	**The hybrid test:** → total worldwide turnover of the group exceeds 500 m. EUR, and → total turnover in Germany by one participant exceeds 50 m. EUR, but the turnover of other participants is less than 17.5 m. EUR, and → value of the acquisition exceeds 400 m. EUR, and → the target undertaking has substantial operations in Germany	**The turnover test:** → total worldwide turnover of the group exceeds 500 m. EUR, and → total turnover in Germany by at least one participant exceeds 50 m. EUR and by another participant exceeds 17.5 m. EUR		GDP: 4,525,703.90 Population: 83,280,000 Per capita: 54.34
Lithuania	**The turnover test:** → total turnover of the group in Lithuania exceeds 20 m. EUR, and → turnover in Lithuania by at least two participants, individually, exceeds 2 m. EUR			GDP: 79,789.88 Population: 2,871,585 Per capita: 27.79

combination of companies that allows one or more firms to exert a significant competitive influence on another company, either directly or indirectly.

In the UK (2002, Sec. 23), a merger occurs when two or more undertakings "cease to be distinct". Sec. 26 specifies that "cease to be distinct" happens when undertakings come under common ownership or control, irrespective of the form. This definition indicates that, despite the differing language, the concept of a merger is similar to that in the already--discussed jurisdictions.

In all analysed countries, except the UK, the law mandates that the merger must be authorised by the competition regulatory authority before it can be implemented (France, 2000, Art. L430-3; Grece, 2011, Art. 7 (1); Finland, 2011, Sec. 23; Spain, 2007, Art. 9 (1), Germany, 2013, Sec. 39 (1); Lithuania, 1999, Art. 8(1)), if the merger group exceeds the established thresholds (Table 1). In the UK, the notification can be done voluntarily.

The thresholds are very different in the countries (France, 2000, Art. L430-2; Grece, 2011, Art. 6; Finland, 2011, Sec. 22; Spain, 2007, Art. 8, Germany, 2013, Ch.7 Sec. 35; UK, 2025, p.14; Lithuania, 1999, Art. 8).

All analysed countries apply the turnover test to identify relevant merger transactions; however, the test varies significantly among countries. France has even three of them. Some countries consider worldwide turnover (France, Greece, Finland, and Germany), whereas others account for only national turnovers (the UK, Spain, and Lithuania). The turnover value also differs significantly among countries; for example, the requirement for worldwide turnover in Greece is 150 million EUR, whereas in Finland, it is 350 million EUR. It is even hard to say that it has some correlation with the country's GDP (World Bank, 2023).

In addition to the threshold tests, some countries apply the share of supply tests (UK and Spain) and hybrid tests (UK and Germany). The requirements for the share of supply and hybrid tests are not uniform, either.

When comparing the rules for substantive assessment, some countries define the rule similarly to that provided in the EU Merger Regulation. They apply significant impediments to the effective competition (SIEC) test, in which creating a dominant position in the market is considered one of the forms which would significantly impede effective competition. For example, competition regulatory authorities in Germany (2013, Ch.7, Sec. 36(1)) prohibit a merger that would significantly impede effective competition, particularly if it is expected to create or strengthen a dominant position. In Finland (2011, Sec. 25), the law specifies that the merger would be prohibited if it substantially prevents effective competition in the Finnish market or a substantial part of it, particularly if it creates or strengthens a dominant market position.

France and Greece have slightly different assessment rules than the EU Merger Regulation. However, the essence of the assessment is as defined in the EU Merger Regulation. In France (2000, Art. L430-6), the merger would be prohibited if it is likely to harm competition, in particular, by creating or strengthening a dominant position or by creating or strengthening purchasing power that places suppliers in a situation of economic dependence. In Greece (2011, Art 7), the merger would be prohibited if it significantly impedes competition in the national market or a substantial part in the specified market of goods or services, especially by creating or strengthening a dominant position.

In Lithuania (1999, Art. 3 (12)), the strengthening of a dominant position and the significant impediment to effective competition are separate forms of harm to competition. The Lithuanian Competition Council would not authorise the merger when it creates or strengthens the dominant position of involved undertakings or would significantly impede effective competition in the defined market.

No specific test exists for assessing mergers in Spain (2007, Art. 10 (1)). The law indicates that while assessing the notified merger, the National Competition Commission analyses the possible hindrances to maintaining effective competition.

The UK (2013, Art. 22 (1)) applies the substantial lessening competition (SLC) test, which is different from that of other countries. The merger would be prohibited when it resulted, or may be expected to result, in an SLC within any market or markets in the UK for goods or services (UK, 2021, § 2.1). Under the SLC test, the merger would not be considered as substantially lessening competition if "any relevant customer benefits in relation to the creation of the relevant merger situation concerned outweigh the substantial lessening of competition concerned and any adverse effects of the substantial lessening of competition concerned" (UK, 2013, Art. 35). The benefit for the customers means the lower prices, higher quality or greater choices of goods or services, or increased innovation because of the merger.

It should be noted that some countries, even when applying SIEC, consider whether the benefits outweigh the harm to the market. In France (2000, Art. L430-6), while assessing the merger, the Autorité de la Concurrence considers whether the operation contributes sufficiently to economic progress to offset the harm to competition. In Germany (2013, Ch. 7, Sec. 36 (1)), the merger would not be prohibited if its participants proved that the merger would also lead to improvements in the conditions of competition and that these improvements would outweigh the impediment to competition. Such considerations make the merger assessment under the SIEC more like under the SLC. It cannot be said that merger benefits are not considered in other countries. Under SIEC, a significant impediment to effective competition is determined while assessing the merger's overall impact (harming and benefitting the market) on the market.

Finally, it should be highlighted that in some countries, even when the merger should be considered to harm the competition in the market, noneconomic criteria are also considered when deciding whether to allow or prohibit the merger. In Spain (2007, Art.10 (4), even if the National Competition Commission considers prohibiting the merger, the Council of Ministers can authorise it when national defence and security, protection of public safety or health, free movement of goods and services, environmental protection, and promotion of technological research and development require it. In the UK (2002, Sec. 42 & 58), the Secretary of State may consider public interest factors, such as media plurality and other media issues, the stability of the UK financial system, and the need to maintain the capability to combat and mitigate the effects of public health emergencies in the UK. In Germany (2013, Sec. 42 (1) & 187), the Federal Minister for Economic Affairs and Energy can authorise the merger, which an overriding public interest can justify. Additional considerations for mergers in the healthcare sector are foreseen to be implemented by 31 December 2027.

3 THE HEALTHCARE SECTOR IN EC DECISIONS

3.1 General overview

In all 120 merger cases in the healthcare sector from 1 May 2004 to 30 December 2024, found in the Commission case database (Commission, 2025 (b)), the mergers were in the form of acquisition of control under Art. 3(1)(b) of the Merger Regulation.

Under a simplified procedure, the Commission authorised eighty (80) merger cases pursuant to Art. 6 (1) (b) of the Merger Regulation, representing 67% of the total number of notified cases. The Commission determined that these mergers do not raise serious doubts about their compatibility with the common market. Table 2 specifies the conditions and the number of cases authorised under the simplified procedure. Some cases were processed under the simplified procedure based on multiple conditions.

The Commission forwarded 19 cases to the member states under Art. 4(4) of the Merger Regulation for the assessment at the request of the merger participants because the merger was considered to significantly impact competition within a market with distinct characteristics; therefore, it should be examined by that member state, either in whole or in part.

Tab. 2 Mergers under the simplified procedure for the 1 May 2004 – 30 December 2024 period

Conditions for processing the assessment of the merger under simplified procedure	Number of cases
a. If undertakings acquire control of the joint venture which does not have income from the EU market and do not intend to transfer any assets within the EEA	1
b. If undertakings acquire control of the joint venture, which has negligible activities in the EEA (the current and expected annual turnover is 100 m. EUR, and the value of the asset is less than 100 m. EUR)	21
c. If merging undertakings whose business activities were not in the same product and geographic market before the merger.	40
d. If the merger does not create market power, it could harm competition. Criteria: **i.** i. The horizontal overlap in the same product and geographic market 1) is lower than 20 %, or 2) it is lower than 50 %, and the increment (delta) of the Herfindahl-Hirschman Index (HHI) is below 150. **ii.** ii. The vertical combined market share 1) is less than 30 % in upstream and downstream markets or 2) is less than 50 % in upstream and downstream markets, and the increment (delta) of the HHI is below 150).	24
e. If a merger participant obtains sole control of an undertaking over which it already has joint control.	4

In 21 cases, the Commission assessed the notified mergers itself. The analysis shows that in all healthcare sector mergers, the Commission did not need a thorough analysis and authorised the mergers under Art. 6 (1) (b) of the Merger Regulation. Only in one case did the Commission authorise the merger with conditions and obligations (M.4367, 2007).

3.2 Relevant market in the healthcare sector

While apprising whether the merger could significantly impede the competition, the member states consider similar criteria to those which the Commission considers: the structure of all the relevant markets, the actual or potential competition from undertakings located inside or outside the particular market, any legal or other barriers to market entry, merger participants position in the market and their economic and financial power, the alternatives available in the market to suppliers and users, they access to sources of supply or markets for the goods, the supply and demand trends for the relevant goods and services, the interests of the intermediate and ultimate consumers and other. This indicates that the central element in the assessment is defining the relevant market.

By identifying the market, the Commission establishes the boundaries of competition between businesses and identifies the competitive constraints undertakings face when they offer specific products in a particular area (Commission, 2024, § 6). The relevant market includes product and geographic dimensions (Commission, 2024, § 12).

In 21 analysed merger cases in the healthcare sector, the Commission discussed markets in France (3 cases), Greece (1 case), Finland (1 case), Spain (2 cases), Germany (1 case), the UK (3 cases) and in multiple countries (10 cases). Notably, in all cases, the opinion and practice of national competition regulatory authorities had a remarkable influence on the Commission's attitude toward delineating the relevant market.

3.2.1 Product Market

The analysis of the cases revealed that the Commission is reluctant to identify precisely the relevant product market in the healthcare sector. Often, the product market delineation was ultimately left open (M.7813, 2016, § 43; M.8146, 2016, § 15; M.10301, 2022, §32) since the transaction does not "raise serious doubts as to its compatibility with the internal market or

the functioning of the EEA agreement even under the narrowest plausible product market definition" (M.7309, 2014, § 25; M.10247, 2021, §161; M.10255, 2021, §25), or transaction "does not raise serious doubts as to its compatibility with the internal market irrespective of the alternative market definition considered" (M.7833, 2025, § 20; M.5805, 2010, § 11), or "competition concerns are unlikely to arise under any plausible market definition" (M.7323, 2014, § 41).

Nonetheless, the Commission's merger case practices reveal trends in its approach to defining the relevant market within the healthcare sector.

The Commission first examined whether a distinction should be made between (i) private healthcare institutions (hospitals) and (ii) public healthcare institutions (publicly funded hospitals) (M.5548, 2009, § 9). In addressing this issue, the Commission indicated that the answer depends on each member state's structure, regulation, and funding of healthcare systems (M.10301, 2022, §32; M.10247, 2021, §158). The precise delineation depends largely on the specifics of each case and the national market involved (M.9044, 2018, §§ 21 & 145). This perspective considers the variations in the organisation of national healthcare systems and the regulatory environments of individual states (M.4367, 2007, § 11).

The Commission case practice shows that the distinction between private hospital services and publicly funded hospitals can be drawn up in the UK, Greece, and Finland.

The Commission determined that in the UK, there are valid reasons to view private acute general hospitals as a separate market from public acute general hospitals provided by the National Health Service (NHS) (M.4788, 2007, § 9). Private and public healthcare services have several differences. Private healthcare is typically funded by the patient, often through insurance with a national private medical insurer, whereas public healthcare is primarily funded through taxation. This means that public healthcare may require a limited patient contribution or is offered for free (M.4367, 2007, §§ 11-13). Private acute hospitals also distinguish themselves from public acute hospitals regarding patient experience, waiting times, clinical outcomes, and overall comfort (M.4229, 2006, § 13).

In Greece, there are distinct markets for public and private hospital services, which can be attributed to two main factors: i) the differing characteristics of each sector, such as the level of investment in medical equipment, the ability of patients to choose their treating physicians, the speed of service delivery, and the costs involved, and ii) the variations in treatment covered by public health insurance (M.10301, 2022, § 31).

In Finland, the public and private healthcare markets were separated because public and private healthcare institutions (hospitals) do not necessarily provide the same kind of services (M.7058, 2013, § 24). In addition, the Commission found that the Finnish healthcare sector can be segmented into even smaller markets. The Finnish market can be divided considering three basic models of organising healthcare services: (i) fully private, (ii) fully public, (iii) a combined model in which the private healthcare supplier deals with the provision of staff only and uses third-party facilities (owned by the public (municipality) or sometimes by private companies) (M.7058, 2013, § 25).

The Commission found that market investigation results did not support any private/public separation in the German (M.8146, 2016, § 11) and French (M.7833, 2015, § 17; M.5805, 2010, § 10; M.6343, 2011, § 24) healthcare markets. Public and private healthcare institutions in both countries belong to one healthcare market.

Secondly, the Commission conducted an examination of the market for hospital services by differentiating between two types of procedures: inpatient (acute) procedures in hospitals and outpatient (ambulatory) procedures (M.10301, 2022, § 32; M.10255, 2021, § 25; M.9044, 2018, § 21; M.8146, 2016, § 13). For instance, in Germany, the Commission determined that the market for acute hospital services does not include medical care units, where doctors exclusively provide ambulatory healthcare and rehabilitation services (M.8146, 2016, § 9). However, this is not the case in all EU member states. The Commission's investigation suggests that it is unnecessary to segment further the market for general private hospital services in Greece, dividing it between inpatient and outpatient services (M.10301, 2022, § 37). Additionally,

the Commission maintains that hospital and home healthcare services should be classified as separate product markets (M.6504, 2012, §16).

Thirdly, the Commission also discussed whether separate markets should be defined for services in each medical specialisation within the private hospital sector (M.10301, 2022, § 32; M.9044, 2018, § 12; M.8146, 2016, § 12; M.7309, 2014, § 24).

In its practice, the Commission recognised distinct markets separate from general private hospital services for several specialisations: maternity hospital services and diagnostic centre services in Greece (M.10301, 2022, § 36), acute inpatient hospital services for mental illnesses in Germany (M.8146, 2016, § 13) and the UK (M.4788, 2007, § 10), as well as mental rehabilitation services in Germany (M.8146, 2016, § 13), and acute inpatient neurology services in Germany (M.8146, 2016, §§ 14-15). It also acknowledged markets for more "rare" specialisations, such as transplantation, neurosurgery, and major burns in France (M.5805, 2010, § 11), dialysis services in 13 EU member states (M.6091, 2011, §§ 42 & 43), diagnostic tests performed in vitro in the UK (M.4788, 2007, § 12), and biological examinations that contribute to the diagnosis, treatment, or prevention of human diseases in France (M.5805, 2010, § 16). However, the Commission did not separate routine and "rare" analyses (M.5805, 2010, §§ 17-20; M.7833, 2015, § 18).

The Commission has not concluded on the need to further segment the market according to other "group of specialities", namely medicine, surgery, obstetrics, gynaecology (M.8146, 2016, § 12; M.7323, 2014, § 40; M.7309, 2014, § 24; M.5805, 2010, § 11), and ophthalmological treatments and services (M.10255, 2021, § 41) etc.

The analysis of the decisions of the Lithuanian Competition Council shows that the definition of the product market in the health sector differs from the practice of the Commission and other EU countries and is very narrowly segmented. In Lithuania, outpatient and hospital services are divided into different product markets. Also, private and public health services are divided into different markets. In addition, private outpatient services at the primary, secondary, and tertiary levels constitute separate product markets. (Primary outpatient services are primary health care. Secondary outpatient services are services provided by specialists (cardiologists, neurologists, endocrinologists). Tertiary outpatient services are services provided by consultant doctors, who consult patients and provide advice and treatment methods to doctors of primary or secondary health care institutions.) Moreover, the product market is divided according to private outpatient service specialists (cardiologist, urologist, rheumatologist, etc.) (Lithuania, 2021, §§ 18-76)

3.2.2 Geographical Market

The analysis of merger cases in the healthcare sector conducted by the Commission revealed that, across all areas of health services, it typically defines the geographical market as national or even narrower. This finding is supported by several cases, including M.9044 (2018, § 22), M.10247 (2021, § 162), M.7323 (2014, § 42), M.4229 (2006, § 38), M.4788 (2007, § 14), and M.7058 (2013, § 28). For example, in Spain, the Commission stated that the relevant geographic market for private hospitals, when broadly defined, would be national in scope; when narrowly defined, it would be provincial (M.5548, 2009, § 10).

When considering the narrower than the national market, the Commission typically refrains from concluding on the exact geographic scope of this market (M.5548, 2009, §11; M.10255, 2021, § 46; M.4788, 2007, §§ 14 & 16; M.9044, 2018, § 22; M.6091, 2011, § 49; M. 4229, 2006, § 38 & 39; M.5548, 2009, § 11). It stated that considering the case at hand, "competition concerns are unlikely to arise under any plausible market definition" (M.7323, 2014, § 19; M.7058, 2013, § 30; M.7309, 2014, § 28, M.8146, 2016, § 27), the transaction does not raise any serious doubts whatever the market definition adopted (M.5805, 2010, § 15), "whatever definition is adopted, the transaction does not raise serious doubts as to its compatibility with the internal market" (M.7833, 2015, § 23), or "serious doubts can be excluded whether the market is defined as regional/local or national" (M.6091, 2011, §52). For example, the Commission has recognised

that the geographic market for acute general hospitals—both public and private—might be considered national from insurers' perspective. At the same time, it may appear local from the patient's viewpoint. However, the Commission has left open the precise scope of the geographic market (M.6343, 2011, § 26; M.4788, 2007, § 14).

The precise geographic market also would not be defined if "under either delineation of the geographic market concerned competition concerns would be likely to be identified" (M.4367, 2007, § 36).

If the Commission considers the geographic market narrower than the national geographical market, it inquires to the national competition regulatory authorities about the distance patients are typically willing to travel to undergo medical treatment (M.10255, 2021, § 50). The geographic dimension would be limited to a catchment area around the merger participants' clinics, hospitals, or other healthcare facilities (M.10255, 2021, § 51).

The Commission merger case practice revealed that for diagnostic and hospital care services, the Commission considered a local scope for the geographical market extending over a radius of a 30-minute car drive around the institution in the UK (M.4367, 2007, § 34) and France (M.7221, 2014, § 26). In Germany, however, the geographical market for general acute hospital services and the acute treatment of mental illnesses is defined by catchment areas of 50–200 km. For acute neurology services, a narrower catchment area of 30 km was determined (M.8146, 2016, § 23). The smallest catchment area for mental rehabilitation services in Germany was identified as 100 km (M.8146, 2016, § 27). In Sweden and Norway, patients seeking refractive ophthalmological treatment and surgery in urban areas typically consider clinics within the city or a catchment area of up to 100 km. However, patients in remote and less populated regions are generally willing to travel longer distances, often exceeding 100 km and potentially up to 200 or even 300 km, to access their preferred clinic. Consequently, the Commission opted to analyse a potentially narrower relevant market limited to the city level and a catchment area of 100 km (M.10255, 2021, § 51 & 55).

The geographic area seems to differ in the case of specific specialised treatment or treatment for which long waiting lists exist (M.4367, 2007, § 34). In particular, the Commission found that in France, the geographic market in the medical biology analysis sector is rather local for routine analyses and rather national for "rare" analyses (M.5805, 2010, § 21).

The analysis of the Lithuanian Competition Council's decisions shows that the geographical market in the health sector is also very narrowly segmented in Lithuania. The market is defined as encompassing the patient's residential area, corresponding to the administrative boundaries of a city or district (Lithuania, 2021, §§ 77-92).

4 DISCUSSION AND CONCLUSIONS

The legal framework analysis governing mergers at both the EU and national levels reveals significant shortages. While the EU Merger Regulation allows a consistent approach to merger assessments at the EU level, the criteria used in national laws vary considerably among member states. This variation includes differences in merger assessment tests, threshold criteria, and even differing definitions of what constitutes a concentration (merger).

The majority of analysed states define "concentration" in a manner consistent with the description found in the EU Merger Regulation. Concentration refers to the merger of undertakings or the acquisition of control of one undertaking by another, or by an individual who already controls at least one undertaking. However, some countries have different definitions. As discussed in this paper, Germany includes two additional forms of concentration: acquiring 50% or 25% of the shares or voting rights in another company, or in any combination of companies, which allows one company to exert significant competitive influence over another. In the UK, a merger occurs when two or more undertakings "cease to be distinct".

The EU, as well as member states, have criteria to determine concentrations that require attention from the EU or national regulatory authorities. Like the EU, all member states utilise a threshold test; however, significant differences exist in these thresholds across member states. In addition to the threshold tests, some countries apply share-of-supply tests and hybrid tests. However, these tests also differ between the countries.

Finally, the EU Merger Regulation employs the Significant Impediment of Effective Competition (SIEC) test for evaluating mergers that have an EU dimension. However, the assessment tests at the national level vary among member states. Some countries use the same SIEC test as outlined in the EU Merger Regulation or a similar test. In contrast, others utilise the dominance test or the Substantial Lessening of Competition (SLC) test.

Moreover, non-economic objectives may influence national regulations, such as national security, public safety, health, and environmental protection. These inconsistencies hinder uniformity and predictability in merger regulation. As a result, similar transactions may be authorised in one member state while prohibited in another, leaving businesses uncertain in this regulatory landscape.

These inconsistencies not only affect the predictability of the merger control across the EU but also may hinder the development of the EU internal market. Therefore, it would be beneficial to consider options for achieving more uniform regulation among EU member states.

The analysis of merger cases indicates that, in the healthcare sector, merger transactions at the EU level typically do not raise concerns for the Commission. The Commission has authorised all notified mergers, over half of which were processed through a simplified procedure. Only in one instance did the Commission impose conditions and obligations on a particular merger transaction.

When discussing the Commission's approach to identifying product and geographical markets, it is important to note that the Commission does not put much effort into determining relevant markets in the healthcare sector. It mainly collects opinions from the competition regulatory authorities of member states and other interested parties regarding the criteria for defining relevant markets and then, after making a "first glance" assessment, leaves questions open. This lack of clear guidance on market definition in the healthcare sector hinders the development of uniform practices and more coherent health systems across EU member states. Currently, some states adopt a very narrow market segmentation at the local level based on specialisation, while others take a broader view. The Commission's more precise delineation of the relevant market could provide a roadmap for national competition regulatory authorities, fostering a more cohesive development of competition policy in EU member states.

REFERENCES

COMMISSION. 2013. Notice on a simplified procedure for treatment of certain concentrations under Council Regulation (EC) No 139/2004 (2013/C 366/04). *Official Journal of the European Union*. 366, 5-9. [Accessed: 2025-01-10] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013XC1214(02)

COMMISSION. 2023. Notice on a simplified treatment for certain concentrations under Council Regulation (EC) No 139/2004 on the control of concentrations between undertakings (2023/C 160/01), *Official Journal of the European Union.* 160, 1–10. [Accessed: 2025-01-10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=oj:JOC_2023_160_R_0001

COMMISSION. 2024. Notice on the definition of the relevant market for the purposes of Union competition law, C/2024/1645. *EUR-Lex*. [Accessed: 2025-01-10] http://data.europa.eu/eli/C/2024/1645/oj

COMMISSION. 2025a. EU Health Policy. Overview. *European Commission* [Accessed: 2025-01-10] https://health.ec.europa.eu/eu-health-policy/overview_en

COMMISSION. 2025b. Competition Policy. Case search instrument. *European Commission* [Accessed: 2025-01-10] https://competition-cases.ec.europa.eu/search?caseInstrument=M

COUNCIL. 2004. Regulation No 139/2004 of 20 January 2004 on the control of concentrations between undertakings (the EC Merger Regulation). *Official Journal L.* 024, 29/01/2004 P. 0001 – 0022.

EUROPEAN UNION. 2006. *Case M.4229, APHL / L&R / NETCARE / GENERAL HEALTHCARE GROUP, Commission decision of 25.07.2006.* EU: Brussels.

EUROPEAN UNION. 2007. *Case M.4367, 2007, APW / APSA / NORDIC CAPITAL / CAPIO, Commission decision of 16.03.2007*. EU: Brussels.

EUROPEAN UNION. 2009. *Case M.4788, 2007, ROZIER / BHS, Commission decision of 21.08.2007*. EU: Brussels.

EUROPEAN UNION. 2009. *Case M.5548, 2009, BARCLAYS / RBS / HILLARY, Commission decision of 06.07.2009*. EU: Brussels.

EUROPEAN UNION. 2010. *Case M.5805, 2010, 3i / VEDICI GROUPE, Commission decision of 21.05.2010*. EU: Brussels.

EUROPEAN UNION. 2011. *Case M.6091, 2011, GALENICA / FRESENIUS MEDICAL CARE / VIFOR FRESENIUS MEDICAL CARE RENAL PHARMA JV, Commission decision of 05.10.2011*. EU: Brussels.

EUROPEAN UNION. 2011. *M.6343, 2011, APAX / KINETIC CONCEPTS, Commission decision of 07.10.2011*. EU: Brussels.

EUROPEAN UNION. 2012. *M.6504, 2012, LINDE / AIR PRODUCTS HOMECARE, Commission decision of 18.04.2012*. EU: Brussels.

EUROPEAN UNION. 2013. *M.7058, 2013, EQT VI / TERVEYSTALO HEALTHCARE, Commission decision of 03.12.2013*. EU: Brussels.

EUROPEAN UNION. 2014. *M.7221, 2014, BRIDGEPOINT CAPITAL / MEDI-PARTENAIRES, Commission decision of 28.04.2014*. EU: Brussels.

EUROPEAN UNION. 2014. *M.7309, 2014, BRIDGEPOINT / EdRCP, Commission decision of 04.08.2014*. EU: Brussels.

EUROPEAN UNION. 2014. *M.7323, 2014, NORDIC CAPITAL / GHD VERWALTUNG, Commission decision of 14.08.2014*. EU: Brussels.

EUROPEAN UNION. 2015. *M.7833, 2015, CDC INTERNATIONAL CAPITAL / MUBADALA DEVELOPMENT COMPANY / VIVALTO BEL / GROUP VIVALTO SANTE, Commission decision of 14.12.2015*. EU: Brussels.

EUROPEAN UNION. 2016. *M.7813, 2016, SANOFI / GOOGLE / DMI JV, Commission decision of 23.02.2016*. EU: Brussels.

EUROPEAN UNION. 2016. *M.8146, 2016, CARLYLE / SCHÖN FAMILY / SCHÖN KLINIK, Commision decision of 15.11.2016*. EU: Brussels.

EUROPEAN UNION. 2018. *M.9044, 2018, CVC / RECORDATI, Commission decision of 04.12.2018*. EU: Brussels.

EUROPEAN UNION. 2021. *M.10247, 2021, CVC / COOPER, Commission decision of 22.10.2021*. EU: Brussels.

EUROPEAN UNION. 2021. *M.10255, 2021, TRITON / BERGMAN CLINICS, Commission decision of 03.08.2021*. EU: Brussels.

EUROPEAN UNION. 2022. *M.10301, 2022, CVC / ETHNIKI, Commission decision of 24.02.2022*. EU: Brussels.

FINLAND. 2011. Competition Act, No. 948/2011, 1.11.2011, last amendment No 749/2024, 5.12.2024. *FINLEX*. [Accessed: 2025-01-10] https://www.finlex.fi/fi/laki/smur/2011/20110948

FINLAND. 1997. Accounting Act, No. 1336/1997, 30.12.1997, last amendment No 991/2024, 19.12.2024. *FINLEX.* [Accessed: 2025-01-10] https://www.finlex.fi/fi/laki/smur/1997/19971336

FRANCE. 2000. Code de commerce, 21.09.2000, last amendment 13.01.2025. *Légifrance*. [Accessed: 2025-01-10] https://www.legifrance.gouv.fr/codes/texte_lc/LEGITEXT000005634379

GERMANY. 2013. *Competition Act in the version published on 26 June 2013 (Bundesgesetzblatt (Federal Law Gazette) I, 2013, p. 1750, 3245), as last amended by Article 1 of the Act of 25 October 2023 (Federal Law Gazette I, p. 294)*. [Accessed: 2025-01-10] https://www.gesetze-im-internet.de/englisch_gwb/englisch_gwb.html

GREECE. 2011. *Law 3959/2011 on the Protection of Free Competition in English (codified Jan 2022), Gov't Gazette Issue A' 93/20.04.2011, Codification of 31.01.2022, L. 4886/2022 (GG A' 12/24.1.2022*. [Accessed: 2025-01-10] https://www.epant.gr/en/legislation/protection-of-free-competition.html

LITHUANIA. 1999. *Competition Act, No. VIII-1099, 23 March 1999, last amendment No. XV-41, 5.12.2024, Žin. 1999, Nr. 30-856, i. k. 0991010ISTAIII-1099*. [Accessed: 2025-01-10] https://www.e-tar.lt/portal/lt/legalAct/TAR.B8B6AFC2BFF1/asr

LITHUANIA. 2021. *Resolution of the Competition Council of the Republic of Lithuania, On the authorisation of the implementation of the concentration of the closed-type private capital investment fund for professional investors INVL Baltic Sea Growth Fund, under which it indirectly, through the managed company „BSGF Sanus" Ltd., „Litgaja" Ltd and „RP Pharma" Ltd, acquires joint control of „Inmedica" Ltd and indirectly acquires joint control of „Medica Klinika" Ltd, „Kardiolita" Ltd, „Bendrosio medicinos praktika" Ltd and Svalbono klinika Ltd with the conditions and obligations for implementing the concentration set by the Competition Council, of 2021.11.12*. [Accessed: 2025-01-10] https://kt.gov.lt/docs?query=&search=&category=10&pubdate_from=&pubdate_to=

SIMANAVIČIENĖ, Ž. *et al*. 2024. *Transformations, challenges and security*. Collective monograph. Mykolas Romeris University. ISBN 978-609-488-096-4

SPAIN. 2007. *Law on Protection of Competition, No. 15/2007, 3 July 2007, BOE-A-2007-12946*. [Accessed: 2025-01-10] https://www.boe.es/eli/es/l/2007/07/03/15

UK. 2002. *Enterprise Act 2002, 22 November 2002, last amendment 23 August 2024, UK Public General Acts 2002 c. 40*. [Accessed: 2025-01-10] https://www.legislation.gov.uk/ukpga/2002/40/part/3/2024-08-23

UK. 2013. Enterprise and Regulatory Reform Act 2013, 25 April 2013, last amendment 16 October 2015, UK Public General Acts2013 c. 24. [Accessed: 2025-01-10] https://www.legislation.gov.uk/ukpga/2013/24/contents

UK. 2021. Competition and Markets Authority (CMA), Merger Assessment Guidelines, CMA129, 18.03.2021. *GOV.UK*. [Accessed: 2025-01-10] https://www.gov.uk/government/publications/merger-assessment-guidelines

UK. 2025. Competition and Markets Authority (CMA), Mergers: Guidance on the CMA's jurisdiction and procedure, 02.01.2025. *GOV.UK*. [Accessed: 2025-01-10] https://www.gov.uk/government/publications/mergers-guidance-on-the-cmas-jurisdiction-and-procedure

WORLD BANK. 2023. World Bank Open Data. *World Bank Group.* [Accessed: 2025-01-10] https://data.worldbank.org/

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OPTIMIZING PROMPTS THROUGH AI FRAMEWORKS: A PATH TO MORE RELEVANT RESPONSES

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ABSTRACT

The rapid growth of large language models has increased the importance of prompt engineering in facilitating effective human-computer interaction. While various frameworks have been developed to assist users with prompt engineering, a comparative analysis of these frameworks and their core components is still lacking. This study addresses this gap by analyzing key terms in widely used frameworks such as RACEF (Role, Audience, Context, Example, Format) to identify recurring elements that are critical to prompt optimization. The findings will lead to actionable recommendations and the development of a unified framework incorporating the most important elements for effective prompt engineering.

Keywords: artificial intelligence, prompt engineering, frameworks, core components

JEL Code: O33, J24

1 INTRODUCTION

The rapid development of large language models (LLMs) has changed the way users interact with artificial intelligence (AI) systems. The quality and relevance of the output from generative AI models largely depend on the quality of the prompts provided. LLMs can achieve significantly improved performance through instruction-tuning, which enables them to precisely follow natural language instructions, allowing them to attain state-of-the-art results in numerous language understanding tasks (Ouyang *et al.*, 2022).

Effective prompt engineering has become an essential tool for ensuring that LLMs generate relevant, accurate, and contextually appropriate responses. To address this need, a range of guidelines, strategies, and frameworks has been developed (Cheng *et al.*, 2023; Korzynski *et al.*, 2023; Schulhoff *et al.*, 2024).

Frameworks for prompting are helpful, but each offers a different set of core components for prompt optimization. Despite the growing number of frameworks available, existing literature and studies have focused primarily on individual frameworks without offering a comparative

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analysis of their core components. Consequently, it remains unclear which components and strategies are most commonly employed in generating high-quality responses. This study aims to fill this gap by conducting a comparative analysis of key elements used across various frameworks by:

- Identifying core components across existing prompting frameworks.
- Determining which components are most critical for effective prompt design.
- Developing a unified framework that synthesizes established best practices.

This study is guided by two main research questions:

1. What core components are most frequently mentioned across different AI prompting frameworks?
2. What are the gaps and overlaps in existing prompt frameworks, and how might a unified framework contribute to improved prompt optimization?

A preliminary review of existing frameworks indicates significant overlap in terms such as role, context, example, or format. These terms appear consistently across frameworks, indicating their fundamental role in effective prompt design. However, additional terms such as goal, audience, and intent are used less consistently, suggesting potential gaps that warrant further investigation.

Based on preliminary analysis, terms related to role specification, context definition, and example provision are expected to be among the most frequently referenced components across frameworks. Terms such as goal and audience may emerge as secondary considerations, yet remain important. By analyzing the most frequently used core components in popular frameworks, this research will contribute to the advancement of prompt engineering as an emerging field.

2 LITERATURE REVIEW

2.1 Prompt engineering

In generative AI models, a prompt refers to the textual input provided by users that directs how the model should respond. Prompts typically include instructions, questions, input data, or examples. In practice, to elicit a desired response from an AI model, a prompt must contain either instructions or questions, while other elements are optional (Amatriain, 2024). The prompt serves as a form of guidance, helping the model understand what type of output is expected. Prompts can vary greatly in complexity, ranging from straightforward questions to elaborate instructions or detailed task descriptions. By carefully crafting a prompt, users can significantly enhance the relevance and quality of the model's output, making prompt engineering a crucial element in effective AI interaction (Bang *et al.*, 2023).

Prompt engineering in generative AI models is a rapidly evolving field concerned with designing and optimizing prompts to influence the behavior and outputs of these models. Prompt engineering transcends mere prompt construction; it requires a blend of domain knowledge, understanding of the AI model, and a methodical approach to tailoring prompts for diverse contexts (Amatriain, 2024).

Few-shot prompting involves fine-tuning an AI model using a small number of examples that illustrate the desired task. These examples are presented as prompts, allowing the model to understand the task's structure. By analyzing these limited examples, the model learns patterns and generalizes them to handle new inputs, leveraging its pre-trained knowledge to perform the task with minimal examples (Reynolds and McDonell, 2021).

Chain-of-thought prompting structures the interaction to guide the AI model through a coherent, multi-turn conversation by building on the context of previous interactions. The key feature of this approach is its emphasis on maintaining context and coherence across multiple turns, enabling more natural and engaging conversations between the user and the AI model (Wei *et al.*, 2022).

Multi-turn prompting involves users providing an initial input prompt and then refining or adjusting it across several interactions with the AI model. This iterative process allows users to progressively guide the model toward more accurate or relevant responses by clarifying instructions or introducing new information at each step, leading to progressively more relevant and high-quality outputs (Bang *et al.*, 2023).

Each of these methods relies on human experts who possess both task-specific knowledge and a deep understanding of prompting techniques, which restricts their scalability and limits broader applicability (Zamfirescu-Pereira *et al.*, 2023).

While prompt engineering employs these techniques to improve model performance, their complexity highlights the need for more structured approaches. To streamline and standardize the development of effective prompts, specialized AI frameworks have emerged as valuable tools. These frameworks provide a systematic way to design and optimize prompts, enabling more consistent and reproducible outcomes across various tasks.

2.2 Frameworks for prompting

Many frameworks exist across the sciences, but it is not always clear how they are developed and applied (Partelow, 2023). Frameworks for prompting with AI serve as a kind of instruction manual that helps users achieve more effective interactions with artificial intelligence. Prompting refers to the process of guiding the AI toward a desired output, and frameworks help streamline this process so that the AI's responses are more accurate and useful. Without a structured framework, interacting with AI may result in inconsistent or unpredictable responses, making the process feel trial-and-error-based. By contrast, a framework functions as a conceptual template or set of guidelines that organizes prompts into a clear structure, facilitating more accurate interpretation of user requests by the AI model. Frameworks contribute to more effective AI interaction in the following ways:

- Clarifying user intent – improving the AI model's ability to interpret the query accurately.
- Improving response accuracy – ensuring that the model's replies align more closely with the intended outcome.
- Enhancing consistency – reducing variation in responses and making outputs more predictable across repeated prompts.

In summary, frameworks help make AI interactions clearer and more structured, which is particularly valuable for complex tasks that require reliable and accurate answers.

For example, the RACEF framework (Role, Audience, Context, Example, Format) was originally introduced in informal educational and practical AI usage contexts to help non-experts structure prompts more efficiently (Zahid, 2024; Allton, 2024). Similarly, the CARE framework (Context, Action, Result, Example) emphasizes goal-oriented interactions and was developed in UX research for AI-supported tasks (Moran, 2024). However, these frameworks are often evaluated qualitatively or through case-based testing rather than through systematic empirical validation. Some recent studies (e.g., Korzynski *et al.*, 2023; Zamfirescu-Pereira *et al.*, 2023) highlight the need for more formal assessments of framework effectiveness, especially with non-expert users.

2.3 Common prompt components in existing frameworks

Including a **goal** or purpose in an AI prompt ensures clarity and focus, enabling the model to better understand the user's expectations and produce more relevant results (Juuzt, 2025). It reduces ambiguity and guides the AI toward outputs aligned with the intended objectives—whether solving a problem, generating creative content, or analyzing information. A clearly stated goal also helps filter out irrelevant responses, saving users time and effort during refinement. Additionally, it supports prioritization of key aspects within the task, improving the overall quality and precision of the generated output. Overall, including a clearly defined purpose enhances the efficiency and effectiveness of AI interactions.

Assigning a **role** to the AI system helps tailor its responses to a specific context, improving relevance and alignment with the user's needs (Zahid, 2025). When assigned a role—such as teacher, programmer, or consultant—the AI adapts its tone, style, and domain expertise accordingly. This results in more focused interactions that align with the communication context, ensuring that the AI provides solutions, explanations, or advice appropriate to the assigned role. It also enhances the model's ability to simulate real-world scenarios, which supports both problem-solving and creative tasks. Overall, defining a role enhances output accuracy and practical relevance.

AI models rely on clear instructions to generate relevant and accurate outputs (Ozturk, 2025). In 68% of the frameworks analyzed, the **action** component—representing the core task or requirement—is explicitly emphasized to encourage users to formulate clear and specific prompts. A well-defined task description helps guide the AI toward producing focused and appropriate responses, whereas ambiguous or poorly formulated instructions may result in incomplete or irrelevant answers.

Specifying required **steps** in an AI prompt enhances the precision and organization of the model's output by guiding it through a clearly defined process (Juuzt, 2025). By explicitly outlining a sequence of actions or logical steps, the user ensures that the AI approaches the task methodically and that all necessary components are addressed in the intended sequence. This reduces ambiguity and minimizes the risk of incomplete or disorganized responses. It also enables the AI to manage complex tasks more effectively by breaking them into manageable parts, improving both clarity and coherence. Furthermore, step-by-step instructions promote consistency across outputs, making it easier to evaluate results and ensure alignment with the user's expectations.

Including **context** in an AI prompt enhances the relevance and appropriateness of the model's responses by situating them within a specific context or background (Allton, 2024). Context provides the AI with critical information about the audience, purpose, or environment, enabling it to adapt tone, language, and content to the task's specific requirements. This improves the accuracy and usability of the output, particularly in tasks involving nuanced situations such as professional communication or culturally sensitive topics. Additionally, context reduces ambiguity and ensures that the AI fully understands the task environment, leading to more precise, efficient, and targeted results.

Example helps the AI understand the expected format, tone, style, or structure of the response (Moran, 2024). It clarifies the task, reduces ambiguity, and increases the likelihood that the AI will generate output aligned with the user's intentions. This technique is especially valuable in tasks requiring specific patterns, such as writing, coding, or summarization.

When the model produces outputs with consistent errors—such as misinterpreting the prompt or producing formatting mistakes—providing a clear example helps clarify expectations and correct these issues. A concrete example guides the model toward outputs that match the intended tone, content, and structure. This reduces variability in responses and helps maintain overall quality and relevance.

Examples are particularly useful for open-ended tasks or those that could be interpreted in multiple ways. In such cases, an example can explicitly disambiguate the prompt, illustrating the desired direction. In few-shot prompting (Song *et al.*, 2022), examples serve as demonstrations of how to complete the task, offering the model contextual guidance even when the task is unfamiliar or complex.

Moreover, even the order in which examples are provided can influence model behavior. As noted by Lu *et al.* (2022), changing the sequence of examples may lead to different outputs, which gives users an additional strategy for optimizing performance.

Format specifies the desired structure of the AI's response, shaping it to meet the user's specific needs and enhancing clarity, usability, and precision (Saleem, 2024). Defining the output format is essential for ensuring that responses are actionable, consistent with expectations, and practically applicable. This component helps bridge the gap between the model's general capabilities and the user's task-specific requirements, ultimately improving the relevance and effectiveness of AI-generated content.

3 METHODOLOGY AND DATA

The first step involves selecting appropriate frameworks. This step entails compiling a set of widely recognized frameworks commonly used in prompt engineering. Examples include RACEF (Role, Audience, Context, Example, Format), CARE (Context, Action, Result, Example), and RISE (Role, Input, Steps, Execution). These frameworks were selected based on their relevance and established application in diverse AI prompting contexts.

This approach is consistent with methods used in previous studies that involved content extraction and synthesis of framework elements in AI interaction research (e.g., Ozturk, 2025; Zamfirescu-Pereira *et al.*, 2023). The frequency-based analysis enables generalization and reveals the most common semantic components across diverse prompting frameworks.

The next step involves extracting the core components of each selected framework. This includes identifying and categorizing the key terms that characterize the structure and intent of each framework. The extracted terms will serve as the basis for subsequent stages of analysis. Terms with identical or closely related meanings and contexts are grouped for analytical purposes.

Subsequently, a frequency analysis is conducted. In this phase, the occurrence of each core component is calculated across all selected frameworks. This analysis aims to identify the most frequently used terms, thereby highlighting the components essential to effective prompt formulation.

Following the frequency analysis, a comparative analysis is conducted to examine similarities and differences among frameworks. The comparison helps determine which terms are universally applicable and which are specific to individual frameworks.

Finally, based on the results of these analyses, a new unified framework is proposed. This framework incorporates the most critical and commonly used components identified throughout the process. The objective is to develop a refined and comprehensive structure for prompt engineering that addresses existing gaps and enhances the clarity, precision, and effectiveness of AI-generated responses. This methodological approach provides a systematic process for framework development and contributes to the advancement of research in AI prompt engineering.

4 RESULTS

Although a total of 80 distinct terms were identified across all 31analyzed frameworks[1], many of them were semantically similar and served overlapping functions. To enhance analytical clarity, these terms were grouped based on shared meaning and contextual usage. The seven presented components represent the most frequently occurring and semantically dominant categories derived from this grouping process. Less frequent or framework-specific terms were excluded from the final synthesis due to low recurrence or limited general applicability.

1. **Context** (also referred to as ***Audience*** or ***Relevance*** in certain frameworks) is present in 22 out of 31 frameworks (71%). When a user includes context in an AI prompt, they offer background information or situational details to frame the task. This may include specifying the target audience, intended purpose, setting, or other relevant factors that influence how the AI should respond. For example, a user might indicate that the task involves writing for a professional audience, explaining a concept to beginners, or addressing a particular cultural or technical situation. This contextual information helps guide the model toward generating a response that is appropriate and well-suited to the given scenario.
2. **Action** (also referred to as Ask, Task, Requirements, or Request in certain frameworks) occurs in 21 out of 31 frameworks (68%). While task formulation is a fundamental part of every prompt, many frameworks explicitly emphasize this component as central to prompt design. This element typically defines what the user wants the model to do and may also specify input data to be processed as part of the task.
3. **Parameters, Constraints**, or **Format** appear in 18 out of 31 frameworks (58%). This component defines the rules, boundaries, or structural expectations that the AI should follow when generating its response. Typical elements of this component include:
   - **Content constraints** – specifying what the AI should or should not include in its response.
   - **Structural requirements** – defining how the response should be organized.
   - **Length constraints** – setting limits on the length of the output.
   - **Language and style** – indicating tone, formality, or language preferences.
   - **Domain-specific guidelines** – introducing rules tailored to a particular field or audience.
   - **Output format** – determining the exact structure or format of the generated output.
4. **Example** (also referred to as Sample in some frameworks) appears in 14 out of 31 frameworks (45%). Examples provide the AI model with a reference output that illustrates the desired structure, style, or level of detail. By including an example, users can guide the model more effectively toward producing responses that meet specific expectations.
5. **Goal** (also referred to as Expectations, Purpose, or Objective in some frameworks) appears in 14 out of 31 frameworks (45%). Including a clear goal in a prompt helps the AI understand what it is expected to achieve—such as solving a problem, generating content, or analyzing data. Stating a goal reduces ambiguity, improves relevance, and aligns the response with the user's intent.
6. **Role** (also referred to as Character in some frameworks) appears in 13 out of 31 frameworks (42%). Defining a role within the prompt instructs the AI to adopt a particular perspective, profession, or identity when generating responses. For example, the model may be asked to act as a teacher, programmer, salesperson, or consultant, adjusting its tone, vocabulary, and domain knowledge accordingly.
7. **Steps** (also referred to as Instructions or Actions in some frameworks) appear in 11 out of 31 frameworks (35%). This component outlines a specific sequence of operations the AI should follow. It may include breaking down a problem, analyzing individual components, or performing tasks in a defined order to reach a coherent and structured output.

[1]A full list of the frameworks analyzed is available upon request.

Tab. 1 Frequency of Core Components in AI Prompt Frameworks (N=31)

Component	Frequency	Percentage (%)
Context	22	71%
Action	21	68%
Format/Constraints	18	58%
Example	14	45%
Goal	14	45%
Role	13	42%
Steps	11	35%

The framework containing the greatest number of the identified components among the 31 analyzed is the RASCEF framework (Juuzt, 2025). It includes six out of the seven core elements—Role, Action, Steps, Context, Examples, and Format—with the only missing element being Goal. A revised version including Goal could be designated as **GRASCEF**. This extended framework would comprise the following elements: Goal, Role, Action, Steps, Context, Examples, and Format.

To quantify the relevance of individual components, a frequency analysis was conducted. Table 1 presents the number of frameworks (out of 31) that explicitly include each of the seven core components. This analysis confirms that Context and Action are the most commonly used elements, followed closely by Format, Example, and Goal. The results support the validity of the proposed unified framework.

Figure 1 illustrates this distribution graphically, highlighting the dominant components that form the foundation of the GRASCEF framework.

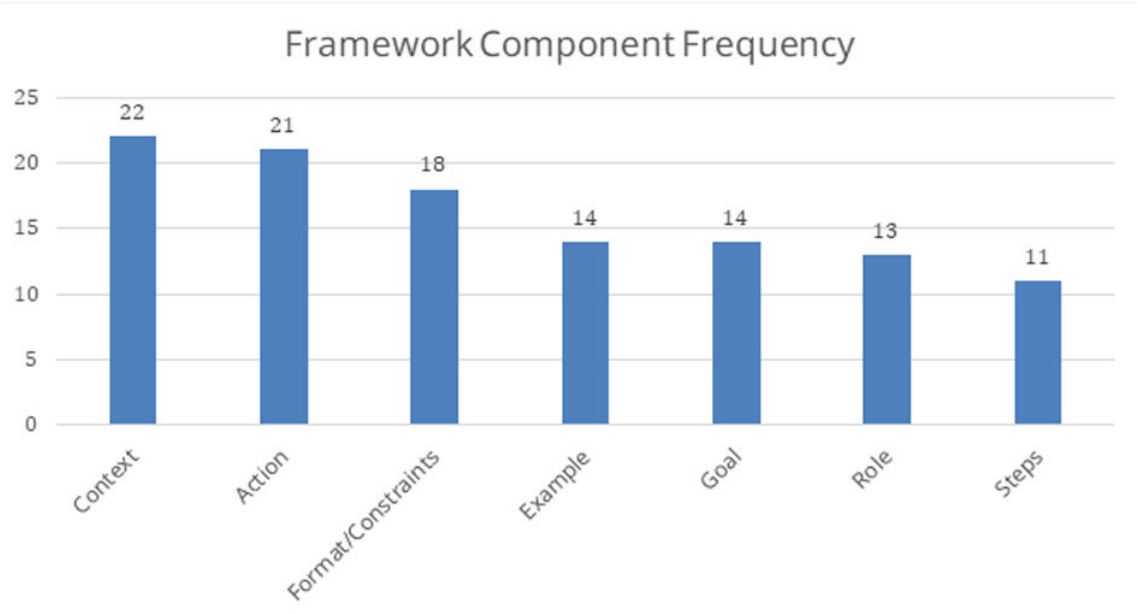

Fig. 1: Distribution of core components in 31 prompting frameworks

5 DISCUSSION

The consolidation of 80 unique terms into seven semantic categories reveals a striking convergence in prompt design practices. Despite originating from diverse contexts, the analyzed frameworks emphasize similar core elements, suggesting that effective prompt engineering may rely on a relatively stable conceptual foundation. The proposed GRASCEF framework represents a synthesis of these shared components and can serve as a practical tool for guiding prompt creation, especially for non-expert users.

An analysis of 31 AI prompting frameworks identified seven semantic prompt components that can enhance the relevance and usability of AI-generated outputs in various ways. By supplementing an existing framework (RASCEF) with the missing component Goal, the GRASCEF framework was formed, incorporating all components identified in the analysis: Goal, Role, Action, Steps, Context, Examples, and Format.

To illustrate the practical application of the GRASCEF framework, the following example shows how each component contributes to a high-quality AI prompt:

- Goal: Generate a professional summary of a research article.
- Role: You are an experienced academic editor.
- Action: Read the article and produce a concise summary focused on methodology and main findings.
- Steps:
  - Identify the research question and hypothesis.
  - Summarize the methods used.
  - Highlight key findings.
  - Note limitations and conclusions.
- Context: The summary will be used by postgraduate students in a research seminar.
- Example: “This study investigates the impact of gamification on user engagement in e-learning platforms. Using a mixed-methods approach with 150 university students, the authors found that leaderboards and badges significantly increased time-on-task and satisfaction. Limitations include short study duration and lack of long-term tracking.”
- Format: Bullet-point summary of 150–200 words in academic English.

This example demonstrates how GRASCEF elements guide the AI model toward more structured, accurate, and context-aware outputs. Each component contributes to reducing ambiguity, clarifying expectations, and ensuring relevance—particularly in academic or professional environments.

Furthermore, these recommendations align with previous findings by Zamfirescu-Pereira *et al.* (2023) and Korzynski *et al.* (2023), who emphasize the need for clear, structured prompting guidance especially for non-expert users.

6 CONCLUSION

This study conducted a comparative analysis of 31 existing prompt engineering frameworks and identified seven core components that appeared most frequently. By synthesizing these components into the GRASCEF framework, the study provides a descriptive basis for understanding the common structures behind effective prompt design.

While the findings offer a comprehensive overview of current frameworks and highlight recurring patterns in prompt construction, this research does not yet validate the practical effectiveness of the proposed GRASCEF framework. Therefore, conclusions regarding its impact on prompt quality or user performance should be regarded as preliminary.

The GRASCEF framework may serve as a useful conceptual tool for researchers and practitioners interested in standardizing prompt development. However, its application in practice

requires further empirical testing and user evaluation. Future research should focus on assessing the framework's usability, adaptability, and contribution to AI model performance through controlled experiments or case studies in real-world scenarios.

REFERENCES

ALLTON, M. 2024. *Prompt Engineering Made Easy: The RICCE Framework for AI Content Writing.* [Accessed 2024, December 20] https://www.thesocialmediahat.com/blog/prompt-engineering-made-easy-the-ricce-framework-for-ai-content-writing/

AMATRIAIN, X. 2024. Prompt Design and Engineering: Introduction and Advanced Methods. arXiv preprint. *arXiv*:2401.14423.

BANG, Y., CAHYAWIJAYA, S., LEE, N., DAI, W., SU, D., WILIE, B., LOVENIA, H., JI, Z., YU, T., CHUNG, W., DO, Q. V., XU, Y., FUNG, P. 2023. A multitask, multilingual, multimodal evaluation of ChatGPT on reasoning, hallucination, and interactivity. arXiv preprint. *arXiv*:2302.04023. https://doi.org/10.48550/arXiv.2302.04023

CHENG, F., ZOUHAR, V., ARORA, S., SACHAN, M., STROBELT, H., EL-ASSADY, M. 2023. RELIC: Investigating large language model responses using self-consistency. arXiv preprint. *arXiv*:2311.16842. https://doi.org/10.48550/arXiv.2311.16842.

JUUZT. 2025. *Streamlining AI Prompt Engineering with the RASCEF Framework*. [Accessed 2025, January 10] https://juuzt.ai/knowledge-base/prompt-frameworks/the-rascef-framework/

KORZYNSKI, P., MAZUREK, G., KRZYPKOWSKA, P., KURASINSKI, A. 2023. Artificial intelligence prompt engineering as a new digital competence: Analysis of generative AI technologies such as ChatGPT. *Entrepreneurial Business and Economics Review*. 11(3), 25–37. https://doi.org/10.15678/EBER.2023.110302

LU, Y., BARTOLO, M., MOORE, A., RIEDEL, S., STENETORP, P. 2022. Fantastically Ordered Prompts and Where to Find Them: Overcoming Few-Shot Prompt Order Sensitivity. In: *Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics.* Volume 1: Long Papers. Dublin, Ireland: Association for Computational Linguistics, pages 8086–8098. https://doi.org/10.18653/v1/2022.acl-long.556

MORAN, K. 2024. CARE: Structure for Crafting AI Prompts. [Accessed 2024, December 10] https://www.nngroup.com/articles/careful-prompts/

OUYANG, L., WU, J., JIANG, X., ALMEIDA, D., WAINWRIGHT, C.L., MISHKIN, P., ZHANG, C., AGARWAL, S., SLAMA, K., RAY, A. *et al*. 2022. Training language models to follow instructions with human feedback. arXiv preprint. *arXiv*:2203.02155.

OZTURK, A. 2025. *Another Prompting Framework: RACE (Role, Action, Context, Execute)*. [Accessed 2025, May 16] https://drayseozturk.org/2025/02/22/another-prompting-framework-race-role-action-context-execute/

PARTELOW, S. 2023. What is a framework? Understanding their purpose, value, development and use., *Journal of Environmental Studies and Sciences.* 13, 510–519. https://doi.org/10.1007/s13412-023-00833-w

REYNOLDS, L., MCDONELL, K. 2021. Prompt programming for large language models: Beyond the few-shot paradigm. Paper presented at the Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. *arXiv*:2102.07350. https://doi.org/10.48550/arXiv.2102.07350

SALEEM, M. 2024. *11 ChatGPT Prompt Frameworks Every Marketer Should Know*. [Accessed 2024, September 30] https://buttercms.com/blog/chatgpt-prompt-frameworks/

SCHULHOFF, S., ILIE, M., BALEPUR, N., KAHADZE, K., LIU, A., SI, C., LI, Y., GUPTA, A., HAN, H., SCHULHOFF, S., DULEPET, P. S., VIDYADHARA, S., KI, D., AGRAWAL, S., PHAM, C., KROIZ, G., LI, F., TAO, H., SRIVASTAVA, A., DA COSTA, H., GUPTA, S., ROGERS, M. L., GONCEARENCO, I., SARLI, G., GALYNKER, I., PESKOFF, D., CARPUAT, M., WHITE, J., ANADKAT, S., HOYLE, A., RESNIK, P. 2024. The Prompt Report: A Systematic Survey of Prompting Techniques. arXiv preprint arXiv: *arXiv*:2406.06608. https://doi.org/0.48550/arXiv.2406.06608

SONG, W., LIYAN, T., AKASH, M., JUSTIN, F. R., GEORGE, S., YING, D., YIFAN, P. 2022. Trustworthy assertion classification through prompting. *Journal of Biomedical Informatics*. 132, 104139. ISSN 1532-0464. https://doi.org/10.1016/j.jbi.2022.104139

WEI, J., WANG, X., SCHUURMANS, D., BOSMA, M., ICHTER, B., XIA, F., CHI, E. H., LE, Q. V., ZHOU, D. 2022. Chain-of-Thought Prompting Elicits Reasoning in Large Language Models. arXiv preprint. *arXiv*:2201.11903v6. https://doi.org/10.48550/arXiv.2201.11903.

ZAHID, E. 2024. *How to get ChatGPT to Roleplay*. [Accessed 2025, January 3] https://xpertprompt.com/2024/07/15/how-to-get-chatgpt-to-roleplay/

ZAMFIRESCU-PEREIRA, J., WONG, R. Y., HARTMANN, B., YANG, Q. 2023. Why johnny can't prompt: How non-ai experts try (and fail) to design LLM prompts. In: *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. New York, USA: Association for Computing Machinery. ISBN 9781450394215. https://doi.org/10.1145/3544548.3581388

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WHICH AI MODEL LEADS IN SUMMARIZING FINANCIAL ARTICLES? A COMPARATIVE ANALYSIS OF GPT, MISTRAL, AND LLAMA

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ABSTRACT

In an era where financial data grows at an unprecedented pace, effective summarization is vital for informed decision-making. This study rigorously evaluates the summarization capabilities of three advanced AI models—GPT-4o, Mistral Instruct, and Llama 3.1 8B Instruct 128k—when applied to diverse financial articles. A key contribution of this research is the development of a comprehensive evaluation framework, which assesses the models across critical dimensions, including accuracy, clarity, relevance, adherence to formatting specifications, and practical usability. While GPT consistently achieved the highest overall scores, Llama demonstrated superior performance in certain criteria, such as clarity and compression efficiency, highlighting its potential for applications where brevity and conciseness are prioritized. Despite occasional inconsistencies, Mistral excelled in generating concise summaries with high compression ratios. Our findings emphasize that the selection of an AI model should depend on specific task priorities—whether it is accuracy, brevity, or response speed. These insights underline the importance of both rigorous evaluation methodologies and careful model selection based on task-specific requirements, paving the way for more targeted applications and further research into AI-driven summarization tools in finance.

Keywords: artificial intelligence, LLMs, AI summarization, financial articles, evaluation, GPT, Mistral, Llama, metrics

JEL Code: O33, J24

1 INTRODUCTION

Summarizing long pieces of text is a principal task in natural language processing with Machine Learning-based text generation models such as Large Language Models (LLM) being particularly suited to it (Dhaini *et al.*, 2024). The process of text summarization is one of the applications of natural language processing (NLP) that presents one of the most challenging obstacles (Saiyyad & Patil, 2023). Current research in NLP has mainly focused on the general capabilities

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of language models in text summarization, but much less attention has been paid to the application of these models to summarization of specific articles that have specific characteristics. For example, financial articles often contain technical terms, numbers, abbreviations, graphs, and statistics that require deeper contextual interpretation. Specific content, such as descriptions of market performance or risk analysis, can be difficult for traditional summarization models that are not trained on domain data. Finally, often the summary needs to contain not only the key points, but also some subtle meanings or conclusions. Research such as benchmark tests of language models (e.g. GPT, LLaMA, Mistral) typically focus on general datasets (CNN/DailyMail, XSum) that do not contain expert articles. It is unclear how these models perform when summarizing financial text, and whether they need further adaptation (fine-tuning) to perform better in this domain.

Despite significant advancements, text summarization continues to encounter various challenges and limitations. Persistent issues include the potential loss of essential information, semantic inconsistencies in longer summaries, and the need for domain-specific knowledge (Supriyono *et al*., 2024). Many companies and institutions work with sensitive or confidential data that must be protected and cannot be shared with external service providers using global language models. These organizations are therefore faced with the need for local solutions that guarantee a higher level of data security. Local models such as Mistral are an effective alternative because they can be deployed directly on secure internal servers and eliminate the risk of data leakage. This research aims to verify whether these local solutions can compete with the performance of global models in the field of abstract summarization of expert texts.

Generative AI models, such as neural networks and deep learning architectures, are employed to extract salient information and generate coherent summaries that capture the essence of the original articles (Roy *et al*., 2023). Different language models are trained on different datasets and with different architectures, which affects their capabilities and specialization. For example, some models focus on general text comprehension, while others are better suited for analytical tasks or for processing specific types of text. This diversity means that each model is better suited to different types of tasks, including different approaches to text summarization.

The aim of this paper is to analyze and compare the capabilities of selected language models (Mistral, LLaMA and GPT) in summarizing financial expert articles according to the designed methodology.. The research focuses on:

- Development of a unique summarization quality assessment methodology.
- Evaluating the quality of summarization in terms of accuracy, clarity and preservation of key information in the specific context of financial texts.
- Identifying the strengths and weaknesses of the models for processing terminology and analysis-intensive technical texts.
- Proposing recommendations for the effective use of language models in practice, including the possibility of adapting them to domain-specific tasks such as summarizing technical articles in the financial sector.

The results of the work will contribute to a deeper understanding of the capabilities of modern language models in specialized domains and to the design of NLP applications that will improve the processing and use of specialized financial information.

Research questions

- Can local solutions for abstract summarization of financial text match the performance of global models?
- What are the fundamental differences between the models, both in clarity and in the ability to identify key information?
- Which of the models tested best fits the specific needs of summarizing financial articles?

2 LITERATURE REVIEW

2.1 Text summarization

Text summarization endeavors to produce a summary version of a text, while maintaining the original ideas (Nazari and Mahdavi, 2018). According to Liu *et al.* (2023), text summarization is an important NLP task where the goal is to generate a shorter version of an input text while preserving its main ideas. Generally, it is a process of creating a shorter version of a longer text that still contains the main ideas and key information. The goal of summarization is to allow the reader to quickly understand what the text is about without having to read everything. Instead of reading every word, summarization can pick out the most important parts – like main facts, key points, or important conclusions. The summary should have good structure, and the sentences should be coherent (Yadav *et al.*, 2022). The result is a shorter text that is still understandable and effectively captures the original content. In essence, it's about "extracting the essence" from a long text and packaging it into a shorter, simpler version. According to (Raman and Meenakshi, 2020), Text summarization has now become the need for numerous applications, like market review for analysts, search engine for phones or PCs, business analysis for businesses. One of the main approaches, when viewed from the summary results, are extractive and abstractive (Widyassari *et al.*, 2022).

- **Abstractive text summarization:** summarizing using the model's own formulations (Maylawati *et al.*, 2024, Yang *et al.*, 2020, Sinha *et al.*, 2018).
- **Extractive text summarization:** summarizing by directly selecting important sentences from the text (Paulos *et al.*, 2024, Rahman *et al.*, 2021).
- **Hybrid text summarization:** It combines both extractive and abstractive methods. It means extracting some sentences and generating a new one from a given corpus (Binwahlan *et al.*, 2010).

The evaluation of text summarization approaches has undergone a dynamic evolution, progressing from traditional metrics to semantics-focused metrics and incorporating human evaluations (Supriyono *et al.*, 2024). In order to effectively summarize, syntactic, semantic, and pragmatic concerns become crucial, highlighting the necessity of capturing not only grammar but also the context and underlying meaning (Supriyono *et al.*, 2024). According to (Singh & Deepak, 2021, Sinha *et al.*, 2018), semantic, syntactic, and pragmatic considerations form the core of effective text summarization.

2.2 Types of financial articles

Overview articles are intended for general public and experienced investors. These articles summarize current developments in financial markets in order to provide readers with a comprehensive and easy-to-understand overview of key events, trends, or statistics (e.g., interest rate changes, corporate earnings) without deep analysis or forecasts. Example: "Monthly Summary of Stock Market Developments."

Analytical articles are intended for advanced investors, economists and professionals. These articles delve deeper and analyse specific phenomena, trends, or companies based on data and conclusions to give readers insights into the causes and consequences of specific situations, offer justified forecasts, data analyses, graphs, models, interpretations of financial indicators, or make recommendations. Example: "The Impact of ECB Monetary Policy on European Bond Markets."

Technical articles are intended for academics, quantitative analysts, or technical finance experts. These articles focus on the technical aspects of finance, such as mathematical models, algorithms, data analysis methods, or technical details of financial instruments in order to explain, develop specific technical methods or approaches or describe of models, algorithms, case studies. Example: "Portfolio Optimization Using the Markowitz Model in Python."

3 METHODOLOGY AND DATA

It is difficult for people to recognize what information should be included in a summary; therefore, evaluating it is difficult (Yadav *et al.*, 2022). Also (Gambhir & Gupta, 2017) confirm that information changes depending on the summary's purpose, and mechanically capturing this information is a challenging undertaking.

The subject of our research was the ability of the selected AI models to summarize financial articles. Specifically, the versions GPT-4o, Mistral Instruct, and Llama 3.1 8B Instruct 128k were used. The capabilities of the GPT model were tested in the ChatGPT 4o interface, while the capabilities of the Mistral and Llama models were tested in the GPT4All environment, version 3.2.1.

3.1 Data preparation

In the first stage, a representative set of financial articles of varying length, complexity and style were selected. These articles were obtained from public web sites focused on financial markets like Bloomberg[1], SeekingAlpha[2] or YahooFinance[3]. We prepared a diverse dataset, including overview articles (O), analytical articles (A) and technical texts (T). We have also included articles of varying lengths to assess each model's ability to process different volumes of information, ranging approximately from 20 to 6,000 words.

We focused mainly on the ABSTRACT SUMMARIZATION that means summarizing using the model's own formulations. The models' task was to generate a concise and informative summary from the given article. The summary should include important details while maintaining coherence and clarity. For all three models, we set up the same output requirements:

Tab. 1 Output requirements

REQUIREMENT	EXPLANATION
Output format	JSON format with valid, iterable RFC8259 compliant code in your responses
Number of JSON fields	1. summary field with text containing summary of the article 2. bulletpoints field with list of strings containing three main giveaway from the article in a form of short bulletpoints
Length of the summary	Only 5 sentences
Length of the bulletpoints	Only 3 items

3.2 Evaluation criteria

The two most significant aspects of judging a summary are its quality and informativeness (Yadav, 2022). Our evaluation relies on qualitative methodologies combined with manual analysis to ensure a thorough and detailed assessment of the models. Specifically, we concentrated on the following key aspects:

- **Ability to handle text of different lengths** – this criterion evaluates the model's ability to generate coherent and relevant summaries for inputs of varying lengths, from short texts (20–100 words) to longer documents (over 5000 words).

1 https://www.bloomberg.com/europe

2 https://seekingalpha.com/

3 https://finance.yahoo.com/

- **Ability to generate JSON code correctly** – this criterion assesses the model's accuracy in generating properly structured JSON code when required. The evaluation will check whether the output is syntactically valid JSON and whether it includes all required key-values.
- **Ability to meet output length requirements** – this criterion measures whether the model adheres to specific formatting requirements for the output—specifically, generating summaries of exactly 5 sentences and 3 bullet points. The evaluation will be conducted by counting the number of sentences and bullet points in the output.
- **Summarization efficiency** – specifically, we focused on:
  - **Total response length** – this metric captures the overall length of the model's entire response in words.
  - **Length of summary** – this metric measures the length of the generated summary in words.
- **Compression ratio of summary** is calculated as:

$$\textit{Compression Ratio (Summary)= Total Length of SummaryLength of Input}$$

  - **Length of bullet points** – this metric evaluates the total word count of the bullet points generated by the model.
  - **Compression ratio of bullet points** is calculated as:

$$\textit{Compression Ratio (Bullet Points)= Total Length of Bullet PointsLength of Input}$$

- **Quality of summarization**:
  - **Accuracy of information** – measures whether the summary captures the key points and is factually accurate, with a high degree of alignment with the essential information in the original article.
  - **Clarity of message** – assesses the quality of the language, readability, and clarity of the summary.
  - **Relevance of information** – evaluates the model's focus on essential information (e.g., the main ideas and arguments of the article).

3.2.1 Rating scale for the summarization quality criteria

For evaluating the quality of summarization, a five-point rating scale was employed For evaluating the quality of summarization, a five-point rating scale was employed across three key criteria: **accuracy**, **clarity**, and **relevance**. The scale allows to compare the performance of different AI models in producing high-quality summaries. Below is a detailed explanation of the meaning of each item on the scale:

1. (Very Poor) – The model fails to meet the basic requirements of the criterion.
2. (Poor) – The model meets some requirements but has significant shortcomings.
3. (Average) – The model meets the basic requirements but lacks precision or consistency.
4. (Good) – The model meets most of the criterion's requirements with minor issues.
5. (Excellent) – The model fully meets all requirements without significant errors.

This five-point scale ensures that both quantitative analysis (through numerical scores) and qualitative analysis (based on detailed human evaluation) are considered in the overall assessment. The final score for summarization quality is determined by averaging the scores across the three criteria (accuracy, readability, and relevance). The following table summarizes the detailed scoring methodology for each of the summarization quality criteria.

Tab. 2 Detailed scoring methodology for each of the summarization quality criteria

POINTS	INFORMATION ACCURACY	CLARITY OF THE MESSAGE	RELEVANCE OF INFORMATION
1	The summary contains inaccuracies, distortions, or misses key points.	The language is unclear, full of errors, and difficult to read.	The summary primarily includes irrelevant or unrelated information.
2	Some key points are captured, but many important details are missing or distorted.	The language has frequent errors, and the summary is unclear or poorly organized.	Includes a few relevant points but still has excessive irrelevant or redundant content.
3	Most key points are accurate, but some details may be incorrect or omitted.	The language is readable but occasionally unclear or stylistically inconsistent.	Focuses on main ideas but includes some unnecessary or secondary information.
4	The summary is factually correct and captures nearly all key points.	The language is clear, readable, and stylistically appropriate.	Focuses on essential information with minimal extraneous details.
5	The summary accurately and comprehensively captures all key points of the article.	The language is highly understandable, stylistically polished, and well-structured.	The summary focuses entirely on the main ideas and arguments, with no superfluous details.

3.3 Experimental setup

First, we tested a small number of articles to evaluate how the models behave and to adjust the settings. To obtain statistically valid results, we selected a sufficient number of articles depending on the variability of the texts. For the evaluation, we used qualitative scores to provide a comprehensive view.

3.4 Testing principles

In particular, we always started each conversation with an AI model in a new chat, as the model only retains context within the current chat. Starting a new chat ensures that the model is not influenced by previous context, minimizing the risk of misinterpreting the question or biasing the answer. It also improves the accuracy and consistency of the output, because the model is working with clean and unambiguous input. The conversation always started with the sentence setting the context for the model: "*You are a helpful, respectful and honest assistant. Always answer as helpfully as possible, while being safe. Your answers should not include any harmful, unethical, racist, sexist, toxic, dangerous, or illegal content. Please ensure that your responses are socially unbiased and positive in nature. If a question does not make any sense, or is not factually coherent, explain why instead of answering something not correct. If you don't know the answer to a question, please don't share false information.*" This formulation improves the consistency and correctness of the answer.

4 RESULTS AND DISCUSSION

A total of 30 articles from the field of finance were analyzed in detail, ensuring a diverse representation of financial topics, such as corporate finance, investment strategies, and market analysis. This sample size is sufficient to capture variability in content while maintaining a manageable scope for thorough evaluation. Additionally, this number allows for basic statistical analysis, enabling comparisons and trend identification across models. A larger sample could have reduced the depth of evaluation, while a smaller one might not have provided enough variability for reliable conclusions.

4.1 Ability to handle text of different lengths

During testing, the GPT model successfully processed all inputs, including those up to 6000 words. In contrast, the Mistral and Llama models frequently encountered input length issues, returning errors indicating that the prompt size exceeded their respective context windows. Specifically, the Mistral model refused to process inputs longer than approximately 1200 words, while the Llama model could not handle inputs exceeding 1400 words. The context window sizes reported by the models varied significantly: Mistral indicated a limit of 10,240 characters, Llama reported a maximum prompt size of 2048 characters (approximately 300–400 words), while GPT claimed a substantially larger capacity of approximately 100,000 tokens, encompassing both input and output within a conversation.

Notably, the texts that Mistral and Llama failed to process were predominantly analytical in nature. These texts involved complex arguments, detailed explanations, and extensive use of data, which likely contributed to their increased length. This highlights a potential limitation of Mistral and Llama when handling information-dense, structured inputs, particularly in contexts requiring detailed analytical thinking.

For consistency in evaluation, only texts for which all three models produced responses were included. This approach ensured a balanced comparison by focusing exclusively on cases where the output from all models could be analyzed.

4.2 Ability to generate JSON code correctly

The evaluation of the models' ability to generate JSON code correctly revealed that both the Llama and GPT models consistently produced valid and error-free JSON outputs. In two instances, the Mistral model failed to include the trailing parenthesis, resulting in syntactically invalid JSON code, which could not be parsed correctly.

GPT consistently generates well-formatted JSON code with proper indentation, ensuring a clear and organized structure. This improves readability and facilitates better comprehension of the logical flow, particularly in complex outputs. In contrast, both Mistral and Llama produce JSON outputs without proper indentation, presenting the code as a single continuous block of text. This lack of formatting complicates readability, making it more difficult for users to discern key elements or understand the hierarchical structure of the data.

Proper formatting, such as indentation, is essential for improving the user experience, particularly in scenarios involving complex JSON structures where readability and ease of debugging are critical.

4.3 Ability to meet output length requirements

All three models consistently met the requirement of generating three bullet points for each text tested. However, there were notable differences in meeting the requirement to produce exactly 5 sentences of summarization. The GPT model fully met the specification, consistently generating 5 sentences in each case. In contrast, the Llama model deviated on three occasions, producing 4 sentences instead of 5, which may reflect minor challenges in sentence segmentation or adherence to the specification.

The Mistral model showed the greatest inconsistency, failing to meet the 5-sentence requirement in 18 of the cases tested. The number of sentences generated by Mistral varied significantly, ranging from 1 to 7 sentences. This variability suggests potential limitations in Mistral's ability to consistently follow output length constraints, and highlights a need for improvement in handling precise output formatting requirements.

An additional test was conducted using an edge case, where the financial article consisted of a single informative sentence containing 19 words. The GPT model adhered strictly to the specified requirements, generating 5 sentences and 3 bullet points. However, it lengthened

the original text by expanding the single sentence into multiple sentences rather than condensing it. The Llama model generated the required 3 bullet points but produced only 3 sentences instead of the specified 5, indicating a tendency to condense content.

We also tested the extreme case where the financial article was a single informative sentence of 19 words. The GPT model stuck strictly to its specification and again generated 5 sentences and 3 bullets, lengthening the text instead of shortening it. The Llama model also generated 3 bullets, but shortened the summary to 3 sentences. The Mistral model was the only one to generate a one-sentence summary, dropping 3 irrelevant words from the original sentence. However, it still generated 3 bullet points. The Mistral model was the only one to produce a one-sentence summary, effectively shortening the original input by omitting 3 irrelevant words. Despite its brief summary, it still fulfilled the requirement by generating 3 bullet points, demonstrating its capacity to condense content while adhering to the specified output format.

4.4 Summarization efficiency

In this section, we evaluated summarization efficiency by measuring the average length of the total responses, the summaries, and the bullet points in terms of word count. The average length of the total responses varied across models. The Llama model produced the shortest output with an average of 118 words, followed by the Mistral model with 138 words. The GPT model generated the longest output with and average of 141 words. These results suggest that Llama prioritized brevity, while GPT tended to provide more detailed responses.

Regarding the length of the generated summaries, Mistral produced the shortest summaries, averaging 72 words, followed by Llama with 83 words. GPT generated the longest summaries, averaging 98 words. This indicates that GPT provided more detailed summaries, while Mistral prioritized conciseness.

The Llama model generated the shortest bullet points, averaging 32 words, followed by GPT with 36 words. Mistral produced the longest bullet points, averaging 61 words. Shorter bullet points, such as those generated by Llama, are generally more readable and suitable for quick information retrieval, while longer bullet points, like those from Mistral, may reduce clarity.

The compression ratio, which measures the degree of output compression relative to the input length, was also evaluated. For summarization, Mistral achieved the highest compression (0.187), followed by Llama (0.278), while GPT had the lowest compression (0.341), corresponding to its longer average output. A similar trend was observed for bullet point compression, with Llama achieving the highest compression ratio (0.101), followed by GPT (0.138), and Mistral producing the least compressed bullet points (0.195)

4.5 Quality of summarization

The summarization quality of all three AI models was evaluated based on three key criteria: **accuracy of information, clarity of message**, and **relevance of information**. Each criterion was rated on a five-point scale, where 1 represents the lowest quality and 5 represents the highest.

Overall, the summarization quality of the AI models was found to be very high, with an average score of 4.36 across all three criteria and models. This is also confirmed, for example, by a study of Goriparthi (2021) which states significant improvements in both summarization and translation quality of AI models. Our results indicate that, despite minor differences, the models are generally capable of producing high-quality summaries. Among the three criteria, the highest average score was achieved in **clarity of message** (4.85), followed by **relevance of information** (4.19) and **accuracy of information** (4.13). This suggests that while all models excel at presenting information clearly, slight inaccuracies may still occur.

Tab. 3 Overall results of the quality of summarization

	MISTRAL	LLAMA	GPT
Accuracy of information	3.81	4.04	4.54
Clarity of message	4.65	4.92	4.96
Relevance of information	7.73	4.12	7.72
Total score	4.06	4.36	4.74

The average scores for each model across the three criteria are as follows:

- Accuracy of information: Mistral (3.81), Llama (4.04), GPT (4.54)
- Clarity of message: Mistral (4.65), Llama (4.92), GPT (4.96)
- Relevance of information: Mistral (3.73), Llama (4.12), GPT (4.73)

These results show that GPT consistently outperformed the other models, particularly in accuracy and relevance, while all three models excelled in clarity. While there are some differences in performance, all three models demonstrated a high capacity for summarization, with even the lowest-performing model achieving an overall score above 4.0. This indicates that current AI models are well-suited for generating clear and relevant summaries in the field of finance. The following table brings the overall results of the quality of summarization.

4.6 Overall evaluation

The following table presents a comprehensive summary of the evaluation results for all three AI models. In addition to the core criteria outlined in the methodology, two additional factors were identified during testing as critical for practical application: **response speed** and **visual formatting of code**.

Tab. 4 Overall evaluation

EVALUATION CRITERION	MISTRAL	LLAMA	GPT
Length of input	*	**	***
JSON code correctness	**	***	***
Requirements for output	*	**	***
Total response length	**	***	*
Length of summary	***	**	*
Compression ratio of summary	***	**	*
Length of bullet points	*	***	**
Compression ratio of bullet points	*	***	**
Accuracy of information	*	**	***
Clarity of message	**	***	***
Relevance of information	*	**	***
Response speed	**	**	***
Visual formatting of code	*	*	***

While the main focus of the evaluation was on summarization quality, response speed emerged as a significant criterion, with GPT consistently outperforming both the Mistral and Llama models. Fast response times are essential in real-world applications, particularly in environments where quick information retrieval and decision-making are required. A slow response may hinder user productivity, especially in scenarios involving large datasets or time-sensitive analyses.

Another important factor beyond the core methodology was the visual formatting of generated code. GPT demonstrated superior formatting, producing well-indented and structured code, whereas Mistral and Llama often generated code as a single continuous block of text. Proper formatting enhances readability and facilitates easier debugging and integration of the generated code into existing systems. This is especially critical for developers and analysts working with structured data, as poorly formatted code increases the cognitive load and the likelihood of errors.

These additional criteria highlight that beyond pure summarization quality, practical usability factors such as speed and output clarity play a vital role in determining the overall performance of AI models in real-world tasks.

The results showed that GPT consistently outperformed both Mistral and Llama in terms of overall summarization quality, achieving the highest scores in accuracy, clarity, and relevance. Specifically, GPT excelled at producing clear, concise, and well-structured summaries with minimal errors in information accuracy. It also demonstrated superior adherence to output formatting requirements, consistently producing summaries of the specified length and properly structured JSON code with excellent visual formatting.

While Llama demonstrated competitive performance, particularly in terms of message clarity and summarization efficiency, it occasionally struggled with adherence to strict length requirements, sometimes generating fewer sentences than specified. Mistral, while the least consistent of the three models, demonstrated strengths in conciseness and compression ratio, but showed significant variability in meeting output requirements and generating error-free JSON code.

An additional aspect evaluated during the study was the practical usability of the models, specifically response speed and visual formatting of the generated code. GPT once again outperformed its competitors in these areas, providing the fastest response times and the most user-friendly output formatting. These factors are critical in real-world applications where clarity of output and fast response times are essential for efficient decision making and information retrieval.

5 CONCLUSION

This research highlights the significant potential of advanced AI models for financial summarization tasks, with GPT emerging as the most capable model in terms of quality, usability, and adherence to specified output requirements. However, the study also underscores the need for further improvements in model consistency, especially for Mistral and Llama, and suggests several directions for future research that could enhance AI summarization capabilities in specialized domains. As AI models continue to evolve, their application in financial analysis and other high-stakes fields is likely to become increasingly prominent, making rigorous evaluation frameworks such as the one used in this study essential for guiding their development and deployment.

REFERENCES

BINWAHLAN, M. S., SALIM, N., SUANMALI, L. 2010. Fuzzy swarm diversity hybrid model for text summarization. *Information Processing and Management*, 46(5), 571–588. https://doi.org/10.1016/j.ipm.2010.03.004

DHAINI, M., ERDOGAN, E., BAKSHI, S., KASNECI, G. 2024._Explainability Meets Text Summarization: A Survey. In: *Proceedings of the 17th International Natural Language Generation Conference*. Tokyo, Japan: Association for Computational Linguistics, p. 631–645.

GAMBHIR, M., GUPTA, V. 2017. Recent automatic text summarization techniques: a survey. *Artificial Intelligence Review*. 47(1), 1–66. https://doi.org/10.1007/s10462-016-9475-9

GORIPARTHI, R. G. 2021. AI-Driven Natural Language Processing for Multilingual Text Summarization and Translation. *Revista de Inteligencia Artificial en Medicina*. 12(1), 513–535. [Accessed 2025, January 11] http://redcrevistas.com/index.php/Revista/article/view/226

LIU, Y. L., CAO, M., BLODGETT, S. L., CHEUNG, J. C. K., OLTEANU, A., TRISCHLER, A. 2023. Responsible AI Considerations in Text Summarization Research: A Review of Current Practices. arXiv preprint. *arXiv*: 2311.11103v1. https://doi.org/10.48550/arXiv.2311.11103

MAYLAWATI, D. S., SHALIH, K. M., RAMDHANI, M. A., SLAMET, C., RAMDANIA, D. R. 2024. Indonesian Abstractive Text Summarization with Bidirectional Long Short-Term Memory (Bi-LSTM). In: 12th International Conference on Cyber and IT Service Management (CITSM). https://doi.org/10.1109/CITSM64103.2024.10775593

NAZARI, N., MAHDAVI, M. A. 2018. A survey on Automatic Text Summarization. *Journal of AI and Data Mining*. 7(1), 121-135. https://doi.org/10.22044/jadm.2018.6139.1726

PAULOR, E. B., WOLDEYOHANNIS, M. M., DANA B. S., YESUF S. M., YIGEZU M. G. 2024. Extractive Text Summarization for Wolaytta Language Using Recurrent Neural Network. In International Conference on Information and Communication Technology for Development for Africa (ICT4DA). https://doi.org/0.1109/ICT4DA62874.2024.10777225

RAMAN, J., MEENAKSHI, K. 2021. Automatic Text Summarization of Article (NEWS) Using Lexical Chains and WordNet—A Review. In: HEMANTH, D., VADIVU, G., SANGEETHA, M., BALAS, V. (Eds.). *Artificial Intelligence Techniques for Advanced Computing Applications*. Lecture Notes in Networks and Systems, vol 130. Singapore: Springer. https://doi.org/10.1007/978-981-15-5329-5_26

RAHMAN, N. A., ; RAMLAM, S. N. A., AZHAR, N. A., HANUM, H. M., RAML, N. I. AND LATEH, N. 2021. Automatic Text Summarization for Malay News Documents Using Latent Dirichlet Allocation and Sentence Selection Algorithm. In: *Fifth International Conference on Information Retrieval and Knowledge Management (CAMP)*. IEEE. https://doi.org/10.1109/CAMP51653.2021.9498029

ROY, K., MUKHERJEE, S., DAWN, S. 2023. Automated Article Summarization using Artificial Intelligence Using React JS and Generative AI. *Journal of Emerging Technologies and Innovative Research (JETIR)*. 10(6), 78–87. ISSN: 2349-5162.

SAIYYAD, M. M., PATIL, N. N. 2024. Text Summarization Using Deep Learning Techniques: A Review. *Engineering Proceedings*. 59(1), 194. https://doi.org/10.3390/engproc2023059194

SINGH, S., DEEPAK, G. 2021. Towards a Knowledge Centric Semantic Approach for Text Summarization. In: *Data Science and Security*. Lecture Notes in Networks and Systems, vol 290. Singapore: Springer. https://doi.org/10.1007/978-981-16-4486-3_1

SINHA, A., YADAV, A., GAHLOT, A. 2018. Extractive Text Summarization using Neural Networks (Version 1). *arXiv*. 1802.10137. https://doi.org/10.48550/ARXIV.1802.10137

SUPRIYONO, WIBAWA, A. P., SUYONO, KURNIAWAN, F. 2024. A survey of text summarization: Techniques, evaluation and challenges. *Natural Language Processing Journal*. 7, 100070. Elsevier BV. https://doi.org/10.1016/j.nlp.2024.100070

WIDYASSARI, A. P., RUSTAD, S., SHIDIK, G. F., NOERSASONGKO, E., SYUKUR, A., AFFANDY, A., SETIADI, D. R. I. M. 2022. Review of automatic text summarization techniques and methods. *Journal of King Saud University – Computer and Information Sciences*. 34(4), 1029–1046. Springer Science and Business Media LLC. https://doi.org/10.1016/j.jksuci.2020.05.006

YADAV, D., DESAI, J., YADAV, A. K. 2022. Automatic Text Summarization Methods: A Comprehensive Review (Version 1). *arXiv:*2204.01849v1. https://doi.org/10.48550/ARXIV.2204.01849

YANG, M., WANG, X., LU, Y., LV, J., SHEN, Y., LI, C. 2020. Plausibility-promoting generative adversarial network for abstractive text summarization with multi-task constraint. *Information Sciences*. 521, 46–61. https://doi.org/10.1016/j.ins.2020.02.040

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ANALYZING CONSUMER BEHAVIOR USING NEURAL NETWORKS AND GRAMMATICAL EVOLUTION

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ABSTRACT

In this contribution, we will present an approach to the automatic classification of customers based on their behaviour in the food market. The analysis is based on the data from a survey on meat product consumption in the Czech Republic. Classifiers were created to categorize customers into classes according to their habits of purchasing meat products, dividing the customers with respect to such characteristics as age or education. To accomplish this task some selected types of artificial neural networks (Multi-Layer Perceptron Neural Network, Kohonen Neural Network) were trained and also an approach based on grammatical evolution was used. These classifiers were compared with regard to their abilities to perform the given task. Also, the survey data pre-processing is described.

Keywords: Consumer's Behaviour, survey analysis, classification, grammatical evolution, neural networks

1 INTRODUCTION

All organizations should pay attention to optimizing their workflows, also follow regulations, and dynamically respond to the situation on the market and customer needs (Rábová, 2012). Customer Relationship Management (CRM) can be viewed as a holistic framework that allows interaction between organizations and their customers (Dařena, 2008). To explore consumer behaviour, CRM uses marketing research. Marketing research is a process of collecting and using information for marketing decision-making (Boone and Kurt, 2013).

Birčiaková *et al.* (2014) describe consumer society by many distinctive features: increasing consumer activities, the new phenomenon of recreational shopping, strongly location-based consumption, strengthening customers' role on the market, developing IT and its impact on consumer behaviour in the form of a broader and more varied selection and availability of products and services, and easier access to the information from both the supply and demand side. There are a lot of factors that influence customer behaviour (Hajko *et al.*, 2014). Factors which influence the behaviour of consumers are very important for businesses because they

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can focus clearly on their business policy based on these factors, which should lead to better business results (Novotný and Duspiva, 2014). The knowledge of fundamental relations gives the possibility to realize predictions and helps with the decide-making process about reasonable actions in order to achieve the desired objectives (Bína and Jiroušek, 2015).

Data for research on consumer behaviour can be obtained from multiple sources. In the secondary research being typically used in national and international sources, such as the Czech Statistical Office or Eurostat, data is provided in electronic form, easily accessible via the Web. In the primary research, the most often used data is from surveys in which consumers respond to specific questions.

Tools that enable individual steps of marketing research, particularly the collection of data and its analysis can be more effective through the increased use of databases and data mining techniques (Bradly, 2007; Kříž and Dostál, 2010; Munk *et al.*, 2013, Beránek and Knížek, 2012). As a part of a Marketing Information System, these tools provide persons with decision responsibility with an instant flow of information relevant to their area. (Boone and Kurt, 2013).

The aim of this contribution is the automatic classification of customers based on their behaviour in a food market. The analysis is based on the data from a survey on meat product consumption in the Czech Republic. This article is related to the research from Lýsek and Šťastný (2013) where grammatical evolution was tested for survey data classification and compared to neural networks from Šťastný *et al.* (2011).; other applications of these methods include customer segmentation tasks (e.g., Mitchell, 1999 for GA; Kohonen, 1982 for SOM; Skorpil and Stastny, 2006 for MLP comparisons)

This study addresses two key research questions (RQ):

- RQ1: Is it possible to classify consumer types using passively collected behavior data instead of direct survey responses?
- RQ2: Which classification method (MLP, Kohonen network, grammatical evolution) provides the best accuracy in this domain?

It is very costly and time-consuming to ensure a sufficiently high-quality prediction of customer behaviour. We must also take into account data protection and the willingness of customers to disclose their data. It is better to avoid these problems and find minimized easy-to-detect criteria for customer behaviour analysis. This paper shows multiple techniques that solve the above-described problem. The use of neural networks and genetic algorithms is also shown as a possible solution to these analyses.

2 MATERIALS AND METHODS

For analysing customer behaviour, it is quite common to use data from marketing survey research (Turcinkova, Stavkova, 2012; Litavcova *et al.*, 2015). The data used in our research was gathered in a customer survey on meat product consumption, the same data items were also used in Turcinkova *et al.* (2014). Customers answered a set of questions based on their opinions and preferences. There were also a few questions the purpose of which was to categorize each participant by such parameters as age, gender, education, type of household, size of his/her hometown or employment status, and a few others. The survey contained 1027 responses.

The survey responses were stored as 0 or 1 values for yes/no questions. The ranking questions stored the response as numbers. If the answer to a survey question is enumerative, the answer was stored as an index of the corresponding answer. We selected four parameters that the survey participants indicated (age, gender, education, and employment) as target classifications to test the proposed algorithms.

2.1 Selection of classification indices

Our goal was to create a classifier which would be able to recognize customers by the least number of parameters. The ideal state is that the customer is classified without even knowing about it – we do not want the customer to fill out any survey forms. The survey data items were therefore filtered out from the information that is undetectable without asking the customer directly.

Most customers use their credit cards or some kind of store membership/discount card.

We can track and connect the shopping sessions of these customers and gather information such as the frequency of shopping, the time when a customer visits the shop most, the amount of money spent, and the type of goods bought. This information was gathered from a survey but it can also be gathered from the company's accounts.

To satisfy our goal we selected the following customer parameters from this survey data:

- What days do you usually do your shopping for meat products? (8 options)
- What time do you usually go shopping for meat products on weekdays and what time on weekends? (10 options)
- How often do you usually buy meat products? (15 options)
- What type of payment do you usually use when shopping for meat products? (3 options)
- Frequency of purchasing selected meat products classes (68 options).

The resulting vector describing a customer had 104 indices. Table 1 shows classification criteria and their number of classes.

Tab. 1 Number of classes

Classification criteria	Number of classes
Age	6
Gender	2
Education	5
Employment status	8

2.2 Pre-processing of training data

To select a training set of data for classifiers, a 1NN search was executed. Only instances of survey responses with the same class label as their nearest neighbour were selected to enter the training set. The training set size was from 1/3 to 1/2 of the original dataset after this pre-processing step.

Response values for enumerative questions were converted into binary indicators by creating a new column for each possible response. That column contained the value 1 if the survey participant selected that option or the value 0 if he/she did not.

2.3 Used methods

Classifier configurations were selected based on prior experiments and related literature. No extensive hyperparameter tuning was conducted due to computational constraints. For each method, a simple train-test split (approximately 70/30) was used without stratification. This setup was intended to simulate realistic classification performance in a CRM context.

Since the Multi-Layer Perceptron (MLP) network is often used for traditional classification tasks (Skorpil and Stastny, 2006 and 2009), we will include a basic implementation of this network as one of proposed classifiers.

The Kohonen neural network (or Self-organizing map) by Kohonen (1982) will be used as the second type of the classifier. As for the given task we expect that it will perform adequately as the nature of the input data is a vector of indices and this network can naturally cluster such a kind of input (Konecny *et al.*, 2010).

Another type of the classifier will be created using genetic programming introduced by Koza (1992), namely the grammatical evolution approach will be used. The performance of these classifiers depends heavily on the given grammar which is used to build a short computer program. That program is used as the classifier in the final phase.

Grammatical evolution is an optimization process which can be used to develop short computer programs. It is an evolutionary algorithm. These algorithms are inspired by the process of the evolution in nature (Mitchell, 1999; Goldberg, 2002). These algorithms work in an iterative manner with a population of individuals where each individual represents a candidate solution to the problem (see Fig. 1).

Grammatical evolution uses context free grammar G = {N, T, P, S} to translate a sequence of numbers (chromosome) into a computer program (Ryan and O'Neill, 2003). The grammar consists of these components: N is a set of non-terminal symbols, T is a set of terminal symbols, P is a set of production rules and S is the starting symbol from N set (Hopcroft and Ullman, 1969). We used backward processing modification of chromosome translation in our grammatical evolution framework proposed by Popelka and Stastny (2011).

The grammar we used for this classification task is the same as in Lysek and Stastny (2013). The grammar can create classifier programs with multiple output values using the semicolon node, (Lysek and Stastny, 2019).

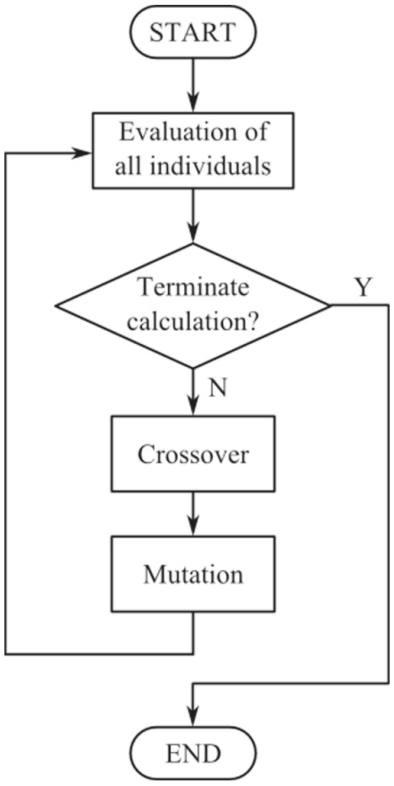

Fig. 1: Genetic algorithm visual representation

The purpose of the program created by grammatical evolution is not restricted. The process is guided by a fitness value which describes the performance of the evolved program for the given task. The fitness value of the member M is calculated according to the formula (1).

$$Fit(M) = W_1 SR + W_2 \frac{RC}{CC} \tag{1}$$

$$W_1 = \frac{CC}{CC+1} \tag{2}$$

$$W_2 = \frac{1}{CC+1} \tag{3}$$

$$SR = \frac{\sum_{i=1}^{CC} \frac{S_i}{MS_i}}{CC} \tag{4}$$

The given formula calculates the classification success rate in the first part. The SR value (4) is an average of success rates for each class i of CC classes. The second part encourages the classifier to be able to classify all classes as the variable selection of rewriting rules from the grammar allows an omission of some output values. Value RC is the number of classes that the classifier is capable of recognizing. These formulas were proposed for classification tasks in Lysek and Stastny (2019). Weights w1 and w2 distribute the importance of those two parts according to the number of classes.

3 RESULTS

We present the result and setup of selected artificial intelligence methods.

3.1 MLP network

A three layer (104 – 10 – N) MLP neural network was used. Back-propagation was used as the training algorithm for 100 iterations. The number of output neurons N was set according to the number of classes of the classification task. An output vector was M-dimensional for each task and each class was associated with one basis vector of M-dimensional space. Each basis vector was associated with one class. The classification result was a basis vector (it is an associated class label) closest to the neural network output for the given input. A Euclidean distance formula was used to calculate the distances of vectors. The result can be seen in the Table 2.

3.2 Kohonen network

The Kohonen network was trained on pre-processed training data. Two variants were tested. One with 64 output neurons and one with 25 output neurons. The training algorithm was executed for 200 iterations. The labelling of output neurons was done by measuring the most frequent class label for each neuron on training data. We used a square grid and corresponding

Tab. 2 Results of classification using MLP network with 25 output neurons

Results of classification	Training data performance [%]	Testing data performance [%]
Age	6.03	19.07
Gender	31.78	39.30
Education	54.83	41.08
Employment status	35.50	36.02

Tab. 3 Results of classification using Kohonen network with 25 output neurons

Results of classification	Training data performance [%]	Testing data performance [%]
Age	47.98	30.52
Gender	69.72	60.60
Education	59.35	42.05
Employment status	64.32	48.53

neighbourhood function for weight updates. A higher number of output neurons gives the network the ability to create a finer clustering and improves the classification quality. Tables 3 and 4 show the results.

3.3 Grammatical evolution

Result of grammatical evolution algorithm is shown in the Table 5.

The parameters of the grammatical evolution process are stated in the following list.

- Length of chromosome: 80.
- Number of iterations: 1000.
- Population size: 200.
- Mutation rate: 10%.
- Crossover rate: 90%.

Tab. 4 Results of classification using Kohonen network with 64 output neurons

Results of classification	Training data performance [%]	Testing data performance [%]
Age	58.62	31.76
Gender	72.73	62.46
Education	63.87	42.67
Employment status	70.15	52.17

Tab. 5 Results of classification using classifier evolved by grammatical evolution

Results of classification	Training data performance [%]	Testing data performance [%]
Age	37.93	17.83
Gender	56.02	54.30
Education	41.07	25.55
Employment status	50.60	33.62

4 DISCUSSION

The classification results are rather average. The reasons are many, the most significant reason would probably be that customers often act randomly and it is not really possible to gain better results from classification methods that work on the basis of finding patterns. Nevertheless, the presented Kohonen neural network is capable of quite a good classification performance on the given data.

The advantage of the Kohonen network is that it has the capability to create custom clusters by grouping similar input patterns. We can observe that with a rising number of output neurons the performance of classification grows as well. This fact indicates that the data contains more interesting information about the customer's patterns of behaviour but we do not have class labels for such a fine clustering.

The Grammatical evolution approach would perform better if we let the evolutionary process use longer chromosomes. The Classifier program using a chromosome of length 80 cannot be able to use all input terminals because the input vector has high dimensionality. On the other hand, a longer chromosome would increase the number of possible program forms and therefore the duration of the search for an optimal solution would increase significantly. We would prefer grammatical evolution for the classification of input vectors with significantly lower dimensionality.

Generally, the worst classification results are for the age classification and we think that age is not the main parameter that defines customer behaviour in the food market. In our opinion, the main parameter is the amount of money the customer is willing to spend and that is given by his/her education and employment status. Both of these characteristics showed a higher classification success rate. Also, the customer‘s gender can be determined with quite a high success rate.

5 CONCLUSION

A predictive customer behaviour analysis is a highly demanding activity not only financially but also in terms of time. Simplifying this analysis by using easily discoverable classifiers appears to be a possible solution.

By conducting research on classification methods using neural networks and genetic programming, their effectiveness in solving a consumer behaviour analysis is demonstrated. The research has shown that the methods were chosen correctly and thus the most appropriate classification method for this analysis can be derived. The use of the Kohonen network shows the most accurate results among the studied classification methods for broad-spectrum classifiers. The expectation of the best-performing solution when using the MLP network as a classification method was found to be insufficient in the setting used. However, even when using a Kohonen network, it is still very difficult to deliver an accurate analysis of customer behaviour approaching at least an 80 % success rate.

Although we performed the analysis correctly, we were limited by the performance of the specific classifiers used. Their independent potential does not allow for substantial progress in the analysis, but external influences, not mentioned in this paper, are the cause.

Further research on a better-performing solution should focus on refining the selection of specific classifiers. There also appears to be great potential in using a close correlation of at most two to three classifiers. The results of these analyses could be used, for example, to support managerial decision-making. From a practical perspective, the Kohonen network, due to its clustering capability and relatively robust performance, is a promising method for integration into CRM tools that aim to profile customers without direct engagement. This has implications for automated marketing strategies, loyalty systems, or dynamic pricing mechanisms.

REFERENCES

BERANEK, L., KNIZEK, J. 2012. The Usage of Contextual Discounting and Opposition in Determining the Trustfulness of Users in Online Auctions. *Journal of Theoretical and Applied Electronic Commerce Research*. 7(1), 34–50.

BINA, V., JIROUSEK, R. 2015. On computations with causal compositional models. *Kybernetika*. 51(3), 525–539.

BIRCIAKOVA, N., STAVKOVA, J., SOUCEK, M. 2014. How Marketing Instruments Affect Consumer Behavior in Times of Economic Turbulence. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*. 62(6), 1257–1263.

BOONE, L. E., KURT, D. L. 2013. *Contemporary Marketing*. Mason: Cengage Learning.

BRADLEY, N. 2007. *Marketing Research: Tools and Techniques*. New York: Oxford University Press.

DARENA, F. 2008. A research on CRM systems in the Czech Republic. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 56(3), 29–34. https://doi.org/10.11118/actaun200856030029

GOLDBERG, D. E. 2002. *The Design of Innovation: Lessons from and for Competent Genetic Algorithms*. Boston: Kluwer Academic Publishers.

HAJKO, V., BIRCIAKOVA, N., STAVKOVA, J. 2014. *The trends in the income distributions in the EU-27 countries: Measuring the differences*. Paper presented at the 32nd International Conference Mathematical Methods in Economics.

HOPCROFT, J., ULLMAN, J. D. 1969. *Formal languages and their relation to automata*. Addison–Wesley.

KOHONEN, T. 1982. Self-Organized Formation of Topologically Correct Feature Maps.
Biological Cybernetics. 43, 59–69.

KONECNY, V., TRENZ, O., SVOBODOVA, E. 2010. Classification of companies with the assistance of self-learning neural networks. *Agricultural Economics*. 56(2), 51–58.

KOZA, J. R. 1992. *Genetic Programming: On the Programming of Computers by Means of Natural Selection*. Cambridge MA: The MIT Press.

KRÍZ, J., DOSTAL, P. 2010. Database System and Soft Computing. *Systemova integrace*. 17(4), 17–26.

LITAVCOVA, E., BUCKI, R., STEFKO, R., SUCHANEK, P., JENCOVA, S. 2015. Consumer's Behaviour in East Slovakia after Euro Introduction during the Crisis. *Prague Economic Papers*. 24(3), 332–353. https://doi.org/10.18267/j.pep.522

LYSEK, J., STASTNY, J. 2013. Classification of Economic Data into Multiple Classes by Means of Evolutionary Methods. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 61(7), 2445–2449.

LYSEK, J., STASTNY, J. 2019. Grammatical evolution for classification into multiple classes. *Advances in Intelligent Systems and Computing*. 61(837), 192–207.

MITCHELL, M. 1999. *An Introduction to Genetic Algorithms*. Cambridge MA, MIT Press.

MUNK, M., DRLIK, M., KAPUSTA, J., MUNKOVA, D. 2013. Methodology design for data preparation in the process of discovering patterns of web users behaviour. *Applied Mathematics and Information Sciences*. 7(1), 27–36.

NOVOTNY, J., DUSPIVA, P. 2014. Factors Influencing Consumers' Buying Behavior and their Importance for Enterprises. *E+M Ekonomie a Management*. 17(1), 152–166. https://doi.org/10.15240/tul/001/2014-1-012.

POPELKA, O., STASTNY, J. 2011. Automatic generation of programs. In: *Advances in Computer Science and Engineering*. InTech Open, pp. 17–36. ISBN 978-953-307-173-2

RABOVA, I. 2012. Using UML and Petri nets for visualization of business document flow. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*. 60(2), 299–306.

RYAN, C., O'NEILL, M. 2003. *Grammatical Evolution: Evolutionary Automatic Programming in an Arbitrary Language*. Kluwer.

SKORPIL, V., STASTNY, J. 2006. *Back-Propagation and K-Means Algorithms Comparison*. In: *2006 8th International Conference on Signal Processing*. Guilin, China. IEEE Press.

SKORPIL, V., STASTNY, J. 2009. *Comparison Methods for Object Recognition*. Paper presented at the 13th WSEAS International Conference on Systems. Rhodos, Greece.

STASTNY, J., TURCINEK, P., MOTYCKA, A. 2011. *Using Neural Networks for Marketing Research Data Classification*. Paper presented at the International WSEAS Conference on Mathematical Methods and Techniques in Engeneering & Environmental Science. Catania, Italy.

TURCINKOVÁ, J., STAVKOVA, J. 2012. Does the Attained Level of Education Affect the Income Situation of Households? *Procedia – Social and Behavioral Sciences. Special Issue 3rd International Conference on New Horizons in Education - INTE 2012*. 55, 1036–1042. https://doi.org/10.1016/j.sbspro.2012.09.595

TURCINKOVA, J., TURCINEK, P., MOTYCKA, A., STAVKOVA, J. 2014. *Exploring How Customers Shop for Meat Products*. Paper presented at the Recent Advances in Economics, Management and Marketing, Cambridge, MA, USA.

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STUDENT-DRIVEN RESEARCH ON BLOCKCHAIN SOLUTIONS FOR MICRO-CREDENTIALING SYSTEMS

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ABSTRACT

The rapid advancements in blockchain technology and cryptocurrencies have catalysed a growing demand for professionals equipped to navigate this transformative domain. Mendel University's Blockchain and Cryptocurrencies course addresses this need by integrating theoretical foundations with hands-on project-based learning. The curriculum delves into blockchain architecture, consensus mechanisms, smart contracts, decentralized applications, and economic and regulatory implications. Students engage with diverse blockchain platforms, including Hyperledger Fabric, BigchainDB, Avalanche, Corda, and Polygon Mumbai, to develop real-world solutions for micro-credentialing systems.

The comparative analysis of these platforms reveals distinct trade-offs in scalability, security, privacy, and functionality, offering insights into selecting optimal technologies for specific use cases. Through interdisciplinary projects, students gain practical experience, foster innovation, and prepare for strategic roles in the blockchain industry. This approach highlights the critical interplay between theory and application, equipping students to tackle complex challenges and contribute to blockchain innovation across diverse sectors.

Keywords: blockchain, digitalization, micro-credentials

JEL Code: L8, O3

1 INTRODUCTION

The rapid evolution of blockchain technology and cryptocurrencies has fundamentally transformed industries, driving a demand for professionals equipped with the knowledge and skills to navigate this disruptive landscape. In response to this need, Mendel University in Brno offers a comprehensive course titled Blockchain and Cryptocurrencies. This course combines theoretical insights with practical training to provide students with a deep understanding of blockchain's decentralized systems, the cryptographic principles underpinning cryptocurrencies, and their broader economic, social, and regulatory implications.

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The curriculum is designed to address the multifaceted nature of blockchain and cryptocurrencies. It begins by exploring the foundational concepts of blockchain as a distributed ledger, including its consensus mechanisms such as Proof-of-Work (PoW) and Proof-of-Stake (PoS), as detailed in Nakamoto's seminal work on Bitcoin (Nakamoto, 2008). Students gain a solid grounding in the mechanics of cryptocurrencies, smart contracts, and decentralized applications (dApps), enabling them to analyze the technical and strategic elements of these innovations. Additionally, the course delves into the economic implications of blockchain, such as its potential to disrupt traditional financial systems and enable decentralized finance (DeFi) (Gudgeon *et al.*, 2020).

A distinctive feature of the course is the emphasis on interdisciplinary learning, equipping students to tackle the broad applicability of blockchain technology across industries. From supply chain transparency (Kshetri, 2018) to healthcare data security (Azaria *et al.*, 2016) and energy trading (Kouhizadeh *et al.*, 2019), blockchain's potential applications are vast. This breadth is reflected in the course content, which encourages students to adopt a systems--oriented approach to addressing complex challenges. Regulatory and ethical considerations are also emphasized, fostering critical thinking about issues such as privacy, governance, and sustainability in blockchain systems.

An essential component of the course is its focus on experiential learning through student-led projects. These projects provide students with hands-on experience in applying blockchain concepts to real-world problems. Guided by teachers, students design and implement blockchain-based solutions.

These projects not only deepen technical competencies but also encourage creative problem solving. For instance, students might create smart contracts for Micro-credentials platform or energy trading platform. Through these endeavours, students engage with cutting-edge platforms such as Ethereum, Hyperledger, and Solana, preparing them for industry roles that require both strategic insight and technical expertise.

The student projects also foster collaboration, as students often work in teams to tackle interdisciplinary challenges (Merbret *et al.*, 2020). Such initiatives encourage peer learning and develop skills in project management, communication, and teamwork. Furthermore, by presenting their projects to peers and industry professionals, students receive valuable feedback, bridging the gap between academia and practice. The impact of such project-based learning aligns with the findings of Anwar *et al.* (2020), who emphasize that real-world applications enhance student engagement and learning outcomes in blockchain education.

2 METHODOLOGY AND DATA

Blockchain technology was selected for a decentralized approach of issuing certificates, with emphasis on speed, energy efficiency and security. Proof of Authority algorithm was preferred for its speed, proven reliability and wide use in private blockchains. Trusted authority-formed voters were selected as participants in the network, contributing by issuing and verifying certificates. The evaluation of different blockchains led to the preference of Proof of Authority over other algorithms to achieve optimal security and efficiency results. Considering privacy and legal issues, an analysis of challenges related to the right to be forgotten and certificate updates was also considered. The system was designed to support not only certificate issuance but also revocation and renewal, as some certificates are valid only for a limited period. Furthermore, the network had to provide authorized institutions or businesses with access to read and verify valid micro-credentials stored on the blockchain. These requirements were presented to the students as a project assignment. The students formed groups of 3–5 members. Each team chose one of the possible blockchain technologies. They then implemented a certificate management tool using selected technology. Each team then presented and defended their solution.

The research question addressed by the project was whether blockchain technology, specifically various consensus mechanisms, can be effectively used to design a decentralized system for micro-credential management that supports secure issuance, verification, revocation, and renewal. The scientific contribution includes a practical exploration of this approach, insights into implementation challenges, and analysis of legal implications such as the right to be forgotten. Student teams were assessed based on the functionality, security, and usability of their implemented solutions, as well as the clarity of their documentation and final presentations. Evaluation criteria included adherence to project requirements, successful use of blockchain features, and demonstration of certificate management capabilities.

3 RESULTS

3.1 Hyperledger Fabric

Stable development and feature rich. Security features, endorsement policies, handling private data using private collections, generation of user certificates. (Androukali *et al.*, 2018)

Linking chain of certificate changes using composite keys. Chaincode written in Golang, but many possible like Java or TypeScript. Chaincode needs to be approved by peers before deployment.

Advantages:

- Supports private data channels and encrypted sharing of information between specific network participants (e.g., personal identification number can be protected).
- Ability to define complex rules for managing certificates through smart contracts.
- Flexible access control, allowing only authorized institutions to read data.
- Good support for certificate revocation and expiration handling through modifiable smart contracts.
- Strong focus on security and performance.

Disadvantages:

- Higher complexity in configuration and implementation.
- Requires robust infrastructure for network operation.

3.2 BigchainDB

This project implements a decentralized certificate management system built on BigchainDB (McConaghy *et al.*, 2016), a blockchain database that combines the key characteristics of blockchain (decentralization, immutability, and owner-controlled assets) with the advantages of traditional databases (high transaction rate, low latency, and indexing capabilities). The system utilizes a network of four nodes running on Docker containers, each consisting of BigchainDB Server, MongoDB, and Tendermint for consensus.

The implementation leverages FastAPI for the backend REST API and React with Chakra UI for the frontend interface. The system provides comprehensive certificate lifecycle management functionality, including creation, verification, renewal, and revocation of certificates. A notable security feature is the encryption of sensitive personal data (identifiers) using Fernet symmetric encryption, where only the issuing node can decrypt the information. The architecture supports multiple nodes working in a network, with each node maintaining its own cryptographic key pair and the ability to verify certificates issued by other nodes. The system also implements immutable audit trails through blockchain transaction history and provides ledger visualization capabilities, making it suitable for scenarios requiring transparent, tamperproof certificate management such as academic credentials, professional certifications, or digital identity documents.

Advantages:
- High transaction speed.
- Simple data storage and access.

Disadvantages:
- Limited support for smart contracts, making functions like certificate revocation and renewal difficult to implement.
- Insufficient access control and protection for sensitive data.
- Unsuitable for solutions requiring high levels of security and decentralization.

3.3 Avalanche blockchain

The system leverages Avalanche's high-performance (Amores-Sesar *et al.*, 2024), low-latency infrastructure consisting of three chains: **X-Chain:** Handles asset management, **P-Chain:** Handles validator coordination, **C-Chain:** Handles smart contract execution (primary chain).

Advantages:
- High transaction speed and low costs.
- Support for smart contracts, enabling implementation of certificate revocation and renewal.
- Option to create custom subnets with access control and privacy rules.

Disadvantages:
- Sensitive data require encryption and additional protections, increasing complexity.
- Requires knowledge of the Ethereum Virtual Machine (EVM) for smart contract development.

3.4 Corda

Corda (Brown *et al.*, 2016) is a distributed ledger platform designed specifically for enterprise use in the financial sector. Here is an overview of the key concepts that underpin Corda:

States: States represent the current position or status of a ledger and are continuously updated. Each state is an object with a specific value and is uniquely identifiable within the network.

Transactions: Transactions in Corda are proposals to change one or more states. A transaction must be verified and approved by all relevant parties before it can be included in the ledger. Transactions ensure that state changes are valid according to the rules defined in contracts.

Contracts: Contracts in Corda are programs that contain the rules according to which transactions must be executed. Each transaction must comply with the rules defined in the contracts that are relevant to the states changed by the transaction.

Flows: Flows are procedures that enable nodes in the network to coordinate necessary actions to achieve successful execution of a transaction. These flows may include message exchanges, obtaining signatures from consenting parties, and verifying transactions.

Notary: The notary is a special node in the Corda network that prevents double-spending by ensuring that each state can only be used in one transaction at a time. The notary does not judge the content of transactions but verifies their uniqueness and chronological order.

Consortium and private networks: Corda allows the creation of private networks among organizations with similar business interests. These networks can have their own rules and agreements that regulate their interactions.

Compatible privacy: In Corda, transaction data is shared only between parties directly involved in the transaction. This approach ensures that data is kept private and reduces the amount of unnecessary data each node must process.

Advantages:
- Transactions are shared only among involved parties, naturally protecting sensitive information (e.g., social security numbers).
- Support for complex business logic, including certificate revocation and renewal.
- Emphasis on interoperability and integration with existing systems.

Disadvantages:
- Limited decentralization (not a fully decentralized blockchain).
- More complex implementation for less experienced teams.

3.5 Polygon Mumbai

The project utilizes the Polygon Mumbai (Rana *et al.*, 2022) network for efficient and cost-effective blockchain interactions, a Python-based FastAPI backend for seamless communication with the blockchain, and integration with tools like Brownie and Alchemy for contract deployment and testing. This system addresses challenges related to certificate fraud and lifecycle management while showcasing the potential of blockchain technology in sensitive data protection and decentralized governance.

Advantages
- Support for smart contracts through the Ethereum Virtual Machine (EVM).
- Low operational costs and fast transactions.
- Easy implementation of encryption and other safeguards for sensitive data.

Disadvantages
- The public nature of the network makes protecting sensitive data challenging without additional measures.
- As a test network, it is not meant for production, requiring migration to the main network (Polygon Mainnet).

4 DISCUSSION AND CONCLUSIONS

The comparison of Hyperledger Fabric, BigchainDB, Avalanche blockchain, Corda, and Polygon Mumbai for issuing micro-credentials highlights the diverse capabilities and trade-offs inherent in blockchain platforms. Each platform offers unique advantages, reflecting its architectural design, consensus mechanisms, scalability, security, and integration potential, making it suitable for different micro-credentialing use cases.

From an educational perspective, these platforms underscore the multifaceted nature of blockchain technology, reflecting the interdisciplinary focus of the Blockchain and Cryptocurrencies course at Mendel University. By engaging with these cutting-edge platforms, students not only gain technical expertise but also develop a strategic understanding of how blockchain systems can be tailored to solve real-world problems, such as in the domain of credentialing. This aligns with the course's goal of bridging theory and practice, preparing students for innovative roles in the blockchain industry.

In conclusion, the exploration of these platforms for micro-credential issuance demonstrates the importance of selecting the right blockchain based on specific requirements, such as security, scalability, cost, and ecosystem compatibility. These findings enrich the curriculum and provide students with actionable insights into the practical applications of blockchain, fostering a generation of professionals ready to drive blockchain innovation across industries.

REFERENCES

AMORES-SESAR, I., CACHIN, C., SCHNEIDER, P. 2024. An Analysis of Avalanche Consensus. arXiv preprint. *arXiv*:2401.02811. ISSN: 2331-8422. https://arxiv.org/abs/2401.02811

ANDROULAKI, E., BARGE, P., BORTNIKOV, V., MURTHY, C., CACHIN, C., CHANDRA, T., CHAUBEY, P., GETH, K., HENDRICKS, S., LAVENTMAN, G., MANEVICH, Y., YELLICK, J., SETHI, M., SHERER, T., SMITH, A., SORENSEN, B., STATHAKOPOULOS, M., VUKOLIC, M., WAGNER, D. 2018. Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains. In: *Proceedings of the Thirteenth EuroSys Conference*. Article 30- ISSN: 0163-5999. https://doi.org/10.1145/3190508.3190538

ANWAR, S., AZIZ, S., KHAN, M. A. 2020. Project-Based Learning in Blockchain Education: Improving Student Engagement and Technical Skills. *Journal of Emerging Technologies in Computing Systems*. 16(3), 57-65. ISSN: 1550-4832

AZARIA, A., EKBLAW, A., VIEIRA, T., LIPPMAN, A. 2016. MedRec: Using Blockchain for Medical Data Access and Permission Management. In: *2016 2nd International Conference on Open and Big Data (OBD)*. IEEE, pp. 25-30, ISSN: 2472-6988. https://doi.org/10.1109/OBD.2016.11

BROWN, R. G., CARLYLE, J., GRIGG, I., HEARN, M. 2016. Corda: An Introduction. arXiv preprint *arXiv*:1605.05834. ISSN: 2331-8422. https://arxiv.org/abs/1605.05834

GUDGEON, L., WERNER, S., PEREZ, D., KNOTTENBELT, W. 2020. DeFi Protocols: Risks, Collateral, and the Case for Governance. In: *Proceedings of the International Conference on Decentralized Applications and Infrastructures*. New York: Association for Computing Machinery, pp. 92–112.

KOUHIZADEH, M., SARKIS, J., ZHU, Q. 2019. At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion. *International Journal of Production Research*. 57(7), 2083-2091. ISSN: 0020-7543. https://doi.org/10.1080/00207543.2018.1542176

KSHETRI, N. 2018. Blockchain's Roles in Meeting Key Supply Chain Management Objectives. *International Journal of Information Management*. 39, 80-89. ISSN: 0268-4012. https://doi.org/10.1016/j.ijinfomgt.2017.12.005

MCCONAGHY, T., MARQUES, R., MÜLLER, A., DE JONGHE, D., MCCONAGHY, T. T., MCMULLEN, G., HENDERSON, R., BELLEMARE, S., GRANZOTTO, A. 2016. BigchainDB: A Scalable Blockchain Database. arXiv preprint, *arXiv*:1605.04984. ISSN: 2331-8422. https://arxiv.org/abs/1605.04984

MERBRET, C., THORP, R., DEVOS, K. 2020. Collaborative Blockchain-Based Learning Environments: Enhancing Engagement and Knowledge Sharing. *Education Technology Research and Development*. 68(4), 987–1002. ISSN: 1042-1629.

NAKAMOTO, S. 2008. *Bitcoin: A Peer-to-Peer Electronic Cash System*. https://bitcoin.org/bitcoin.pdf.

RANA, S. K., RANA, A. K., RANA, S. K., SHARMA, V., LILHORE, U. K., KHALAF, O. I., GALLETTA, A. 2022. Decentralized Model to Protect Digital Evidence via Smart Contracts using Layer 2 Polygon Blockchain. *IEEE Access*. 10, 1-12. ISSN: 2169-3536. https://doi.org/10.1109/ACCESS.2023.3302771

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AWARENESS OF AGILITY IN SLOVAK MANUFACTURING AND SERVICE ENTERPRISES

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ABSTRACT

The article deals with the awareness of agility in Slovak industrial and service companies, reflecting on the experience gained during the unpredictable changes caused by the coronacrisis. The aim is to identify the attitude to agility in enterprises as the ability to respond quickly to dynamic market conditions and to implement agile principles. The research was conducted through a questionnaire survey, examining activities undertaken to build agility, the ability of enterprises to be agile, perceptions of agile barriers, benefits of agility and the importance of enterprise agility. The results of the research present benefits for theory, science and practice. The findings offer new empirical insights from the Slovak industry and service sectors environment that can contribute to increasing the competitiveness and sustainability of enterprises.

Keywords: agility, awareness, attitude, Slovak enterprises, flexibility, competitive advantage, coronacrisis

JEL Code: L21, M10, D22

1 INTRODUCTION

Agility represents the ability of businesses to respond quickly and effectively to change, making it a key factor for their long-term success (Motwani, Katatria, 2024). In today's dynamic and unpredictable environment, where technological, economic or societal changes are constantly occurring, agility is of increasing importance for businesses. Businesses that can adapt quickly are better prepared to face challenges and exploit new opportunities, thereby gaining a competitive advantage (Yamin, 2024; Kiilu *et al.*, 2024). The benefits of agility are manifested not only in the rapid implementation of change, but also in better team collaboration, greater flexibility, and the ability to manage complex problems effectively (Tsilionis *et al.*, 2024; Motwani, Katatria, 2024). The coronacrisis that has hit the global

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economy has brought unprecedented challenges and has also accelerated the need for the adoption of agile approaches in business (Alkaabi *et al.*, 2024). Firms have been forced to respond promptly to changes, whether it was to migrate to digital platforms, reorganize work processes, or adapt to changing market conditions (Wang *et al.*, 2024; Fang *et al.*, 2024). Experience with the application of agility during this crisis has shown that companies that used agile management methods were able to react more flexibly, innovate faster and thus minimise the negative impacts of the crisis (Rofiaty *et al.*, 2022; Ludviga, Kalvina, 2024). These firms were not only able to manage the crisis period effectively, but also created a stronger foundation for adapting to future challenges (Twaissi, ALawad, 2023). Thus, the application of an agile approach has proven to be essential not only in times of crisis, but also as an enduring advantage for sustainable development and innovation.

Exploring agile awareness is a well-known issue in the world. Wendler (2014) states that despite the growing awareness of agile, the concept cannot be considered easily applicable in practice. As Kumar *et al.* (2016) state, agility offers, especially for SMEs, a revolution in the understanding of how a business can be taken to a new level by applying agile practices and methods. Authors Nassar and Khalil (2020) offer their own perspective on building agile awareness, which they consider as the ability of an organization to anticipate, act and recover from unpredictable changes through the implementation of flexible practices and lean management. In an industrial setting, the study by Padovitz *et al.* (2003) can be highlighted, who focused their efforts on raising agile awareness in the context of individual distribution systems. The group of authors Nguyen *et al.* (2020) used the so-called Awareness-Motivation-Capability (A-M-C) model to increase the possibility of applying agile concepts in the organization and increasing its awareness. In doing so, attention was directed by way of digitalization and its synergies in the transformation period, to new business models. Authors Palanisamy, Chelliah and Muthuveloo (2021) conducted research that was partly devoted to ascertaining the agility awareness of small and medium enterprises (SMEs) in the industrial sector. In their research, they revealed that building agile awareness in SMEs significantly contributes to improving organizational performance. Research by Al-Essawi (2023) demonstrated that the agile awareness present in a given organization directly influences the level with which agility is built.

In the conditions of the Slovak Republic, there are no studies yet that would address the issue of agility in terms of its awareness in the group of manufacturing and service enterprises. Absence of such research creates a research gap that needs to be filled.

The aim of the paper is to assess the awareness and attitude towards agility after the experience with the implementation of unplanned, rapid changes during the coronacrisis in industrial and service companies in the Slovak Republic.

The contribution of the article presents new empirical findings from the environment of Slovak manufacturing and service enterprises in the meaning and importance of agility, which is the basis for building agility in enterprises.

2 METHODOLOGY AND DATA

The methodological procedure of this research was divided into several parts that were logically organized. In the first part, an analysis of secondary sources was carried out and constituted the basis of the research in the field of agile awareness in Slovak manufacturing and service enterprises. In this part, mainly logical methods such as: analysis, synthesis, deduction, comparison, summarization, description and analogy were used. In the following section, we focused on primary data collection using a questionnaire survey. The aim of the survey was to find out how Slovak enterprises have coped with the changes caused by the COVID 19 pandemic, what their attitude towards agility is, how they perceive it and to what extent they are agile. The questionnaire survey was conducted using the Google questionnaires platform

between January 2024 and June 2024. Our respondents were managers or owners of firms in industries and selected service sectors: accommodation, catering and transport, which were most affected by the coronacrisis interventions. In total, there are 135,088 businesses in the industrial and service sectors (Finstat, 2024), from which we randomly distributed 5,327 questionnaires. The return rate of our questionnaire survey was 5,19 %. In total, the questionnaire contained 10 questions. The first part of the questionnaire focused on the identification of the research sample: size of the enterprise, ownership, line of business, industry, and ROE ratio. The second part of the questionnaire focused on questions regarding the awareness and understanding of agility in the enterprise: description of agility capability, steps implemented to improve agility, barriers and benefits of agility, importance of agility. The term agility was replaced in the questions by its description as the ability to react to unexpected changes, in order to avoid the risk of the concept not being recognised by company managers.

The data obtained from the questionnaire survey were evaluated using Microsoft Excel and Statistica 12. The present evaluation was preceded by the determination of the minimum size of the research sample. The following formula was used to determine it:

(1)

$$n \geq \frac{z^2 \cdot p \cdot (1-p)}{e^2}$$

Where:

- "n" represents the research sample size,
- "z" is the critical value of the normalized normal distribution for the chosen confidence level,
- "p" is the estimated population size, and
- "e" is the margin of error (Labudova *et al.*, 2021).

Our confidence level (z) was set at 90% and the margin of error (e) was set at 5%. In calculation with population size 135,088 entities, we found that representative sample size is 271 respondents. In total, 277 enterprises participated in our questionnaire survey, including 155 respondents from the manufacturing sector (55.95%) and 122 from the service sector (44.05%). According to data of the Finstat database (2024), the population size of manufacturing sector was 86,406 and of selected service sectors was 48,682. From calculation of representative sample size follows, that the size of both parts of the research sample is representative by 90% confidence level. The distribution of the sample also reflects the structure of the overall population.

The evaluation of the questions in the second part of the questionnaire survey was carried out by finding the relationships between the categorical variables. Our aim was to verify the existence of a relationship between the variables under investigation by means of Contingency Analysis using Pearson's chi-square test. The test statistic has the form (Labudova *et al.*, 2021):

(2)

$$x^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Where:

- "O_{ij}" is the observed abundance in the i-th row and j-th column of the contingency table,
- "Eij" is the expected abundance calculated based on the independence of the variables (Labudova *et al.*, 2021).

3 RESULTS

The return rate of the questionnaire was 5.22% of enterprises engaged in industries or certain service-providing sectors. The results of the basic identification of the research sample are shown in Table 1.

From Table 1 we see that most of the respondents are in the manufacturing sector with a majority percentage. In terms of number of employees, small and micro enterprises are predominant, with capital tied up mostly in the domestic environment (73.64%). The highest return on capital of 26.62% is achieved by companies at ROE of 2.0% to 3.99% and the second significantly highest of 22.30% at ROE of 4.0% to 6.99%. The identification of the research sample was supplemented with an open-ended question that inquired in which sector the company operates. In total, there were 10 different industries: automotive; wood; electrical; metallurgical; chemical; furniture; food; construction; engineering and textile and 4 service sectors: catering, hotels, restaurants and transportation. The highest percentage share was achieved by the catering industry with 22.30%, while the lowest percentage share was achieved by the metallurgical industry with 2.16%.

In the next section we look at the results of the contingency analysis. The contingency analysis was carried out between several questions of the second part of the survey, where results of each question are accompanied by a table, which is divided by sector (manufacturing, services) containing the p-level values.

Testing the relationship between a company's ability to respond to unexpected changes and crisis situations (Question 1) and the other questions 2–4 shows the results in Tables 2–4. The company's ability to respond to unexpected changes and crisis situations could be described through a choice of options – A. we are unable to react to changes in a timely manner; B. we are slow to take action and do not react to changes in a timely manner; C. we react with difficulty; D. we react quickly and effectively and change strategies and processes; E. we are at the forefront of anticipating and predicting market trends.

Table 2 shows the results of testing the dependency of agility capability with the steps companies take to improve their ability to be agile.

From Table 2, we can observe that within the tested contingency, we confirmed a strong dependence in only one case. These are manufacturing enterprises, where the low p-level value (0.001) indicates a significant dependence, in the sense that enterprises that cooperate with external experts in order to gain new perspectives are able to react quickly and effectively to unexpected changes and crisis situations, i.e. they are able to be agile.

Tab. 1 Basic identification of research sample

Questions	Answers					
Business activity subject	Manufacturing		Services		Trade	
	56.03 %		*43.96 %*		*0 %*	
Number of employees	0 - 9		10 - 49		50 - 249	250 +
	43.68 %		*29.96 %*		*16.25 %*	*10.11%*
Company ownership	Net domestic capital		Domestic capital prevail		Net foreign capital	Foreign capital prevail
	70.86 %		*15.47 %*		*6.47 %*	*7.19 %*
Return on Equity (ROE)	< 0 %	0.1% - 1.99%	2.0% - 3.99%	4.0% - 6.99%	7.0% - 9.99%	10% >
	6.12 %	*18.71 %*	*26.62 %*	*22.30 %*	*8.99 %*	*17.27 %*

Source: own research

Tab. 2 Contingency Analysis for: Dependence of steps taken towards building the ability to be agile

	Options (Question 2)	Industry	Services
A	regular monitoring of the market and competition	0.656	0.531
B	investments in research and development of new technologies and products	0.902	0.631
C	flexible workflows and processes	0.274	0.719
D	cooperation with external experts	0.001	0.164
E	continuous acquisition of knowledge regarding customer preferences, processes, work organization	0.236	0.169

Source: own research

Table 3 presents the results, which were devoted to testing the relationship between agility capability and the barriers that companies perceive in the enterprise's efforts to be agile.

In Table 3 we see that a significant dependence in both sectors for the same response was detected. We confirmed the dependence in the manufacturing sector, where the p-level value reached 0.001, and at the same time in the service sector, where the p-level value was at 0.012, where we can claim that companies that are able to be agile consider slow implementation of changes and processes as a barrier. In all other cases we did not confirm the dependency.

We also looked for a statistically significant relationship between agility and the benefits that respondents able to be agile see in their business. The results are shown in Table 4.

For Table 4, we observe that we could not detect a significant dependence between questions 1 and 4, neither for manufacturing nor for service firms.

The following contingency table (Table 5) shows the results between question 2 and question 5. For question 2, we asked what steps respondents are taking to improve their company's ability to be agile (A. regular monitoring of the market and competition; B. investing in research and development of new technologies and products; C. maintaining flexible work practices and processes; D. collaborating with external experts, E. continuously gaining knowledge regarding customer preferences, processes and work organisation). For question 5, we asked respondents how they would rate the importance of a business agility (A. very important – a key factor for success and survival; B. important – without it, the business would fall behind competitors and lose customers; C. moderately important – it is useful but not essential to the business's operations; D. not important – there is no value or benefit to the business). Where 'I' is industry and 'S' is services.

Tab. 3 Contingency Analysis for: Dependence of perception of agile barriers on the ability to be agile

	Options (Question 3)	Industry	Services
A	lack of funds for investments in technology and inovation	0.453	0.275
B	complex bureaucracy and regulatory environment	0.270	0.330
C	lack of qualified employees	0.511	0.984
D	competition that also seeks to respond quickly to chang-es and adapt	0.876	0.301
E	lack of top management commitment	0.104	0.120
F	slow implementation and process changes	0.001	0.012

Source: own research

Tab. 4 Contingency Analysis for: Dependence of benefits from being agile on the ability to be agile

	Options (Question 4)	Industry	Services
A	gaining a competitive advantage over other businesses	0.849	0.085
B	improving reputation, trust and customer satisfaction	0.978	0.890
C	greater probability of survival in the market in adverse conditions	0.611	0.353
D	more effective use of opportunities for growth and development	0.285	0.501
E	faster delivery of products tailored to changing customer needs	0.488	0.543

Source: own research

From Table 5 we observe the percentages of enterprises (manufacturing, services) by degree of agility importance. Agile is considered important or very important by 94% of manufacturing enterprises and by 54% of enterprises in the service sector for step A. For manufacturing enterprises as well as enterprises operating in the service sector implementing step B, agility is considered important or very important by 18% of enterprises. By Step C, the ability to be agile is considered important or very important by 56% of manufacturing enterprises and 46% of service enterprises. Agility is considered highly important for step D by 18% of manufacturing and 22% of service enterprises. By step E, agility is considered important or highly important by 43% of manufacturing and 50% of service enterprises. Furthermore, we can observe that manufacturing enterprises implement more than 2 activities to improve agility

Tab. 5 Contingency Table of: Dependence of importance of company's agility on the steps to improve ability to be agile

Options (Question 2)		Options (Question 5)									
		Very important		Important		Moderately important		Not important		SUM	
		I	S	I	S	I	S	I	S	I	S
A	regular monitoring of the market and competition	57%	23%	37%	31%	4%	4%	2%	2%	100%	60%
B	investments in research and development of new technologies and products	10%	8%	8%	10%	1%	0%	0%	1%	19%	19%
C	flexible workflows and processes	27%	22%	28%	24%	3%	1%	0%	1%	58%	48%
D	cooperation with external experts	11%	9%	7%	13%	0%	1%	1%	1%	19%	24%
E	continuous acquisition of knowledge regarding customer preferences, processes, work organization	31%	27%	12%	23%	2%	1%	0%	0%	45%	51%
SUM		136%	89%	92%	101%	10%	7%	3%	5%	241%	202%
											I - industry, S - services

Source: own research

(241%) and service enterprises 2 activities (202%). The enterprises that consider agility as important and very important are predominant in these activities and carry out activities A, C and E. Only 13% of manufacturing and 12% of service enterprises perform activities towards agility even they don´t consider the agility important.

4 DISCUSSION AND CONCLUSIONS

Agility is a dominant concept in contemporary business management that emphasises the ability of organisations to respond flexibly to dynamic change, anticipate market trends and adapt effectively to new challenges. The scientific purpose of the presented article is to evaluate the perception and awareness of agility after the experience of implementing unplanned, rapid changes during the coronacrisis in industrial and service enterprises in the Slovak Republic.

Based on the research conducted, we were able to uncover several important aspects about the awareness and application of agility. The analysis revealed that businesses assess the level of agility in their enterprise primarily as the ability to respond quickly and effectively to change by changing strategy and processes (41.29%), with the second largest proportion saying as the ability to be at the forefront of anticipating and predicting market trends (24.73%). This attitude corresponds with a global trend where agility is not just about reacting, but also about being proactive and strategically planning. It is evident that the coronacrisis has highlighted the importance of agility, which has motivated businesses to change faster and be more adaptive. The study in question is supported by the work of Wendler (2014) and further by the work of Nassar and Khalil (2020), who highlight the importance of building agile awareness through specific measures such as digitalization or the implementation of lean management. These aspects are significant for deeply embedding agility in individual processes and activities, allowing to increase its contribution to the enterprise. Furthermore, we find that manufacturing companies that collaborate with external experts in order to gain new perspectives react quickly and effectively to unexpected changes. A study by Barhmi (2022) confirms our findings, where the author concludes that agile supply chains that collaborate effectively with external partners perform better in volatile environments than those that lack such collaboration. The results of the relationships between agile barriers and the ability of firms to be agile showed that both manufacturing and service firms perceived the barrier of slow implementation of change and process change as significant. These results are complemented by a study by Koçyiğit and Akkaya (2020), which identified the positive impact of organizational flexibility on the agility of enterprises of different sizes. Other barriers, such as lack of finance or bureaucracy, did not show a significant relationship, suggesting that agile enterprises are able to overcome these barriers. The results highlight the need to focus on improving internal processes and change management as a key factor for increasing agility (Reed, 2021). Another important finding is the analysis of enterprises' actions to improve agility in relation to the assessment of the importance of agility as ability to respond to environmental changes in a timely manner. From the findings, we conclude that enterprises that consider agility important and very important implement the steps of regularly monitoring the market and competition, maintaining flexible work practices and processes, and continuously gaining knowledge regarding customer preferences, processes, and work organization. This coincides with the work of Adele (2021), who emphasises the importance of these steps as a means of achieving market leadership. In contrast, the steps of investing in research and development of new technologies and products and collaborating with external experts are implemented by the respondents to a very small extent compared to the others, even though they are considered important or very important by the companies. These findings are in direct contradiction to the findings of Sukharev (2019) and Grumbach (2023), who consider these steps to be key

to achieving long-term growth and competitiveness, which is considered crucial in their understanding. Continuous acquisition of knowledge about customer preferences and work organisation is also considered important, but a large proportion of surveyed companies do not pay enough attention to this step. Overall, the results suggest that although enterprises are aware of the importance of certain steps to increase agility, their implementation is not always systematic and often remains marginalised. This points to room for improvement, especially in areas related to innovation and collaboration. Agility is an essential pillar of contemporary business, enabling businesses not only to respond flexibly to dynamic market conditions but also to build competitive advantage in a systematic way. The implementation of agile principles can bring a number of benefits to businesses, including better use of resources, greater adaptability and the ability to anticipate market trends.

Furthermore, we were able to find out that the majority of Slovak enterprises, especially micro and small enterprises, perceive agility as a key success factor, with a significant percentage of respondents (41.29%) identifying the ability to react quickly and effectively to change as the most important agile capability. At the same time, 24.73% of respondents highlighted the importance of anticipating market trends as another important agile capability for their business. The results indicated that enterprises that collaborate with external experts achieve better performance and efficiency in responding to crisis situations. This result underscores the importance of gaining external perspectives in increasing the level of agility in an enterprise. Another interesting finding is the absence of a statistically significant relationship between economic indicators such as return on equity (ROE) and the implementation of agile actions, suggesting that the benefits of agility may not immediately translate into financial results. Rather, they point to its strategic value, which manifests itself in the long term through increased adaptability, competitive advantage and the ability of businesses to maintain stability even in times of turbulent change.

The direction of future research should be through a detailed examination of the impact of agile strategies on the long-term performance of businesses, including their financial and non-financial indicators. It would also be beneficial to analyse the extent to which cultural factors and organisational structure influence the successful implementation of agility.

The limitation of this paper is the limited size of the research sample, which may not represent all sectors of the Slovak economy, and the focus on short-term assessment of agility without a deeper examination of its long-term effects.

REFERENCES

ADELE, R. 2021. Analysis and evaluation of the company's competitive advantages. S*cience and Education Today*. (4 (63)), 46–49.

AL-ESSAWI, H. M. A. 2023. The Role of Strategic Awareness in Promoting Strategic Agility. American *Journal of Economics and Business Management*. 6(7), ISSN: 2576–5973

ALKAABI, S. M. Y. O., SOHAIMI, N. S. B., YATIBAN, A. B. 2024. The Effect of Technological Innovation and Knowledge Management Process on Organisational Agility: A Systematic Literature Review. *Engineering, Technology & Applied Science Research*. 14(4), 15121–15126.

BARHMI, A. 2022. Understanding the role of agility and responsiveness capabilities in achieving supply chain performance: The case of manufacturing companies. *International Journal of Managing Value and Supply Chains*. 13(3), 1–20. https://doi.org/10.5121/ijmvsc.2022.13301

FANG, M., KHATTER, A., CHOI, K. 2024. Leadership and Agility: What Can We Learn from Melbourne Quarantine Hotel During the COVID-19 Pandemic? In: *Case Based Research in Tourism, Travel, and Hospitality: Rethinking Theory and Practice*. Singapore: Springer Nature Singapore, pp. 15–35.

FINSTAT. 2024. Database of Slovak enterprises and organizations [Accessed: 2024-12-10]. https://finstat.sk/databaza-firiem-organizacii

GRUMBACH, L. 2023. *Flexible workflows-a constraint-and case-based approach*. Dissertation Thesis. Universität Trier

KIILU, P., MACHUKI, V., AOSA, E., NGAHU, C. 2024. strategic agility and performance of accredited universities in Kenya. *DBA Africa Management Review.* 14(1), 61–69.

KOÇYIĞIT, Y., AKKAYA, B. 2020. The role of organizational flexibility in organizational agility: A research on SMEs. *Business Management and Strategy*. 11(1), 110–123.

KOSASI, S., YULIANI, I. D.. A. E. 2017. Improving organizational agility of micro, small, and medium enterprises through digital marketing strategy. In: *2017 2nd International conferences on Information Technology, Information Systems and Electrical Engineering (ICITISEE)*. IEEE, pp. 68–72.

KUMAR, V., BABU, G., MUTHUSAMY, S. 2016. Assessing the awareness of agile manufacturing for organizational change in Indian small manufacturing firms: an empirical investigation. *Journal of Organizational Change Management*. 29(5), 713–731.

LABUDOVÁ, V., PACÁKOVÁ, V., SIPKOVÁ, Ľ., ŠOLTÉS, E., VOJTKOVÁ, M. 2021. *Statistical methods for economists and managers*. Bratislava: Wolters Kluwer. ISBN 978-80-571-0401-8

LUDVIGA, I., KALVINA, A. 2024. Organizational agility during crisis: do employees' perceptions of public sector organizations' strategic agility foster employees' work engagement and well-being?. *Employee Responsibilities and Rights Journal*. 36(2), 209–229.

MOTWANI, J., KATATRIA, A. 2024. organizational agility: a literature review and research agenda. International Journal of Productivity and Performance Management. 73(9), 2709-2754

NASSAR, E., EL-KHALIL, R. 2020. Assessing Agility Implementation in Manufacturing. In: *Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management*. Detroit, MI, USA, pp. 10–14.

NEUMANN, M., KUCHEL, T., DIEBOLD, P., SCHÖN, E. M. 2024. Agile Culture Clash: Unveiling Challenges in Cultivating an Agile Mindset in Organizations. *arXiv*. 2405.15066.

NGUYEN, D. K., BROEKHUIZEN, T., DONG, J. Q., VERHOEF, P. C. 2020. When it takes three to tango in the digital transformation age: Synergies between digital orientation, change commitment and organizational agility. In: *EventInternational Conference on Information Systems 2020: Making Digital Inclusive: Blending the Local and the Global – Online*. Association for Information Systems (AIS), Hyderabad, India, 13 Dec 2020 – 16 Dec 2020

PADOVITZ, A., ZASLAVSKY, A., LOKE, S. W. 2003. Awareness and agility for autonomic distributed systems: platform-independent and publish-subscribe event-based communication for mobile agents. In: *14th International Workshop on Database and Expert Systems Applications, 2003. Proceedings*. iEEE, pp. 669–673.

PALANISAMY, S., CHELLIAH, S., MUTHUVELOO, R. 2022. The influence of strategic agility on organizational performance during pandemic: a perspective of SMEs in manufacturing sector. In: *Tenth International Conference on Entrepreneurship and Business Management 2021 (ICEBM 2021)*. Atlantis Press, pp. 30–35.

REED, J. 2021. Strategic agility in the SME: Use it before you lose it. *Journal of Small Business Strategy (archive only)*. 31(3), 33–46.

ROFIATY, R., CHONG, D., NUSRON, A., YULIANTI, N. A., SUNARYO, S. 2022. Entrepreneurship orientation and performance of green economy SMEs during COVID-19 pandemic: The mediation of strategic agility. *Journal of Economics, Business, & Accountancy Ventura*. 25(1), 48–60.

SUKHAREV, O. S. 2019. Technological development: investment structure impact. *Economic and Social Changes: Facts, Trends, Forecast*. 12(2), 36–55.

TSILIONIS, K., ISHCHENKO, V., WAUTELET, Y., SIMONOFSKI, A. 2024. Scaling Agility in Large Software Development Projects: A Systematic Literature Review. In: *The International Research & Innovation Forum*. Springer, Cham, pp. 771–784.

TWAISSI, N., ALAWAD, A. 2023. Lessons learned from covid-19 pandemic and its impact on business continuity management BCM in the tourism sector in Jordan. *Uncertain Supply Chain Management*. 11(4), 1383–1396.

WANG, M., JIE, F., and FREDERICO, G.. F. 2024. Measuring supply chain agility during the COVID-19 pandemic: empirical evidence from the firms in the UAE. *International Journal of Agile Systems and Management*. 17(1), 1–14.

WENDLER, R. 2014. Development of the organizational agility maturity model. In: *2014 Federated conference on computer science and information systems*. iEEE, pp. 1197–1206.

YAMIN, M. A., ALMUTERI, S. D., BOGARI, K. J., ASHI, A. K. 2024. The Influence of Strategic Human Resource Management and Artificial Intelligence in Determining Supply Chain Agility and Supply Chain Resilience. *Sustainability*. 16(7), 2688.

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CONSUMER PROTECTION MECHANISMS IN EU REGULATORY SANDBOXES

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ABSTRACT

Regulatory sandboxes have emerged as pivotal tools in fostering innovation within the financial and technological sectors. This article explores the concept of regulatory sandboxes, focusing on their legal regulation under European Union (EU) law and the critical role of regulators in ensuring consumer protection. The EU's approach to regulatory sandboxes is characterized by a flexible yet robust framework that allows for the controlled testing of innovative products and services. This framework aims to balance the need for innovation with the imperative of safeguarding consumer interests. The article delves into the legal foundations of regulatory sandboxes within the EU, examining key legislative instruments and policy initiatives that support their implementation. It highlights the European Commission's efforts to harmonize the AI sandbox regulations across member states, promoting a cohesive and efficient regulatory environment. A significant focus is placed on consumer protection, detailing how regulators ought to implement safeguards to mitigate risks associated with new technologies. In conclusion, the article argues that regulatory sandboxes, when effectively regulated and supervised, can serve as powerful catalysts for innovation while maintaining high standards of consumer protection.

Keywords: regulatory sandbox, consumer protection, FinTech, innovation, artificial intelligence, EU law, regulators

JEL Code: K2, G280

1 INTRODUCTION

The rapid advancement of financial technologies (FinTech) presents a significant challenge for regulators who must balance the promotion of innovation with the need to ensure safety and protect consumer rights. The imminent risks of decisions taken without human intervention are already known and clear including misuse of the clients' collected data, surveillance capabilities potentially infringing on privacy rights, AI automation bias and discrimination especially when credit scoring, manipulative targeted financial products, limited recourse and accountability issues. Regulatory sandboxes have emerged as a potential solution to this dilemma. A regulatory sandbox is a framework that allows businesses to test innovative

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products, services, or business models in a controlled environment under the supervision of a regulatory authority. This setup provides a structured context for experimentation, enabling companies to operate with some regulatory flexibility while ensuring consumer protection and compliance with essential regulations. Regulatory sandboxes were initially developed to promote innovation in the financial services sector. However, they are now beginning to appear in other fields, including energy market regulation, data protection, healthcare, and last but not least the AI regulation. Common goals of regulatory sandboxes are to enable innovation and to ensure safety through legal certainty, law enforcement, and regulatory flexibility. To achieve these objectives, regulatory sandboxes are typically endowed with legal authority to offer legal guidance, issue no-enforcement letters, and/or grant exemptions from certain legal regulations. (Buocza *et al.*, 2023) By leveraging their authority to provide legal guidance, the competent supervisory authority and the innovator can collaboratively determine whether the product or service in question adheres to current legal standards. If it falls short, they can work together to outline a design that meets all legal requirements. The regulator may also commit themselves to refrain from enforcement of generally applicable rules. This means that while the rules still apply, the regulator agrees not to enforce them for a specified period or under certain conditions. They may also provide exemptions from existing legal rules which in this case do not apply to the innovator. Consumer protection is achieved through this process by ensuring that new products and services are closely monitored and guided to comply with existing legal standards and safeguards. If exemptions are granted, strict conditions are imposed on the innovator to mitigate consumer risks. This approach minimizes risks to consumers while fostering innovation. However not all jurisdictions empower the regulators to do so. The aim of this article is to explore the safeguards and measures implemented to protect consumers during the testing of innovative products and services in regulatory sandboxes. Furthermore, the statutory rules that empower the regulators are studied.

2 LITERATURE REVIEW

"Using digital technologies such as artificial intelligence, blockchain and big data analytics, FinTech start-ups develop, test and deliver a wide range of innovative financial services (FS) like digital payment solutions, securing them new opportunities and disrupting the course of traditional banking." (Alaassar *et al.*, 2023, p. 1) However, at the same time FinTech start-ups encounter significant developmental challenges due to the substantial costs associated with compliance and a deficiency in regulatory expertise. In response, regulatory authorities worldwide have actively sought appropriate regulatory solutions, including the implementation of regulatory sandboxes, to stimulate innovation, enhance market competition, and ensure financial market stability. One of the first, in 2016, the UK's Financial Conduct Authority (FCA) established a regulatory sandbox to achieve these objectives. (Alaassar *et al.*, 2023, Brown and Piroska, 2022) Regulatory sandboxes are legal frameworks that enable limited testing of innovations under regulatory supervision. (Council of the EU, 2020) They represent a novel approach to overseeing the activities of financial market participants, with the oversight being carried out by regulatory agencies as they "provide a "safe space" for FinTech firms to offer real products to real customers with the benefit of a waiver, or a significant relaxation, of otherwise applicable regulations, while getting guidance and supervision from the regulators." (Raudla *et al.*, 2024, p. 613) The sandboxes are to be designed also to ensure consumer protection. "Regulatory sandboxes include consumer protection measures, and allow NCAs to terminate the testing if a firm fails to comply with the agreed testing plan or testing parameters."

Regulators that have established a regulatory sandbox typically possess the legal authority to provide guidance, issue no-enforcement letters, and grant exemptions from specific legal

regulations to the entrepreneurs who have successfully entered their sandbox. (Buocza *et al.*, 2023) Currently, there is no uniform approach to FinTech regulations or a standardized framework for regulatory sandboxes at the EU level, with the EU's efforts based on a comparative analysis of Member States' legislation. (Hesekova Bojmirova, 2021) However, there needs to be a legal basis in the law on which regulators can create a sandbox. Thus, "regulation should be guided by financial regulatory agencies' statutory mandates, which are typically drawn from the following menu: financial stability, consumer or investor protection, efficiency, competition, and the prevention of financial crime." (Allen, 2024, p. 1)

There is presently no regulatory sandbox or similar FinTech hub operated by the Czech financial regulator. Although the Czech National Bank generally adopts a liberal stance towards innovative financial services, it remains cautious about regulatory easing for specific market participants, such as FinTechs, compared to traditional financial service providers. (Handrlica *et al.*, 2023) Thus, the regulatory sandbox established by the National Bank of Slovakia, which oversees the Slovak financial market, can be used to illustrate the activities and domains that regulatory sandboxes generally cover. "From the point of view of the factual definition of the innovation hub in the conditions of the Slovak Republic, these are mainly the following business models: alternative payment methods, crowdfunding, automated advice, crypto-assets and ICOs, Insurtech, and algorithmic trading. The innovation hub was subsequently supplemented with new technological areas, including smart contracts, biometric authentication, big data a machine learning, blockchain, mobile wallet with NFC, cloud computing." (Hesekova Bojmirova, 2021, p. 405)

The sandboxes used to test new technologies have not yet been governed by a unified EU legal framework as mentioned above. However, this may change with the new EU AI legislation introducing the AI sandboxes. Updating regulations and ending regulatory uncertainty would make the jurisdiction a more attractive destination for technology developers and investors. (Truby *et al.*, 2022) AI is often used in the FinTech sector. The new AI legislation, the EU's AI Act[1], foresees the creation of regulatory sandboxes specifically for AI. These controlled environments will allow developers to test innovative AI technologies under the supervision of regulatory authorities, ensuring compliance with safety and ethical standards while fostering innovation. AI sandbox regulation, like AI regulation in general, should aim for uniformity since the use and effect of the AI technology would ultimately extend beyond each individual Member State. (Truby *et al.*, 2022)

Regulators can use the regulatory sandboxes to support the growth and development of the FinTech market in a safe manner that does not pose risks or cause negative effects for the financial system and consumers. However, the ESAs find that regulators perceive reputational and legal risks as the key risks of operating innovation facilitators. (European Supervisory Authorities, 2023) Reputational risks refer to the potential damage to a regulator's reputation if an innovation facilitator is associated with any negative outcomes, such as financial misconduct or failure of a FinTech company. Legal risks involve the possibility of legal challenges or liabilities arising from the activities of the innovation facilitators or the companies they support. Additionally, a robust consumer protection may be another challenge for the regulator. A crucial issue is the question of liability for damage caused to consumers during the implementation of these new technologies. Competing sandboxes treat the issue of liability in different ways, and some are silent on the matter. Generally, sandboxes only exclude businesses from enforcement action by the financial regulator and not from consumer liability. National laws on liability usually still apply. (Truby *et al.*, 2022) The most recent rules for AI regulatory sandboxes, which could serve as a source of inspiration, are similar in nature and do not introduce significant new elements in this respect. The EU views such a sandbox as

[1] Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence and amending various regulations and directives (Artificial Intelligence Act), Official Journal of the European Union, L 1689, 12 July 2024.

a pre-market deployment phase, but it does not exempt sandbox participants from AI liability. However, Article 58(1) of the AI Act stipulates that to prevent fragmentation across the Union, the Commission will adopt implementing acts detailing the establishment, development, implementation, operation, and supervision of AI regulatory sandboxes, including the terms and conditions for participants. This means that liability issues still may be addressed once these implementing acts are issued.

Regardless of whether the rules are harmonized, national regulators must ensure consumer protection by implementing safeguards to mitigate risks associated with new technologies. Thus, regulatory sandboxes designed to be a facilitator of innovations, bring together a number of benefits and challenges (European Supervisory Authorities, 2023).

3 METHODOLOGY

This study utilizes a comprehensive legal analysis to investigate the regulatory frameworks surrounding regulatory sandboxes and the benefits and challenges that follow from them. The approach includes a thorough examination of relevant legislation, case law, and regulatory guidelines from the perspective of EU law and Czech law. A comparative legal analysis is conducted to pinpoint similarities and differences in regulatory strategies. Additionally, doctrinal research is employed to interpret and evaluate existing legal provisions. This comprehensive methodology ensures a deep understanding of the legal environment and its impact on the implementation and efficacy of regulatory sandboxes.

4 RESULTS

A regulatory sandbox is according to the European Supervisory Authorities "a scheme to enable firms to test, pursuant to a specific testing plan agreed and monitored by a dedicated function of the competent authority, innovative financial products, financial services or business models. Sandboxes may also imply the use of legally provided discretions by the relevant supervisor (with use depending on the relevant applicable EU and national law), but sandboxes do not entail the disapplication of regulatory requirements that must be applied as a result of EU law." (European Supervisory Authorities, 2023) Regulatory sandboxes follow four phases: application, preparation, testing and exit/evaluation. During the application phase the regulators assess firms' admission to regulatory sandboxes. The preparedness, innovativeness of products and potential benefits for consumers are usually tested. The preparation phase in some regulatory sandboxes may be combined with the application phase. When it is present it is used to establish a suitable test scenario that is approved by the regulator and KPIs identification. Throughout the testing phase the admitted entrepreneurs can test innovative activities in "live environment" while regulators provide them with guidance or legal and regulatory advice. Regulators often form ad hoc teams of internal experts to support sandbox participants. They sometimes participate as a remote observer in the most significant tests. Tests may be terminated by the regulator in the case of a breach of the testing parameters or if it is necessary to mitigate consumer detriment. The last phase is dedicated to drafting an exit report by the regulator. The possible outcome may also lead to proposed changes in legislation or regulatory mechanisms. Moreover, the evaluation might result in improved cooperation with other authorities, such as data protection office, consumer protection authorities or competition authorities.

4.1 Innovative products tested in FinTech and technology-driven regulatory sandboxes

Regulatory sandboxes are used to test a variety of innovative products in both financial and technological sectors. In the realm of financial innovations, blockchain solutions are developed for secure and transparent transactions, including digital currencies and smart contracts. Biometric services, such as fingerprint, facial, and voice recognition, are introduced for secure banking transactions. Additionally, automated financial advice platforms, or robo-advisors, provide personalized financial advice using algorithms and AI.

In terms of technology innovations, AI-driven products like chatbots for customer service and AI-based fraud detection systems are tested. Digital identity solutions are created to securely verify and manage digital identities for online transactions and services. Open banking initiatives use APIs to enable third-party developers to build applications and services around financial institutions. These innovations are crucial for advancing the capabilities and security of financial and technological services.

4.2 Role of the regulator in regulatory sandboxes

As follows from the above description of the regulatory sandboxes phases, the role of the regulator in regulatory sandboxes encompasses several key responsibilities. First, they are involved in framework design and implementation, setting the rules, criteria, and processes for participation. They also supervise and monitor the sandbox to ensure compliance with established rules and protect consumers. Additionally, regulators provide guidance and support to help firms understand regulatory requirements and navigate the testing process. They evaluate outcomes and provide feedback to refine products or services. Insights gained from sandbox testing are used for policy development, helping to develop or adjust regulations. Lastly, regulators implement safeguards to protect consumers participating in sandbox tests.

4.3 Consumer protection

Regulatory sandboxes usually incorporate specific measures to protect consumers. Participants must provide a comprehensive exit plan detailing how consumers will be treated upon exit, along with clear communication about the nature of the test and its implications for consumers. Compensation or redress mechanisms are often considered for any detriment experienced during testing. Regulators may also restrict testing to investors with a higher risk tolerance and non-retail clients. Additional safeguards include meticulous monitoring of each test phase and its outcomes.

For instance, consumers and participants must sign a ‘single information document’ to acknowledge their understanding of the nature and risks of the tests, including the liability guarantee regime, the withdrawal process, the handling of their personal data, and the confidentiality of the information obtained, along with provisions on industrial and intellectual property rights or trade secrets. Participants may also need to specify in their testing plan the target client group, primary risks, mitigation measures, and post-exit actions.

4.4 EU Commission’s and ESAs’ guidelines for creation of regulatory sandboxes

Existing regulatory sandboxes are typically limited to specific policy areas (e.g., financial services, energy, digital technologies) and are usually implemented locally for better control. A key challenge is scaling up results from the sandbox to the wider market. EU Commission

in its policy analysis in impact assessments and evaluations provides a general guidance[2] on setting up regulatory sandboxes when establishing and operating regulatory sandboxes is available. Furthermore, the guiding principles for the establishment and operation of innovation facilitators set out by the ESAs in Annex B of the joint ESAs report of 2019 may be applied. (European Supervisory Authorities, 2019) However, the responsibility and details of the regulation sandboxes stay with the national regulators.

The European Commission's AI Sandbox Initiative is a regulatory framework designed to facilitate the development, testing, and validation of innovative AI systems within a controlled environment. It is not a single sandbox run by EU institutions but rather a policy that encourages the establishment of multiple sandboxes across EU Member States.

4.5 Regulators' powers to create and operate regulatory sandboxes

National regulators utilize diverse frameworks to establish regulatory sandboxes. Several scenarios are possible for establishing regulatory sandboxes. In some instances, new legislation aimed at the digital transformation of the financial system has empowered regulators to create sandboxes. In other countries, a ministerial decree serves as the legal foundation for sandbox creation. Alternatively, some regulators have independently developed the legal framework and procedures to establish and manage sandboxes. Furthermore, regulatory sandboxes may be designed so that they do not grant any waivers to participants, eliminating the need for specific mandates or special external regulations. However, this approach may significantly diminish their attractiveness and undermine their fundamental purpose.

Regulators typically find the legal basis to create regulatory sandboxes in their respective statutory mandates, which typically include financial stability, consumer or investor protection, efficiency, competition, and the prevention of financial crime. However, this might be rather difficult in the Czech legislative framework. As mentioned above there is currently no FinTech regulatory sandbox in the Czech Republic. The Czech national bank is not planning to create a sandbox an instead of it decided to establish a new specialised communication channel to receive FinTech-related enquiries from all financial market participants called the FinTech contact point. Still, the development of the Czech FinTech sandbox is part of the digital pillar of the National Recovery and Resilience Plan, which is focused on digital technologies and aims at creating sandboxes in regulated sectors in line with EU priorities (Ministerstvo průmyslu a obchodu České republiky, 2021).

4.6 Regulatory sandboxes in the AI Act – regulatory requirements andrelevant authorities' empowerments

The new AI Act classifies the AI systems according to the risk they may cause. Some are prohibited, the other including high risk systems as described in Art. 6 and Annex III[3] are to be deployed only under strict conditions. Meeting these conditions may be tested by a regulatory sandbox. The AI Act envisions the establishment of a regulatory sandbox in every Member State (or joining a sandbox in another Member State), which could serve as an inspiration for the development of FinTech sandboxes. According to Art. 3 (par. 55) of the AI Act an 'AI regulatory sandbox' means a controlled framework set up by a competent authority which offers

[2] 4 See 'TOOL #69. Emerging methods and policy instruments', pages 599–604. https://commission.europa.eu/document/download/0d32ee11-92da-434d-9c86-fd4579d95dc6_en?filename=BRT-2023- Chapter%208- Methodologies%20for%20analysing%20impacts%20in%20IAs%20evaluations%20and%20fitness%20checks_0.pdf

[3] Most specifically in the financial services field those will include AI systems intended to be used to evaluate the creditworthiness of natural persons or establish their credit score, with the exception of AI systems used for the purpose of detecting financial fraud; and AI systems intended to be used for risk assessment and pricing in relation to natural persons in the case of life and health insurance.

providers or prospective providers of AI systems the possibility to develop, train, validate and test, where appropriate in real-world conditions, an innovative AI system, pursuant to a sandbox plan for a limited time under regulatory supervision. According to Art. 57 of the AI Act Member States shall ensure that their competent authorities establish at least one AI regulatory sandbox at national level, which shall be operational by 2 August 2026. That sandbox may also be established jointly with the competent authorities of other Member States. The Commission may provide technical support, advice and tools for the establishment and operation of AI regulatory sandboxes. The obligation under the first subparagraph may also be fulfilled by participating in an existing sandbox in so far as that participation provides an equivalent level of national coverage for the participating Member States.

As to the actual operation of the sandbox, the AI Act requirements are rather scarce. Article 14 of the AI Act seems to be the most crucial provision as it requires human oversight to mitigate risks of high-risk AI systems. It is understood that human oversight should occur not only during the verification of individual decisions but also throughout the design and training phases. Palmiotto (2024) classifies the human oversight as ex-ante (making sure the AI is programmed correctly) and ex-post (reviewing AI suggestions before implementing them and also the appealed decisions). Thus, the sandbox should ensure efficient oversight of the AI system. According to Art. 14 par. (2) the human oversight shall aim to prevent or minimise the risks to health, safety or fundamental rights that may emerge when a high-risk AI system is used in accordance with its intended purpose or under conditions of reasonably foreseeable misuse. The oversight measures shall be commensurate with the risks, level of autonomy and context of use of the high-risk AI system, and shall be ensured through either one or both of the following types of measures: (a) measures identified and built, when technically feasible, into the high-risk AI system by the provider before it is placed on the market or put into service; (b) measures identified by the provider before placing the high-risk AI system on the market or putting it into service and that are appropriate to be implemented by the deployer. According to Art. 14 (4)(b) of the AI Act persons supervising high-risk systems must be able to recognize the risk of automation bias. AI providers are obliged to deliver their systems to the deployers so that the natural person exercising the human oversight is enabled to stay aware of the possible tendency of automatically relying or over-relying on the output provided by an AI system (automation bias). The automation bias is a psychological phenomenon explaining the human tendency to overly and unjustifiably trust the suggestions of am automated system. The AI Act focus on the provider is a consequence of the European approach to product safety law and its focus on providers. (Laux and Ruschemeier, 2025) Still with regard to the use of AI in discretionary decision-making, the AI Act does not explicitly regulate or prohibit such applications.

Secondly, Art. 86 of the AI Act grants right to explanation of individual decision-making to persons who may be affected by decisions reached on the basis of the output from a high--risk AI system which produces legal effects or similarly significantly affects that person in a way that they consider having an adverse impact on their health, safety or fundamental rights. The deployer is obliged to provide clear and meaningful explanations of the role of the AI system in the decision-making procedure and the main elements of the decision taken. Therefore, the sandbox should also test the quality explanations provided in such situations when creditworthiness of the client be tested or similar.

The AI Act is enacted in the form of a regulation. Regulations, as stipulated by Art. 288 par. 2 of the Treaty on the Functioning of the EU (TFEU), are legal acts of general application that are binding in their entirety and directly applicable in all member states. While it may appear that EU regulations function as 'European law' requiring no additional implementation into national laws, this assumption is not universally applicable. (Whelanova, 2019) To ensure absolute uniformity of rules and their application across all member states, regulations cannot be transcribed into national legislation, according to established case law of the CJEU. However, subsequent case law has confirmed the necessity of adopting additional

implementing measures at the national level in connection with regulations, thus allowing such national legislation. This is since not all regulations are always formulated in such a way that they can produce the intended effects on their own, without further implementation in national law. This may be encountered in cases when national agencies are to make sure the regulation is applied. Their powers must stem from statutory laws, and they are not created by an EU piece of legislation. Thus, a statutory law empowering the agency (selected by the national legislator) must be adopted when a public authority is to be responsible for creation of a regulatory sandbox according to the AI Act in the Czech Republic. According to the Overview of all AI Act National Implementation Plans4 published in November 2024 there are three types of authorities in Member States which should be prepared to take action under the AI Act (a) a 'market surveillance authority', (b) a 'notifying authority' will be the national authority responsible for establishing and performing the procedure for assessment, designation and notification of conformity assessment bodies and for their monitoring, and (c) national public authorities that enforce the respect for fundamental rights obligation in Member States in relation to High-risk AI systems referred to in Annex III. Spain has established a Spanish Artificial Intelligence Supervisory Agency (AESIA) acting as a single market surveillance authority under the Spanish Department of Digital Transformation. In contrast, Finland has proposed a decentralized model appointing 10 already existing market surveillance authorities, including the Energy Authority, The Transport and Communications Agency, and the Medicines Agency. For the Czech Republic it is currently unclear which authorities shall be responsible.5 However, a 'Digital Regulatory Sandbox' under its National Recovery Plan. Ministry of Industry and Trade initiated the project and oversees it, while CzechInvest is the agency responsible for launching and coordinating the sandbox. At the same time Ministry of Finance provides input on regulatory design and financial supervision to ensure alignment with fintech sector needs.

4.7 Lithuania as a case study

While the Czech Republic is in the early stages of developing its regulatory sandbox framework, Lithuania established its FinTech sandbox already in 2018. Thus, the Czech Republic can benefit from insights into effective regulatory practices. While there isn't a specific standalone law dedicated solely to the sandbox, it operates under the broader regulatory and supervisory framework of the Bank of Lithuania. This framework includes various regulations and guidelines that ensure the sandbox functions effectively while maintaining financial stability and consumer protection.

According to Raudla et. al (2024) there were two companies that "The most tangible benefit arising from the regulatory sandbox for the Lithuanian regulators so far has been the ability to draw up guidelines for companies that want to offer P2P insurance. P2P insurance is an insurance mechanism that works without a financial intermediary like an insurance company; instead, people insure each other, mutually." When this new business model emerged, there was no legal basis for it. Testing the model in the sandbox allowed the regulators to delve into it and analyse whether a separate law or regulation was needed or whether some lower-level act offering guidance would suffice (Raudla, 2024).

The regulatory sandbox in Lithuania, established by the Bank of Lithuania, provides a controlled environment for financial market participants to test innovative financial products and services. The sandbox is open to both potential and existing financial market participants who wish to test financial innovations that are new to the Lithuanian market. The innovations must demonstrate clear consumer benefits, such as more convenient, safer,

4 Available at https://artificialintelligenceact.eu/national-implementation-plans/

5 AI Regulatory Sandbox Approaches: EU Member State Overview was published on May 5, 2025 at https://artificialintelligenceact.eu/ai-regulatory-sandbox-approaches-eu-member-state-overview/

and cheaper financial services. Participants can test their innovations in a live environment under the guidance and supervision of the Bank of Lithuania. This controlled setting allows for real-world testing while mitigating potential risks to consumers. The sandbox includes specific measures to protect consumers. Participants must provide a comprehensive exit plan detailing how consumers will be treated upon exit, along with clear communication about the nature of the test and its implications for consumers. Compensation or redress mechanisms are often considered for any detriment experienced during testing. The Bank of Lithuania requires participants to carry out an adaptability assessment, prepare a testing plan with clear objectives, testing conditions, and risk analysis, and allocate sufficient resources. This thorough preparation helps ensure that the testing is conducted safely and effectively. The Bank of Lithuania provides ongoing regulatory guidance to participants, helping them navigate compliance challenges and refine their business models. This support is crucial for ensuring that innovations meet regulatory standards and contribute to the sustainable development of the financial market. By incorporating these elements, the Lithuanian regulatory sandbox aims to balance the need for innovation with the imperative of safeguarding consumer interests. This approach helps foster a reliable financial system and supports sustainable economic growth.

5 DISCUSSION AND CONCLUSIONS

A regulatory sandbox should be a safe space for both innovation and regulation. Although there are FinTech sandboxes in neighbouring states such as in Slovakia or Poland, the Czech National Bank decided to establish instead of a sandbox a new specialised communication channel to receive FinTech-related enquiries from all financial market participants called the FinTech contact point. Establishing a sandbox may be rather difficult under existing Czech legislation. Under the Act No. 6/1993 Coll., on the Czech National Bank, Sec. 2, Par. 1 the role of the Czech National Bank is defined as '... ensuring price stability. The Czech National Bank also takes care of financial stability and the safe functioning of the financial system in the Czech Republic. If this does not affect its primary objective, the Czech National Bank supports the general economic policy of the government aimed at sustainable economic growth and the general economic policies in the European Union with the intention of contributing to the achievement of the European Union's objectives.' Although according to Sec. 1 Par. 3 of the same Act "The Czech National Bank is entrusted with the competencies of an administrative authority to the extent specified by this law and other legal regulations", it would be difficult to create a sandbox, and empowerment would have to be found in every single piece of legislation governing the area of the FinTech new product.

Still, the AI Act foresees the creation of regulatory sandboxes for the providers of AI systems. The National Recovery and Resilience Plan, which is focused on digital technologies also aims at creating sandboxes. Although, the EU regulations should not be duplicated in national statutory laws, the CJEU case law leaves space to national legislators to create laws empowering their national agencies, regulators, or other administrative authorities to apply the common EU rules. Therefore, *de lege ferenda* a set of rules empowering the regulators in a form of new statutory law should be adopted making it at least feasible for the regulators to create the sandboxes. The current practice shows that they may contribute significantly to the development of innovations. The consumer protection (together with the liability of the sandbox participants) which is one of the key factors in drafting the principles and conditions of establishing of the sandbox, is currently left to the regulators. Still, this leaves them with enough room to deal with the issue in the most proper way adhering to the principles of civil law applicable in the respective jurisdiction.

Although, there is a risk of forum shopping (choice of a sandbox that will allow to be entered with the least requirements), till there is an EU common approach adopted, this has to be left to the national regulators. The AI Act does not limit the liability of enterprises participating in regulatory sandboxes; they remain fully liable under applicable EU and national laws for any damage caused during their experimentation.

Given the inherent tension between fostering innovation and ensuring safety and consumer protection, regulatory sandboxes may offer a viable solution. Key features of a regulatory sandbox include real-world testing with consumers, regulatory oversight for safety and compliance, temporary exemptions to foster innovation, and guidance from regulators to refine products or services. The purpose of a sandbox is not to deregulate. Therefore, even within a controlled environment, appropriate safeguards must be in place to maintain policy objectives and comply with legal requirements.

Consumer protection remains a critical focus within regulatory sandboxes. Participants are required to provide clear exit plans and transparent communication about the nature and implications of tests. Compensation mechanisms and regular monitoring are essential to ensure consumer safety. Furthermore, participants must acknowledge the risks and safeguards associated with the tests through comprehensive documentation. The AI Act adds specifically the necessity of human oversight of high-risk systems. It requires informing about recognition of possible automation bias and grants right to explanation of individual decision-making. Those further specific requirements for AI safety and risk mitigation should be implemented by regulatory sandboxes as well.

In conclusion, while regulatory sandboxes are a valuable tool for fostering innovation, they must be carefully managed to balance the benefits of innovation with the need for consumer protection and market stability. Ongoing coordination and refinement of these frameworks are essential to maximize their effectiveness and minimize potential risks. De lege ferenda, these should be the rules that should be in mind of the legislator empowering every single public authority that would be allowed to create a regulatory sandbox under Czech law.

REFERENCES

ALAASSAR, A., MENTION, A., and AAS, T. H. 2021. Exploring a new incubation model for FinTechs: Regulatory sandboxes. *Technovation*. 103, 102237. https://doi.org/10.1016/j.technovation.2021.102237

ALLEN, H. J. 2024. Regulating fintech: A harm focused approach. *Computer Law & Security Review*. 52, 105910. https://doi.org/10.1016/j.clsr.2023.105910

BROWN, E., PIROSKA, D. 2022 Governing Fintech and Fintech as Governance: The Regulatory Sandbox, Riskwashing, and Disruptive Social Classification. *New Political Economy*. 27(1), 19–32. https://doi.org/ 10.1080/13563467.2021.1910645

BUOCZA, T., PFOTENHAUERB, S., EISENBERGERC, I. 2023. Regulatory sandboxes in the AI Act: reconciling innovation and safety? *Law, innovation and technology*. 15(2), 357–389. https://doi.org/10.1080/17579961.2023.2245678

COUNCIL OF THE EU. 2020. *Conclusions on Regulatory sandboxes and experimentation clauses as tools for an innovation-friendly, future-proof and resilient regulatory framework that masters disruptive challenges in the digital age, OJ C447/1*. https://data.consilium.europa.eu/doc/document/ST-13026-2020-INIT/en/pdf

EUROPEAN SUPERVISORY AUTHORITIES (EBA, EIOPA, ESMA). 2019. *Fintech: Regulatory Sandboxes and Innovation Hubs*. https://www.esma.europa.eu/sites/default/files/library/jc_2018_74_joint_report_on_regulatory_sandboxes_and_innovation_hubs.pdf

EUROPEAN SUPERVISORY AUTHORITIES (EBA, EIOPA, ESMA). 2023. *Joint Report on Innovation Facilitators: Regulatory Sandboxes and Innovation Hubs*. December 2023. https://www.eiopa.europa.eu/publications/joint-esas-report-innovation-facilitators-innovation-hubs-and-regulatory-sandboxes_en

GAUDEUL, A. *et al*. 2024. Understanding the Impact of Human Oversight on Discriminatory Outcomes in AI-Supported Decision-Making. *ECAI 2024.* 392, 1067–1074. https://doi.org/10.3233/FAIA240598

HANDRLICA, J., SHARP, V., NEŠPOR J. 2023. Forum shopping in regulatory sandboxes and the perils of experimental law-making. *Juridical Tribune*. 13(3), 408–425. https://doi.org/10.24818/TBJ/2023/13/3.05

HESEKOVA BOJMIROVA, S. 2021. FinTech and Regulatory Sandbox – New Challenges for the Financial Market. *Juridical Tribune*. 12(3), 85–100.

KOVAC M. 2022. Autonomous Artificial Intelligence and Uncontemplated Hazards: Towards the Optimal Regulatory Framework. *European Journal of Risk Regulation*. 13(1), 94–113. https://doi:10.1017/err.2021.28

LAUX, J., RUSCHEMEIER, H. 2025. Automation Bias in the AI Act: On the Legal Implications of Attempting to De-Bias Human Oversight of AI. *arXiv*. 2502.10036. https://doi:10.48550/arXiv.2502.10036

MINISTERSTVO PRŮMYSLU A OBCHODU ČESKÉ REPUBLIKY. 2021. *Národní plán obnovy České republiky*. https://www.planobnovycr.cz/

PALMIOTTO, F. 2024. When Is a Decision Automated? A Taxonomy for a Fundamental Rights Analysis. *German Law Journal*. 25, 210–236. https://doi.org/10.1017/glj.2023.112.

RAUDLA, R., JUUSE, E., KUOKŠTIS, V., CEPILOVS, A., CIPINYS, V., YLÖNEN, M. 2024. To sandbox or not to sandbox? Diverging strategies of regulatory responses to FinTech. *Regulation & Governance*. 18(4), 612–635. https://doi.org/10.1111/rego.12630

RAUDLA, R., JUUSE, E., KUOKSTIS, V. *et al*. 2024. Regulatory sandboxes and innovation hubs for FinTech: experiences of the Baltic states. *Eur J Law Econ.* https://doi.org/10.1007/s10657-024-09830-y

TRUBY, J., BROWN, R. D., IBRAHIM, I. A., CAUDEVILLA PARELLADA, O. 2022. A Sandbox Approach to Regulating High-Risk Artificial Intelligence Applications. *European Journal of Risk Regulation*. 13(2), 270–294. https://doi.org/10.1017/err.2021.52

WHELANOVÁ, M. 2019. Implementace přímo použitelných nařízení Evropské unie do českého právního řádu. *Správní právo*. 52(6), 62–89.

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PROGRESS OF INDUSTRIAL REVOLUTIONS – REALITY CHECK FOR BOSNIA AND HERZEGOVINA

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ABSTRACT

This study examines the level of digitalization in Bosnia and Herzegovina through a survey of 140 companies from various sectors and sizes. Bosnia and Herzegovina, like other countries in the Western Balkans, is classified as a developing country. These Western Balkan countries offer significant nearshoring opportunities due to lower labor costs compared to the EU. To capitalize on these opportunities, digitization, automation of industry, and green transition are among the priority tasks. Supported by EU investments, Western Balkan countries are investing in infrastructure and production, improving development, raising living standards, and adapting production processes to Industry 4.0 standards. However, the survey shows that technology adoption is mostly a continuation of Industry 3.0, with limited integration of advanced analytics and data connectivity. While a significant number of companies possess modern machinery, indicating production capabilities, the adoption of robotics and Industry 4.0 technologies remains concerningly low. Despite their awareness of advanced industrial technologies and significant usage of ERP software, companies lack serious intentions to digitize, suggesting a need for further investigation into the factors hindering this transition.

Keywords: Digitalization, Automatization, Industry, Bosnia

JEL Code: L06, L01

1 INTRODUCTION

The COVID-19 pandemic and geopolitical tensions have disrupted global supply chains, leading to expectations that companies may relocate production facilities closer to their home markets. This process is known as “nearshoring”, which refers to the relocation of business processes, production, or services to a nearby location, closer to the company‘s headquarters or primary market. For example, a company might move its operations from a distant location such as China to Bosnia and Herzegovina due to shorter distribution

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and supply chains. Similarly, an Asian company might invest in Montenegro to be closer to its partners in Europe. This strategy is becoming increasingly important as companies seek to reduce risk and dependency by shortening supply and distribution chains. The Western Balkans (WB) is an excellent location due to its proximity to European markets, relatively low wages, and availability of skilled labor. However, to be competitive, WB countries need to improve the regulatory framework, offer financial incentives to businesses, and reduce red tape to attract investment. Investment in infrastructure and technology is crucial for the region's long-term competitiveness, as digitalization is one of the key enablers to comply with EU regulations and needs. In this study, we wanted to examine the level of digitalization and Industry 4.0 principles in the industrial environment of Bosnia and Herzegovina from the perspective of companies.

2 INDUSTRY 4.0

The goal of Industry 4.0 is to enhance the production environment by enabling self-awareness, self-learning, autonomous decision-making, self-execution, and adaptability in manufacturing processes(Lu, 2021).

2.1 Industry 4.0 in developed countries

Industry 4.0 paradigm is progressing significantly in Europe and globally. Europe, particularly Germany and Italy, has led with national strategies that focus on smart factories and digitalization. Globally, developed countries are ahead, while developing nations are catching up. At its core, Industry 4.0 (German: Industrie 4.0) refers to the strategic initiative by Germany aimed at positioning the country as a leading market and provider of advanced manufacturing solutions (Reinheimer, 2015). Almost simultaneously with the German initiative, the USA also launched recommendations contained in a strategic plan geared to stimulate the next generation of manufacture, designated Advanced Manufacturing Partnership (Liao *et al.*, 2017). Other examples of governments that launched such initiatives are: Australia: "Modern Manufacturing Strategy" (Department of Industry, Science, Energy & Resources, 2020), South Korea: "Manufacturing Innovation 3.0 Strategic Action Programme" (Hee-Cheol *et al.*, 2018), India: "SAMARTH Udyog Bharat 4.0" (Ministry of HI & PE, Government of India, 2020), Japan: "Revitalization Strategy Reform 2015" (Government of Japan, 2014), China: "Made-in-China 2025" (Jost *et al.*, 2016), Singapore: "Research, Innovation and Enterprise 2020 Plan" (Dervishi *et al.*, 2022), Brasil: "Plano de CT\&I para Manufatura Avançada no Brasil – ProFuturo" (Ministério da Ciência, 2020), Russia: "Digital Economy 2024" (Vinokurov, 2021), and South Africa: "Manufacturing Indaba", 2018 (Siyenza Management, 2023). Many other similar initiatives that tend to embrace the same principles and technologies are already started all over the world and can be found in works (Teixeira & Tavares-Lehman, 2022; Majstorovic & Mitrovic, 2019).

2.2 Industry 4.0 in developing countries

While developed countries are investing heavily in Industry 4.0 and paying special attention to digital transformation, developing countries are still struggling due to specific political, social, economic, and infrastructural issues. The distinction between developed and developing countries is primarily determined by their respective levels of economic advancement and the quality of life. One of the most used indicators is Gross Domestic Product (GDP), which is often employed as an indicator of economic health and growth. The growth of GDP is beneficial for industrial development, as it is often associated with increased manufacturing output, economic stability, and improved resource allocation. However, GDP does not

fully encompass all dimensions of development, such as income distribution and environmental sustainability. One of the regions still in the developing phase, according to GDP, is the Western Balkans, including Bosnia and Herzegovina (GDP: 19860), Serbia (GDP: 24511), Montenegro(27776), Albania (GDP: 18060), Kosovo (GDP: 13547), and North Macedonia (GDP: 23424) (Trading Economics, 2023). These countries have similar GDP levels, and accordingly, we can infer a similar stage of industrial development and the application of Industry 4.0 technologies.

The Balkans are an integral part of Europe, a geostrategic priority for the European Union, and a relevant market for products and services. They are therefore all committed to implementing fundamental reforms for economic development and integration. Digitalization is one of the primary objectives for WB countries on their journey to joining the EU, encompassing the integration of advanced technologies in production, healthcare, banking systems, education, and other sectors. Several countries have already established official state digitalization strategies. Additionally, various non-profit and non-governmental organizations aim to develop a robust, globally competitive digital economy within their nations. On the other hand, the European Union, along with individual EU member states, significantly contributes to the advancement of digitalization by providing funding and expertise to facilitate more rapid and effective digital transformation. For example, in June 2023, the Digital Europe Program was opened to all Western Balkan countries (European Commission, 2024), except Bosnia and Herzegovina, which joined in May 2024 (EC B&H, 2024). This initiative also contributes to the implementation of the Economic and Investment Plan (EIP) for the Western Balkans, underpinning the digital transition of the region through the EU4Digital program—an accelerated digital transition for the Western Balkans (EC EU4Dig, 2024). Additionally, the European Bank for Reconstruction and Development (EBRD) and the European Investment Bank (EIB) are providing significant funding to the Western Balkan countries for digitalization (EBRD, 2022) (EBRD, 2023).

2.2.1 Why is progress so slow?

Even though there is significant effort from government and non-government sectors as well as from the EU and its members, the progress is still slow according to the recently published reports (Rupp *et al.*, 2023), (Petar, 2023), (Bajic *et al.*, 2024), (ACIT Centre & EPIK Institute, 2022), (Dervishi *et al.*, 2022). One of the top reasons for such slow progress is technical knowledge. Digital literacy in the Western Balkans, including public administration (Dervishi *et al.*, 2022), lags behind the EU due to lower education levels and structural issues, with additional concerns about data privacy, security, and reliability contributing to a lack of trust in digital services (Bajic *et al.*, 2024), (Rupp *et al.*, 2023). Inadequate technical infrastructure in the Western Balkans, especially in rural areas (Petar, 2023), limits digital transformation efforts, development, and global value chain integration (OECD, 2021), while also increasing susceptibility to cyber threats (Bajic *et al.*, 2024). Also, businesses in the Western Balkans have low adoption of advanced digital technologies and limited integration of emerging technologies, with the lack of e-payment systems being a significant barrier that requires regulatory adoption and trust-building measures. The government sector in the Western Balkans faces challenges in improving online services, enhancing digital solutions, ensuring data security, aligning with legislation principles (Rupp *et al.*, 2023), and addressing legal and regulatory gaps to maximize EU investments in digital transformation (Bajic *et al.*, 2024).

3 METHODOLOGY

According to independent external reports (see Section 3), the adoption of Industry 4.0 technology is progressing slowly due to various factors. This study aims to assess the current state of awareness and implementation of advanced technologies and concepts within industrial environments. Specifically, it investigates the extent of awareness, the perceived benefits, and the barriers to greater engagement with these technologies. To address these questions, we conducted interviews with approximately 140 companies in Bosnia and Herzegovina. The companies interviewed varied in industry sectors and sizes. The study utilized four sets of questions: one focusing on company information (4 questions), then a set of questions for status of machinery (4 questions), another on the digitalization process (11 questions), and a third on the automation process (9 questions). The questionnaires were shared over email, via social networks, or by private visits.

4 RESULTS

In this chapter, we present the results of our research through a series of detailed charts and graphs. These visual representations provide an overview of the data collected, highlighting key trends and anomalies. Each chart is accompanied by an analysis to explain the underlying findings and their implications. The results are organized thematically to provide a clear and logical flow.

4.1 About Companies

- Q1: What type of industry does your company operate in?
- Q2: What is the size of the company in terms of the number of employees?

The interviewed companies span various industries (Figure 1a), with metal and wood being the most dominant (30% and 14%, respectively). Regarding the number of employees, most companies are small-sized, with only 5% having more than 350 employees.

- Q3: What is the size of your company in terms of the year's revenue?
- Q4: Who are the owners of the company?

Figure 2 shows revenue distribution where 27% of companies generate between €10 million and €25 million annually, while 10% exceeds 25 million. Smaller companies with revenues below €500,000 make up 16%. Ownership-wise, 71% of companies are privately owned by domestic entities, and 19% are under private foreign ownership, reflecting significant international investment and diverse market practices.

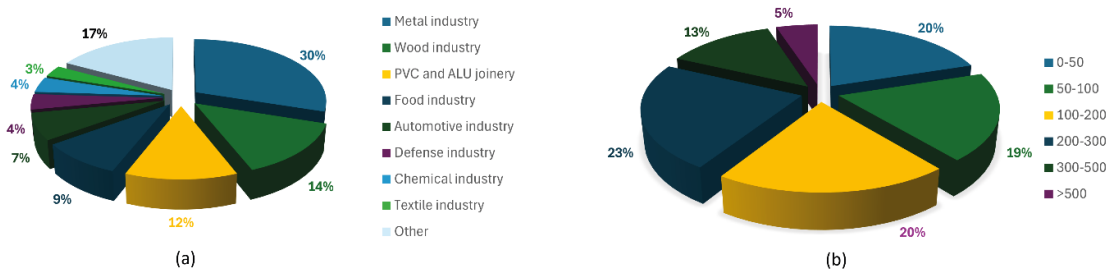

Fig. 1: (a) Distribution of Companies by Industry Sectors
(b) Distribution of companies by number of Em-ployees.

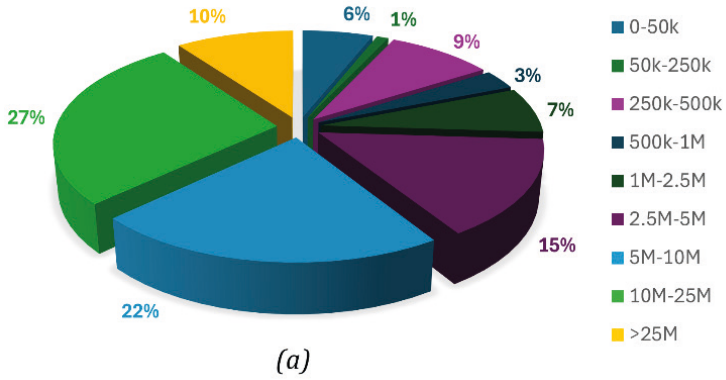

Fig. 2: Distribution of companies by yearly revenues in Euro [€]

4.2 Machines and Robots

The integration of robots and automated machinery has revolutionized production processes, enhancing efficiency and precision. Companies are increasingly implementing robotics and automation to stay competitive and drive innovation.

- Q5: What is the size of your company in terms of the number of machines?
- Q6: What is the average age of machines?

The distribution of companies by the number of machines shows that 48% operate with 20 to 75 machines, indicating moderate mechanization, while 20% have fewer than 10 machines and 9% have over 100, highlighting varying levels of technological adoption shown in Figure 3a. The average age distribution of machinery (Figure 3b) reveals that over half of the fleet is more than a decade old, with 27% over 15 years and 26% within the 10–15 year range, though 17% of the machinery is relatively new, aged between 2–5 years and 7.5–10 years, indicating recent investments in newer equipment.

- Q7: Do you have any robots or cobots implemented?
- Q8: How many robots or cobots do you have?

Survey results show that 28% of companies have implemented robots or cobots, while 72% have not yet adopted such technologies, indicating the early stages of automation for many companies. The distribution of robots among companies is shown in Figure 4 reveals that most companies have only a few.

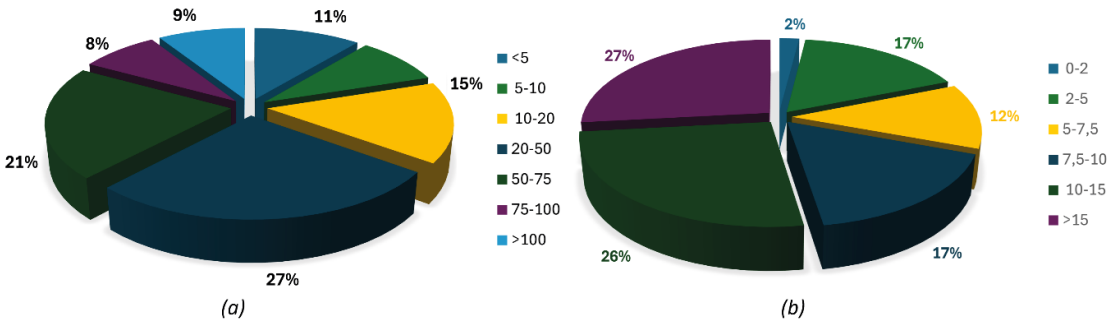

Fig. 3: Distribution of questioned companies by: (a) number of implemented machines (b) average age of machinery.

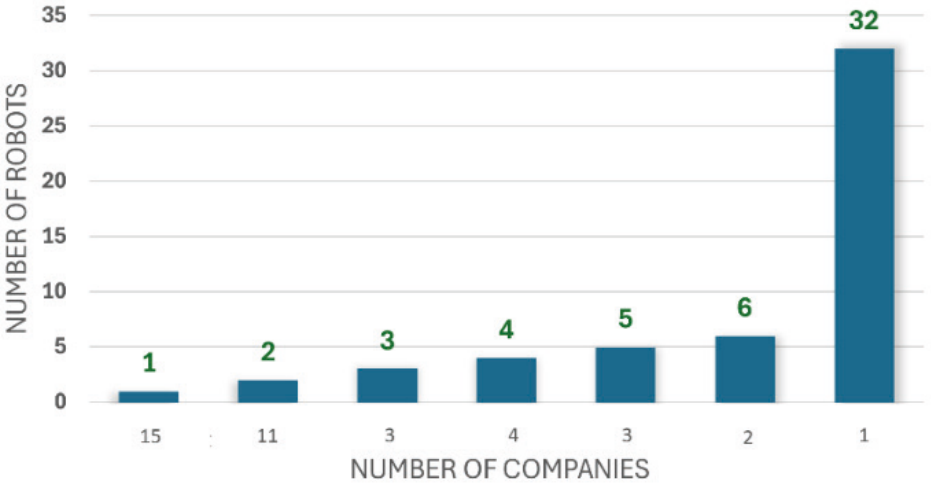

Fig. 4: Distribution of questioned companies by the number of implemented robots

4.3 Digitization

One of the first steps in the process of digitalization and its maintenance is to have people who will take care of your current IT infrastructure and develop it further.

- Q9: Does your company have an internal IT department, or does it use the services of other companies for its IT needs?
- Q10: From which organizational level are digital/IT processes managed in your company?

Many companies use a hybrid approach for IT services, combining internal and third-party expertise (43%), while others rely solely on third-party providers (29%), maintain in-house IT operations (24%), or operate without any IT support (4%). Most companies manage IT processes at the director level (39%) or through the head of IT (28%), but 10% have no designated IT responsibility, posing potential risks. The results are shown in Figure 5.

- Q11: How would you best describe the current level of digitalization in your company?
- Q12: To what extent has your company's management placed digitalization on the list of strategic priorities?

According to the companies questioned, 80% of them claim that they have a medium or high level of digitalization, indicating ongoing or completed digital transformations, while 20% have low digitalization, highlighting growth potential (Figure 6a). A significant portion of companies prioritize digitalization at multiple levels, with 30% prioritizing it and 3% not prioritizing it at all, suggesting varying stages of digital transformation.

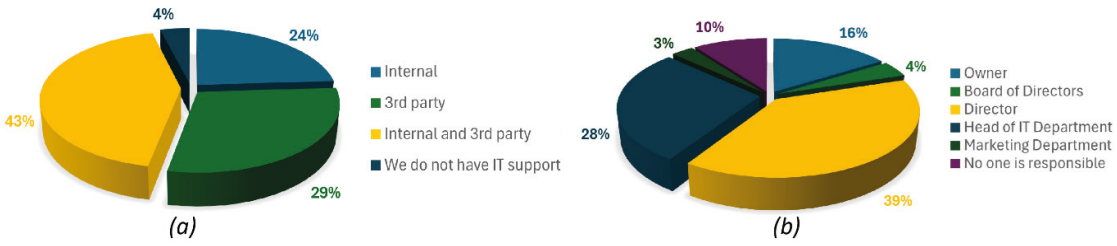

Fig. 5: (a) Distribution of IT Support Strategies Among Companies
(b) Organizational Levels Managing Digital/IT Processes.

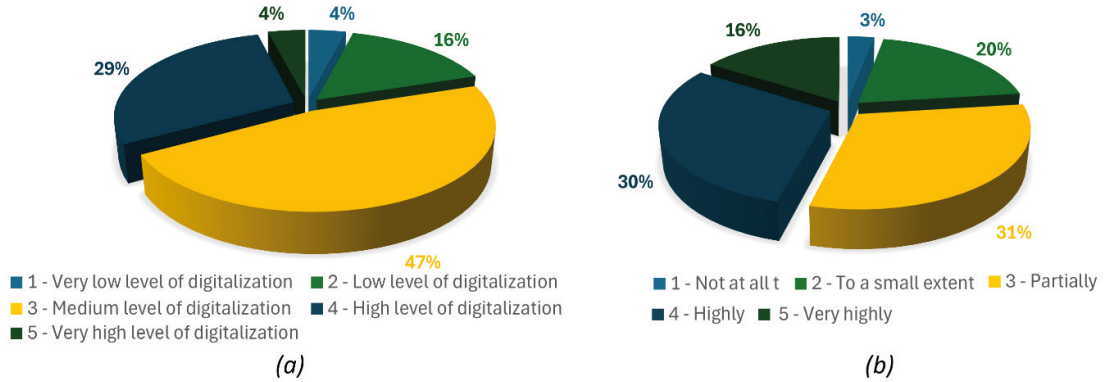

Fig. 6: (a) Current Level of Digitalization in Companies as They See It
(b) Management's Strategic Prioritization of Digitalization.

- Q13: How do you confirm completion in production?
- Q14: Which Enterprise Software Solutions have you implemented and what are the future plans?
- Q15: Which of the Industry 4.0 technologies have you implemented in your business?

The results in Figure 7a show that 31% of companies use mobile phones or tablets and 40% still rely on paper to confirm production completion. This indicates that there is still the possibility for improvement. Positively in Figure 7b, Enterprise Resource Planning (ERP) systems are widely adopted by 82% of companies, with manufacturing execution systems (MES) and computerized maintenance management systems (CMMS) also having significant adoption rates at 44% and 48%, respectively. A similar survey in 2022 with companies from a similar market showed significant growth (see Figure 8a) in enterprise system adoption by 2024. The most notable increases were in Enterprise Resource Planning (ERP) systems, which rose from 50% to 82%, and Computerized Maintenance Management Systems (CMMS), which increased from 17% to 48%. These results suggest companies are increasingly investing in enterprise systems to enhance efficiency and competitiveness.

The current adoption of Industry 4.0 technologies shown in Figure 8b among businesses reveals a mixed landscape. A significant 42% of companies prioritize cybersecurity, while 37% embrace the Internet of Things. However, 27% have yet to implement any Industry 4.0 technology. On a positive note, 21% plan to adopt these technologies, indicating growing awareness. Additionally, 18% are exploring 3D printing and big data, while AI adoption remains low at 8%, and digital twins at 2%.

Fig. 7: (a) Distribution of production confirmation
(b) Acceptance and Future Plans for Enterprise Software Solu-tions

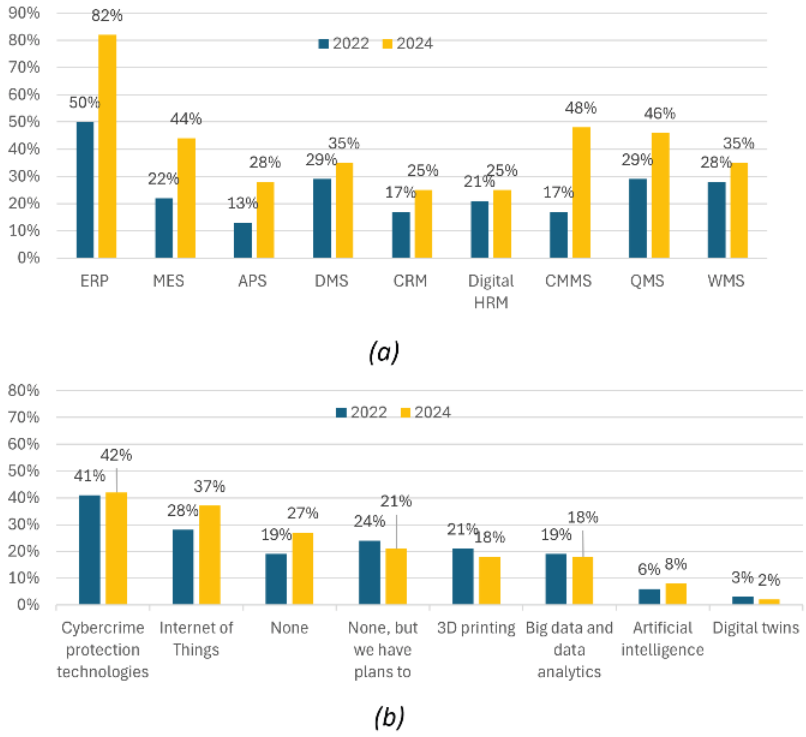

Fig. 8: Comparison between 2022 and 2024:
(a) Enterprise software solutions usage
(b) Technology Implemented

Overall, while some businesses lead the way, many still have untapped potential, suggesting a promising future for advanced technology integration. Between 2022 and 2024, the adoption of various technologies showed mixed trends. Cybercrime protection technologies saw a slight increase from 41% to 42%, and the Internet of Things (IoT) rose from 28% to 37%. However, the percentage of companies not adopting any technologies increased from 19% to 27%. Plans to adopt technologies decreased from 24% to 21%. Adoption of 3D printing and big data analytics remained stable at 18%, while artificial intelligence increased from 6% to 8%, and digital twins decreased from 3% to 2%. These trends highlight evolving priorities and challenges in technology adoption.

Figure 8b shows changes in technological adoption between 2022 and 2024. The results indicate a growing focus on security and IoT, with slight increases in cybercrime protection (41% to 42%) and IoT adoption (28% to 37%). However, more companies are not adopting any technologies (19% to 27%), possibly due to resource constraints. Established technologies like 3D printing and big data analytics remain stable at 18%, while AI adoption is slowly increasing (6% to 8%). These trends highlight evolving priorities and challenges in technology adoption.

- Q16: In your opinion, what are the biggest obstacles to increasing the level of digitalization in your company?
- Q17: What effects has your company experienced from adopting digital technologies/ digitalization?

Figure 9a reveals the main barriers to digitalization in companies. A significant 53% struggle with a lack of expertise and training, while 49% face cultural resistance to change. High implementation costs, affecting 47%, remain a critical hurdle. Overcoming these obstacles is crucial for companies aiming to advance their digital transformation. Digital technologies

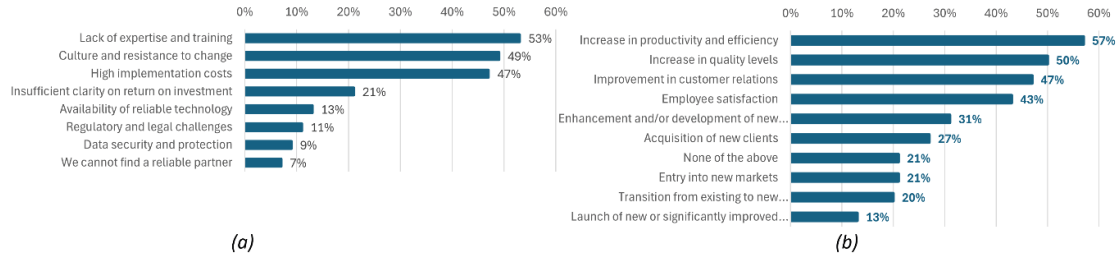

Fig. 9: (a) Key obstacles for digitalization in companies
(b) Effects to the company after adopting digital technologies/digitalization

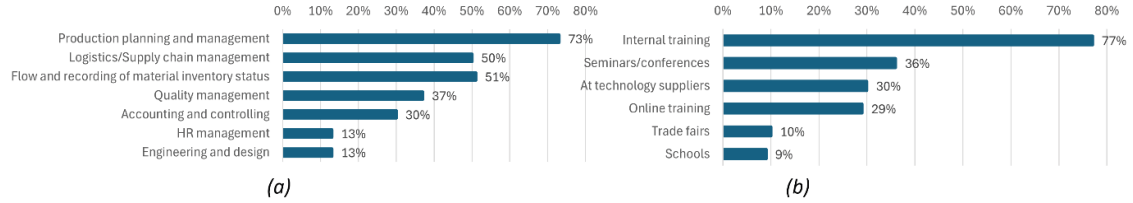

Fig. 10: (a) Business segment that will be enchanted by digitalization
(b) Distribution of Training Locations for Employees.

have revolutionized companies, with 57% reporting increased productivity and efficiency. Nearly half have seen improvements in quality and customer relations, while employee satisfaction has risen due to better workflows and remote work options.

Despite these successes, 21% of companies haven‘t experienced these benefits, likely due to implementation challenges. Overall, as seen in Figure 9b, digitalization is driving positive changes, though some hurdles remain.

- Q18: Which business segment, in your opinion, will become the most efficient because of digitalization?
- Q19: Where do you conduct training for your employees regarding digitalization?

Digitalization has significantly benefited various business segments. Production Planning and Management leads with 73%, thanks to automation, real-time data, and system integration. Logistics/Supply Chain Management (50%) and Inventory Status (51%) also see improvements in tracking and forecasting as shown in Figure **10**a.

As the lack of knowledge presents one of the main obstacles to successful digitalization, we asked companies about their approach to worker training. Figure **10**b shows a strong preference for internal training, with 77% of companies developing their employees‘ digitalization skills in-house.

- Q20: Does your company have a developed digital strategy (with clearly defined activities, goals, and roles)?

In the future, we can expect even more companies to adopt and refine their digital strategies, driving innovation and efficiency in various industries. Nearly half of the companies (46%) have a clearly developed digital strategy, while 45% plan to develop one. Only 9% of companies neither have nor plan to create a digital strategy. This indicates a strong trend towards digital transformation, with most companies recognizing its importance for future growth and competitiveness.

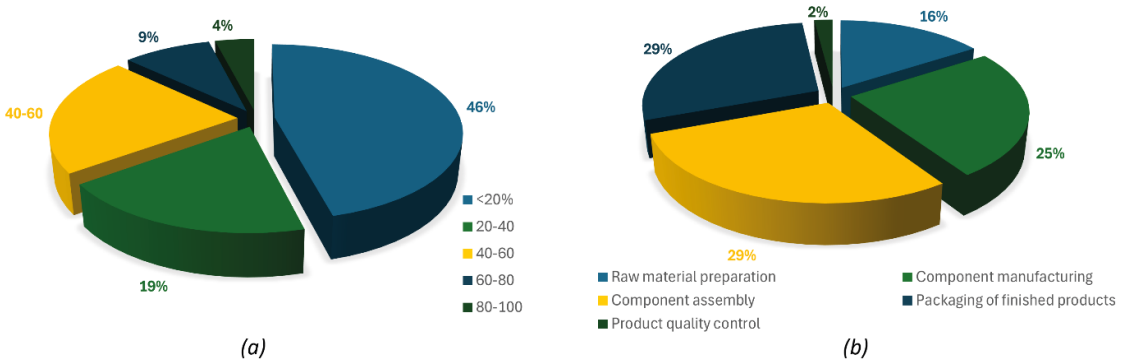

Fig. 11: (a) Levels of Automation in Production Processes
(b) Distribution of manual work in the companies

4.4 Automatization

Automation represents a fundamental aspect of the Third Industrial Revolution, a phase that should now, theoretically, be regarded as part of our historical development. However, our analysis indicates that Bosnia has yet to fully integrate essential elements of this revolution, particularly the automation of processes. Consequently, this study aims to ascertain the extent to which production processes are automated within the companies surveyed through the following questions:

- Q21: How much of your production processes are automated?
- Q22: Which part of the production process relies most on manual labor in your company?

Figure 11a shows that 46% of surveyed companies in Bosnia have less than 20% of their processes automated, while only 4% have high levels of automation (80% – 100%). These findings underscore the significant gap in automation adoption, with many companies still heavily reliant on manual labor in key production areas as shown in Figure 11b. Component assembly and packaging are the most labor-intensive areas, each at 29%, followed by component manufacturing at 25%.

- Q23: How satisfied are you with the current level of automation in your company?
- Q24: Have you considered introducing any form of automation in production?
- Q25: What are the main reasons you are considering introducing automation?

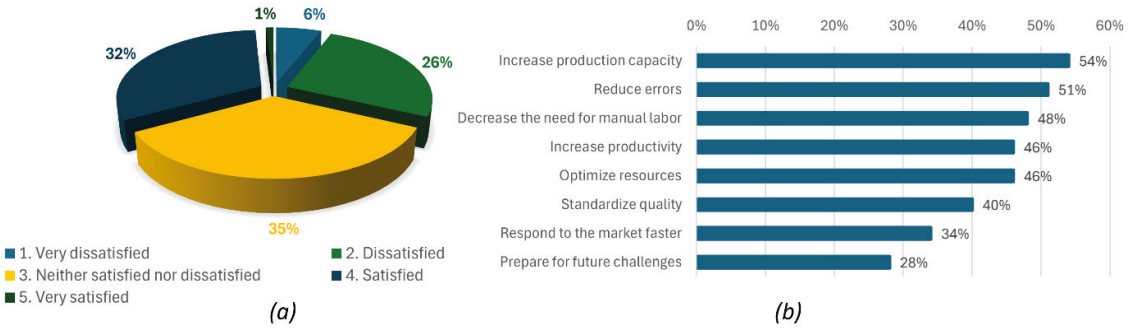

Fig. 12: (a) Satisfaction levels regarding the current state of automation
(b) Main Reasons for Considering Automation

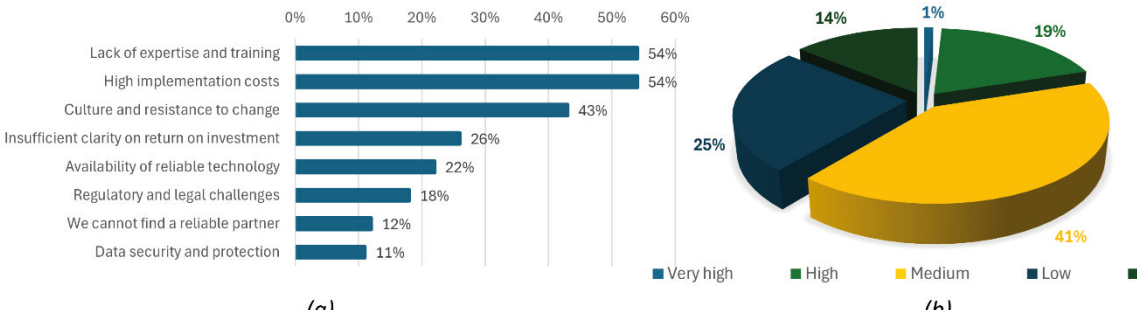

Fig. 13: (a) Main obstacles to not fully automating industrial processes
(b) Employee Knowledge and Skills in Automation Technologies

The survey results in Figure 12a show that 32% of respondents are satisfied with their current level of automation, while 26% are dissatisfied, and 6% are very dissatisfied. These findings highlight a significant trend towards automation, with 74% of respondents considering its introduction. Key motivations include increasing production capacity (54%), reducing errors (51%), and decreasing manual labor (48%), as shown in Figure 12b.

- Q26: What obstacles do you see as the most important in the process of introducing automation?
- Q27: How do you rate the current level of knowledge and skills of your employees regarding automation technologies?

Figure 13a shows that the main obstacles to introducing automation are a lack of expertise and training (54%), high implementation costs (54%), and cultural resistance to change (43%). Figure 13b indicates that only 1% of employees have very high expertise in automation, while 19% have high-level skills. The largest group, 41%, has medium-level knowledge, but 25% have only basic understanding, and 14% have very limited knowledge. These findings highlight the need for strategic investment in training and technology to overcome obstacles and enhance workforce proficiency in automation.

- Q28: Which of the following 4.0 automation technologies have you implemented in your business?
- Q29: To what extent does your company's management prioritize automation on the strategic agenda?

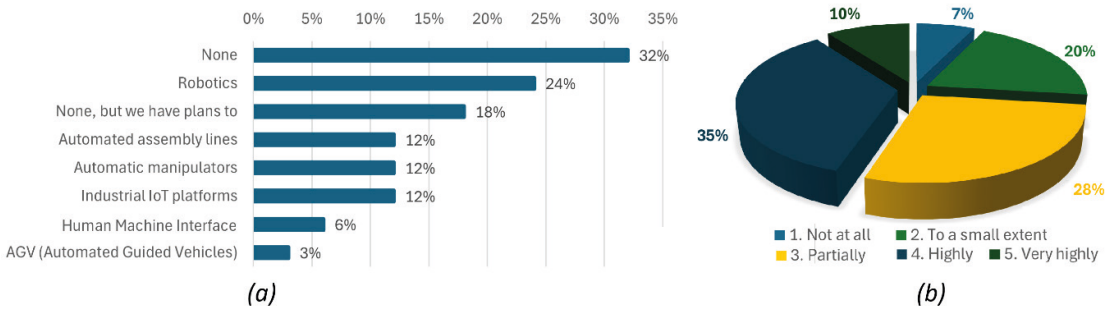

Fig. 14: (a) Adoption of 4.0 Automation Technologies Among Businesses
(b) Management Prioritization of Automa-tion on the Strategic Agenda

The Figure 14a shows varied adoption of 4.0 automation technologies among businesses. A significant portion, 32%, have not implemented any automation technologies, while 24% have integrated robotics, and 18% plan to implement automation technologies. The survey also reveals varying degrees of prioritization of automation by company management. The largest group, 35%, indicates a high level of prioritization, and 10% report very high prioritization.

5 CONCLUSION

Western Balkan countries, including Bosnia and Herzegovina, are strategically positioned to supply Europe with essential products and mitigate future supply chain disruptions, as experienced during the COVID-19 pandemic. However, to be competitive, these countries need to improve their industrial processes and advance digitalization efforts. The survey revealed that while a significant number of companies possess modern machinery, indicating production capabilities, the adoption of robotics and Industry 4.0 technologies remains concerningly low. Only 28% of companies use robots, and the number of robots per company is minimal. The utilization of robots and advanced technologies could significantly enhance production efficiency and quality, and advanced analytics could further boost productivity. Surprisingly, cybersecurity measures are implemented in 40% of surveyed companies, whereas data analytics are used by only 18%. This suggests that the current industry level aligns more with the Industry 3.0 concept rather than Industry 4.0, although a transition towards Industry 4.0 is evident. Conversely, software solutions have been widely adopted, with ERP software usage among 80% of the companies. This indicates that awareness of digitalization and its benefits has permeated industry and management, showing a significant increase compared to previous years. Despite many companies assessing a high level of digitalization within their organizations, the results indicate substantial room for improvement in this area. Struggles with technology adoption persist, with resistance to change being a major challenge, highlighting the need for further education, training, and infrastructure investments. This situation presents an opportunity for investors to leverage the region's proximity to Europe, benefiting from lower labor costs while enhancing manufacturing capabilities and economic stability.

5.1 Future challenges

One of the significant challenges for all countries, particularly developing ones, is the transition to green and sustainable policies. This is due to the substantial investment required in green technologies and infrastructure, which can be financially burdensome. The EU's new Carbon Border Adjustment Mechanism (CBAM) mandates these countries to measure and reduce their carbon footprints to continue exporting to the EU, but many lack the necessary tools and expertise to comply. While the green transition offers opportunities for economic growth and environmental benefits, it demands significant investment and international support. Future surveys we plan to conduct will include questions about green technology adoption to raise awareness and highlight progress in developing countries.

REFERENCES

ACIT CENTRE, EPIK INSTITUTE. 2022. *Balkan Barometer 2022: Public Opinion*. Analytical report. Sarajevo: Regional Cooperation Council.

BAJIC, B., DAMJANOVIC, S., PASTROVIC, G. 2024. *Policy report on the digital transformation in the western balkans*. Policy answers. European Commission.

DEPARTMENT OF INDUSTRY, SCIENCE, ENERGY & RESOURCES. 2020. *Make It Happen*. Australian Government.

EUROPEAN BANK FOR RECONSTRUCTION AND DEVELOPMENT (EBRD). 2022. Go Digital in Bosnia and Herzegovina. *European Bank for Reconstruction and Development*. [Accessed: January 12, 2025] https://tinyurl.com/3uv2647v

EUROPEAN BANK FOR RECONSTRUCTION AND DEVELOPMENT (EBRD). 2023. *Boosting digital development of the Western Balkans*. [Accessed: December 22, 2024] https://tinyurl.com/32vd5m4r

EUROPEAN COMMISSION. 2024. *Digital Europe Programme open for Bosnia and Herzegovina*. [Accessed: December 12, 2025] https://tinyurl.com/2n5t6n9r

EU4DIGITALSME. 2024. *Action Document for 'EU4Digital – An accelerated digital transition for the Western Balkans – Phase 1'.* [Accessed: December 22, 2024] https://tinyurl.com/54avpjt5

EUROPEAN COMMISSION. 2024. *Digital Europe Programme open for Western Balkans*. [Accessed: December 26, 2024] https://tinyurl.com/3warzt4p

GOVERNMENT OF JAPAN. 2014. *Japan Revitalization Strategy*. Government of Japan. [Accessed: January 08, 2025] https://tinyurl.com/y2kmcajc

VINOKUROV, I. V. 2021. Digital economy in the Russian Federation: problems and development prospects. *Public Administration*. 23(5), 60-66. https://doi.org/10.22394/2070-8378-2021-23-5-60-66

MOON, H. C., CHUNG, J. E., CHOI, S. B. 2018. Korea's Manufacturing Innovation 3.0 Initiative. *Journal Of Information And Management*. 38(1), 26-34.

TEXEIRA, J. T., TAVARES-LEHMANN, A. T. C. P. 2022. Industry 4.0 in the European union: Policies and national strategies. *Technological Forecasting and Social Change*. 180, 121664. https://doi.org/10.1016/j.techfore.2022.121664

WÜBBEKE, J., MEISSNER, M., ZENGLEIN, M. J., IVES, J., CONRAD, B. 2016. Made in china 2025. Mercator Institute for China Studies. *Papers on China*. 2(74), 4.

LIAO, Y., DESCHAMPS, F., LOURES, DE FREITAS ROCHA, E., RAMOS, L. F. P. 2017. Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. *International journal of production research*. 55(12), 3609–3629.

LU, Y. 2021. The current status and developing trends of industry 4.0: A review. *Information Systems Frontiers*. 27, 215–234. https://doi.org/10.1007/s10796-021-10221-w

DERVISHI, M., JOSIFOVSKA DANILOVSKA, M., BOJOVIĆ, M., NIKČEVIĆ, S., LAME, X., MERKOCI, A. 2022. *Cumulative report on Digital Agenda advancement in Albania, Kosovo, Montenegro, North Macedonia and Serbia*. ICEDA: Increasing Civic Engagement in the Digital Agenda.

MAJSTOROVIC, V., MITROVIC, R. 2019. Industry 4.0 Programs Worldwide. In: *Proceedings of the 4th International Conference on the Industry 4.0 Model for Advanced Manufacturing (AMP 2019)*. Cham: Springer. https://doi.org/10.1007/978-3-030-18180-2_7

MINISTÉRIO DA CIÊNCIA. 2020. *Plano de CT&I para Manufatura Avançada no Brasil – ProFuturo*. Ministério da Ciência, Tecnologia, Inovações e Comunicações.

MINISTRY OF HI & PE, GOVERNMENT OF INDIA. 2020. A Industry 4.0 initiative of Ministry of HI & *PE. SAMARTH Udyog Bharat 4.0* [Accessed: 10 January 2024]. https://www.samarthudyog-i40.in/about-samarth-udyog

OECD. 2021. *Competitiveness in South East Europe 2021: A Policy Outlook*. Competitiveness and Private Sector Development. Paris: OECD Publishing.

PETAR, M. 2023. *The role of digitalisation in transforming Western Balkan societies*. Österreichische Gesellschaft für Europapolitik (ÖGfE).

REINHEIMER, S. 2015. *Industrie 4.0*. Springer.

SIYENZA MANAGEMENT. 2023. *Manufacturing Indaba 2023 Programme Overview*. [Accessed: January 09, 2025] https://tinyurl.com/mmzb47rc

TRADING ECONOMICS. 2023. *GDP per capita PPP Europe in USD (2023).* [Accessed: January 10, 2025] https://tinyurl.com/yh7f9fxs

RUPP, C., BELCHEVA ANDREEVSKA, J., WEIXLBRAUN, V. 2023, November. E*mpowering progress with digital transition in Western Balkan and Moldova local governments*. Network of Associations of Local Authorities of South-East Europe (NALAS)

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NATIONAL DEVELOPMENT BANKS AS THE DRIVERS OF POST CONFLICT RECONSTRUCTION IN EUROPE

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ABSTRACT

This paper examines the scope of European national development banks, their role, their objectives, their policy mandates, their financial services, which clients they target, how they are regulated and supervised, what business models they have adopted, what their governance structure is and what challenges they face. The research questions passed in the paper are to examine role that National development banks plays in times of post-conflict reconstruction, namely: gap between investment needs and financial capacity; examine the scope of National development banks, their roles, missions and business models in several EU member States; measure and compare their performance to each other and their business models; the actual level of control exercised by the public sector; analyze the missions and visions of public financial institutions in terms of their objectives, geographic scope, stakeholders, products and services.

The research methodology is based on empirical data of development banks from 2012 to the present: periodic reports of the World Bank, Annual reports for 2022–2023 of 23 National development banks (NDBs) from 16 European countries.[1]

Keywords: national development banks, public finance, financial instruments

JEL Codess: G21, G24, G32, G38

1 INTRODUCTION

In the history of banking, the National Development Banks (NDBs) is an important driver of National economic development. They contribute to a country‘s economic growth, SME development, export potential, and even to large private corporations whose financial needs are not met by private commercial banks or local capital markets. In the crisis and post-conflict times in Asia, Africa, Latin America and even Europe development banks have provided a ‘credit boost’ to private financial institutions when they experienced temporary difficulties for providing credit to the private sector. It is no exception that in the current period 2020–2024, when Europe is experiencing by the result of the transformation of it economics

[1] European National development banks content for study had been chosen on the base of the Wikipedia source: https://en.wikipedia.org/wiki/List_of_national_development_banks

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and consequences of Europe‘s transformation and post-conflict reconstruction are forcing European governments to pay more attention to the NDBs. They have come to be seen as instruments of economic and financial policy to overcome cyclical and structural difficulties. They have become a kind of complement to financial systems, helping to improve their functioning and support sustainability. Since new century the number of NDBs has grown on 25% of their total number (Jose de Luna Martinez, 2017, p.14.)

Public financial institutions fulfil a huge range of specific missions. Among themes, banks with a promotional mission stand out by primarily addressing market insufficiencies, such as the SME financing gap, covering the hidden transaction costs of exports and fostering innovation, whereas other financial institutions are more likely to address general-interest missions, from supporting the agricultural sector to developing infrastructure and promoting tourism. These missions all respond to market needs which, for various reasons – ranging from the extent of the investment horizon to the presence of external factors – are underserved by the private banking sector. Development banks are using public money and must be more and more transparent about the way they use it to reach their goals. NDBs need to cooperate with other institutions and complement their offer to efficiently fulfill their tasks.

The governmental interest of development banks was manifested in the need to promote growth and stimulate investment in EU countries. Therefore, NDBs have evolved into public financial institutions that provide financing for a country‘s economic development, addressing the shortcomings of a market economy while utilizing predominantly public financial sources. However, the questions raise: whether development banks can provide the “impetus” for the post-conflict reconstruction of Europe and whether their missions and business models can play a decisive role in transforming the economy through the public sources’ utilization?

2 METHODOLOGY RESEARCH AND RESEARCH QUESTIONS

Research methodology based on researchers and papers in sphere of National development banks: De Luna-Martínez, José and Carlos Leonardo Vicente, Györgyi Nyikos, Roland Berger, Mathias Schmit and Laurent Gheeraert and other researchers.

A great contribution on NDBs topic research made by Eva Gutierrez, Rudolph Heinz, Theodore Homa, and Enrique Blanco Beneit. They are investigating the mechanism of NDB efficiency. Ferrari, D.S. Mare, and Skamnelos make an interesting study on the nature of NDBs State ownership. The same topic has been touched on Micco, A., U. Panizza, and M. Yanez. The issues and Sustainable Infrastructure of Development were researched by Stephania Griffith-Jones. Behavior of Development banks in time of crisis 2008–2009 were devoted by Choi, Gutierrez, and Martinez Peria.

An empirical data for research from 2012 to the present by 2012 the World Bank periodical reports 2012, 2017 and annual reports 2022–2023 of 23 National development banks from 16 European countries were used.

The research methodology was also based on reports and releases of the United Nations Department of Economic and Social Affairs Financing for Development, European Commission’s COM(2005) 551; Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: Implementing the Community Lisbon Programme Modern SME Policy For Growth And Employment, Eurostat (2014); Manual on Government Deficit and Debt. Implementation of ESA 2010. Eurostat, Luxembourg; OECD’s Arrangement on Guidelines for Officially Supported Export Credits. For the EU Member Statesю

The grouping method was widely used in the course of the research. Grouping to divide the development banks of the countries of Central, Eastern and Southern Europe, as well as the countries of Western and Northern Europe was used in order to show significant differences and reserves in their functioning and development.

The research questions passed in the paper are the followings:

- RQ1. To study the role played by National Development Banks in European economies, the scope of their activities, missions, objectives.
- RG2. To analyze the key indicators of their performance.
- RQ3. To analyze the main concentrations of their activities.
- RG4. To measure and compare their performance with each other.
- RG5. To disclose the main discussion points of the polycrisis period.
- RG6. To propose policy recommendations.

3 ANALYSIS

3.1 Analysis of environment NDB operating

An important features of European development banks such as National Development Institutions (hereinafter referred to as NDIs) are that they are public (state) institutions and their shares are owned by the State. Their role is to promote economic and social growth of the country, and their main tasks are: mobilization domestic and international financial resources for development and solving systemic problems.

Development banks focus primarily on long-term financing of projects necessary for the country's development. National development banks can also be defined as National development financial institutions established to achieve the economic and social development goals, regional integration, providing mainly long-term financing or facilitating the financing of projects oriented towards positive effects for society. Another feature is that they operate in a non-competitive environment, as their interests do not 'overlap' with those of commercial financial institutions. Thus, development banks in Europe are a good example of public financial institutions with facilitating missions. As can be seen from Fig. 2, the rank of development bank tasks is extremely complex, diverse and even contradictory at first glance. On the one hand, they need to eliminate 'market failures, ensuring market conditions for their clients

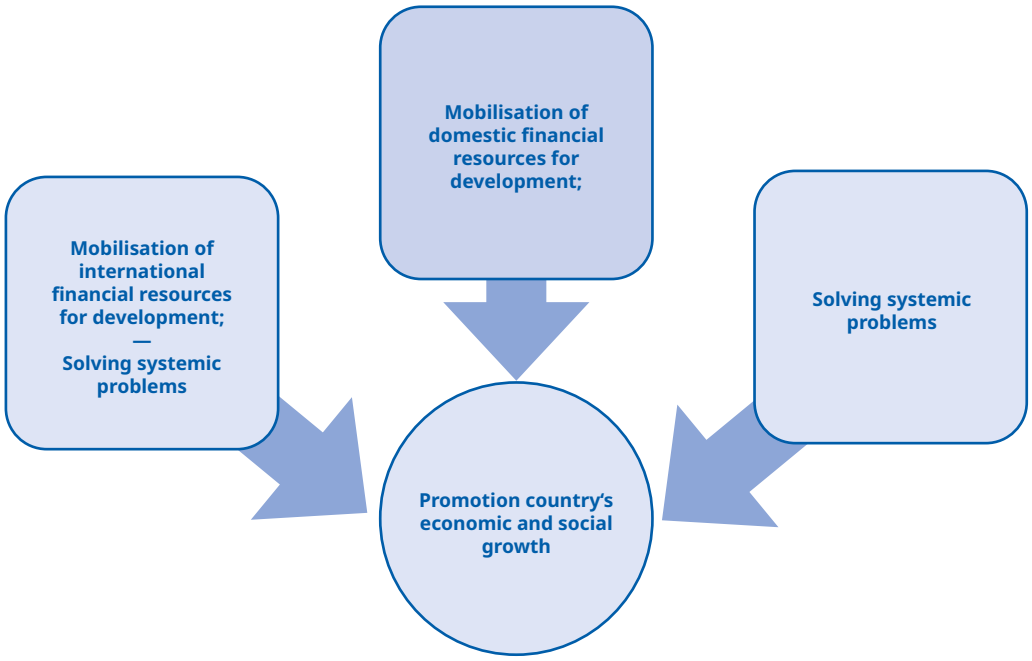

Fig. 1: Role and task of NDIs
Source: Complyed by author

without creating competition. On the other hand, they need to withstand EU competition rules and state aid rules while respecting commercial principles of operation to 'manage' conflicts of interest. Nevertheless, development banks in the role of INRs can and must address the challenges of 'market failure'. They can also contribute to financial sector development by offering long-term credit facilities and other financial products by helping to build financial sectors in the economy.

They can expand the scope of the business climate and attract private sources of capital into the national economy. They function as a catalyst for promoting and supporting small and medium-sized enterprises.

The financial infrastructure of European countries usually consists of national development institutions engaged in lending by pooling government medium-term, long-term and private financial resources. Infrastructure projects supported by INRs have a very wide range: transport networks (railways, highways, airports) and infrastructure-transport projects; energy networks (power grids, gas and oil pipelines), energy generation networks (power plants, renewable energy, etc.), as well as rental, social housing and educational infrastructure. Several options are available for choosing long-term financing:

- Subsidized lending (up to certain amounts) proposals; long-term loans proposals to domestic as well as foreign investors.
- Forming a resource pool. Banks issuing bonds offer two important advantages: risk reduction and economies of scale.
- Developing special instruments: co-financing, credit lines, equity issuance, meso-level finance (subordinated loans or participation certificates) or syndication with other financial institutions.
- Functioning as a market participant. Such participation may be desirable for designing institutional arrangements in which development banks play a significant role in creating new markets, including various mechanisms for long-term lending.

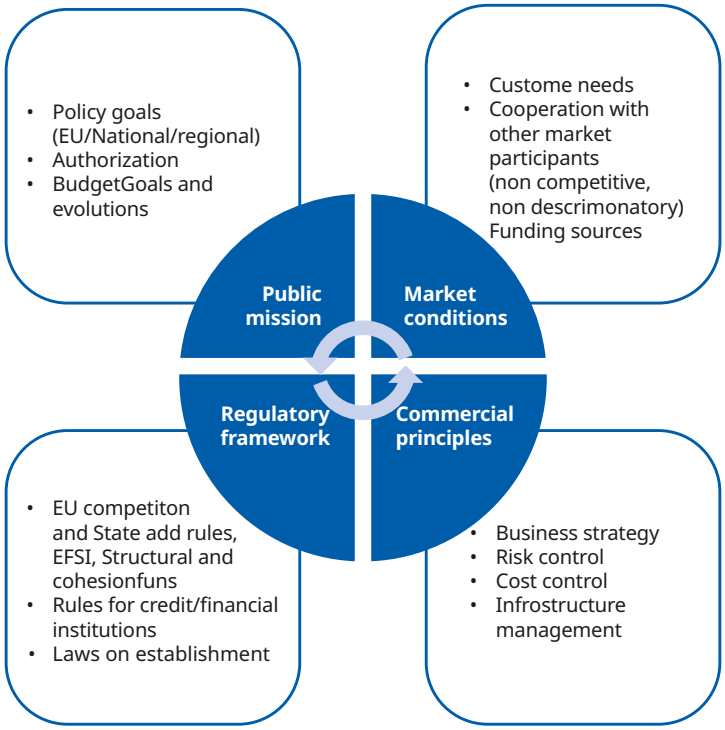

Fig. 2: Scope of development banks functioning and the range of their tasks: Between the State and the market

Source: compiled by author on the data of Investitionsbank Berlin, Deutsche Bank Research.

There are vertical and horizontal dimensions to the European INR system. The vertical dimension means that development banks operate at both European, national and sub-national levels. The horizontal dimension is the heterogeneity of the organization of the banks and the implementation of facilitating tasks. Some institutions are supervised by the European Central Bank (fully or partially); others remain under the supervision of National central banks and public authorities. At the international level, there is general agreement that INRs should be governed by regulatory and supervisory standards, like commercial financial institutions. For example, 72 percent of NDBs are regulating by the same financial Institutions regulation and the save rules regulation normative as a commercial bank's supervising (Jose de Luna Martinez, 2017, p.38).

Before the beginning our analysis, we divided the NDBs studied by size and number and categorized banks by assets into five groups: small (less than €1 billion); medium (€1–99 billion); large (€10–99 billion); mega (more than €100 billion); and super-mega (more than €1 trillion). This is to better show how banks are concentrated by assets and number, and to use the groupings for further detailed analysis. The grouping method is summarized in Figure 3 as follows.

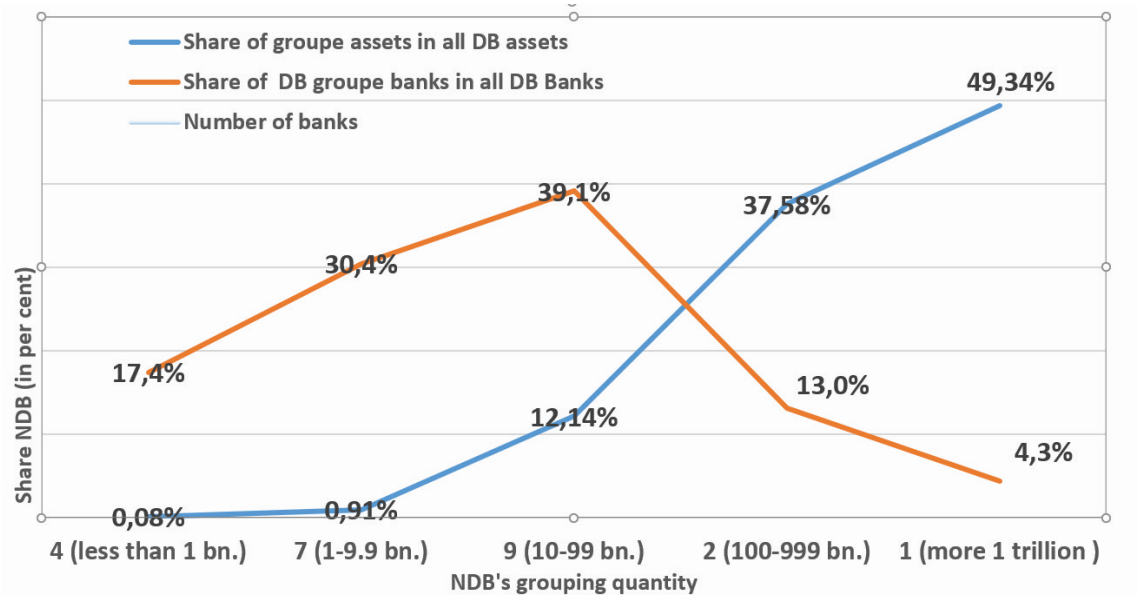

Fig. 3: NDBs concentration by assets and quantity
Source: Authors calculations on the base of annual reports 2023

As can be seen from fig.3, three banks out of 23, whose share is 14.3% belong for almost 87% of total NDBs assets, while the remaining 20 banks only 13% of total assets. At the same time, only one bank – CDC (France) accounts for almost 50% of total NDB assets. This shows the extremely uneven distribution of bank assets and capital among the NDB countries and dominating share of Western European development banks and a smaller one of Central and Eastern European banks and other countries. This is explained by the fact that the economies of these countries are smaller than those of developed Western Europe and their development banks were established in the period after the collapse of the Soviet Union and the disintegration of the CMEA countries

However, as Györgyi Nyikos argues, that in recent years increasing governmental pressure on European development banks has been linked to demands for efficiency in their functioning and justification of confidence in the use of government support funds (Nyikos., G, 2017). Increasing demands for a high level of transparency, accountability and professional management in the use of public funds are becoming a real necessity regardless of whether the development banks operate at the European, national or regional level. The above-mentioned requirement requires compliance with clear, transparent objectives and key performance indicators – KPIs based on broad public

consensus, while seeking the best offer for the taxpayer and achieving the objective economic policy. A transparent strategy and objectives allow for the evaluation of institutions and their performance under established market conditions across the economic cycle. In order to identify the most successful development bank model, it is necessary to analyzes key aspects of the different models. Carrying out such a comparative analysis revealed some successful combinations in the heterogeneous structure of development banks (see Table 1).

Tab. 1 Key aspects of the most successful development banks in Europe

Mission, vision, goals and KPI	Greater differentiation and breadth of tasks of development banks – from assisting small and medium-sized enterprises to supporting the government's economic policies in the private and public sectors
Organisation and administration	Government/stakeholder funds and channels influence strategic decisions. Operational management in banks has differences, especially in maturity between Western European and Eastern European banks
Market environment, customers, segments, distribution	Different customers and market segments (private segment, public sector), complexity of banking product mix, product/service distribution model are areas of significant differences among banks that are managed based on their strategies and objectives
Finances and risk management	The sources of funding, revenue structure differ significantly, although the regulatory rules and standards are similar to commercial banks in terms of risk management, banking product/service lifecycle management, etc.
Business and operational model	Banks are under pressure from both the market and shareholders to increase operational efficiency and customer service from a purely market-based approach to government subsidies.

Source: Györgyi Nyikos, 2017

3.2 Main key development indications

The main evaluation indicators of NDBs that allow judging their potential are the indicators of their share of assets in the country's GDP, as well as the share of assets in the aggregate balance sheet of the country's banking system, the share of loans and borrowings in assets, as well as efficiency indicators ROA & ROE.

The analysis of NDB by assets to GDP and banking system resources of their countries in 2023 is shown by the following picture, which is illustrated in Figure 4.

As the Figure 4 shows, most development banks keeping the share of total assets in the GDP of their countries are within 5–6%. Among the "heavyweights" are development banks of Western European countries: France, Italy and Germany. This is quite understandable due to the developed economic potential of these countries, the long history and traditions of banking in these countries, as well as the long experience of functioning of these banks compared to the banks of Central and Eastern Europe, which have emerged recently.

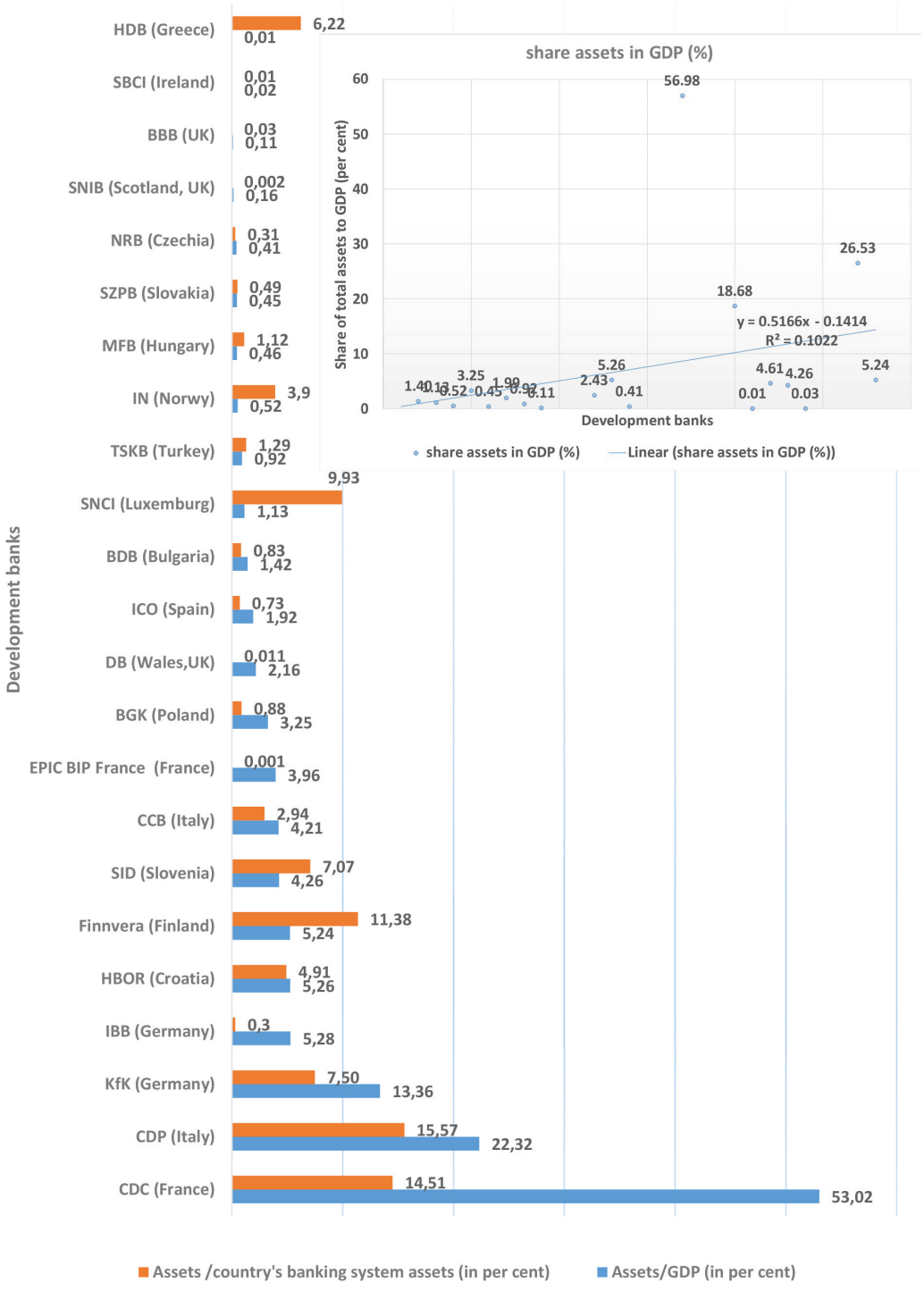

Fig. 4: Total assets of NDBs as percentage to GDP and to total assets of banking system (2023)
Source: comply with the author's calculations on the basis of 2023 annual reports of banks

The next object of analysis was the indicator of development banks' assets in the sum of total banking balances of their countries, where the picture looked somewhat different (see Fig. 4). Here the following banks changed their positions: SNCI (Luxembourg), Finnvera (Finland), SID (Slovenia), TSKB (Turkey), SZRB (Slovakia). The main reason for the discrepancy between Figures 3 and 4 is that in the banking systems of many countries the size of total assets is smaller than the size of GDP. Therefore, development banks that had rather low asset to GDP ratios looked better in Figure 4.

Therefore, development banks in those countries that had a lower ratio of GDP to total banking assets moved to higher positions in this ranking. For example, IN Bank (Norway) had the lowest ratio of 0.13, Bank Finnvera (Finland) – 0.46, SID (Slovenia), TSKB (Turkey) – 0.71, CZRB (Slovakia) – 0.92.in comparison those who had totally big gaps.

The following object of analysis was the main development bank's products in their total assets. Most NDBs issue loans to customs and banks and direct invest. The share of these products is dominated in business models, but not without exception which are illustrated in Fig.5.

Figure 5 shows that 14 banks conduct more than 50% of their active operations in the form of loans and investments. This implies a successful asset structure in fulfilling their direct missions, goals and objectives. But this does not mean that the rest of the banks are weakly involved in their missions, goals and objectives. In their active resource allocation policies, they emphasize resource distribution channels through other banks to wholesale their products. As a rule, the most successful development banks in Western Europe use an indirect lending channel: Germany, France, Italy.

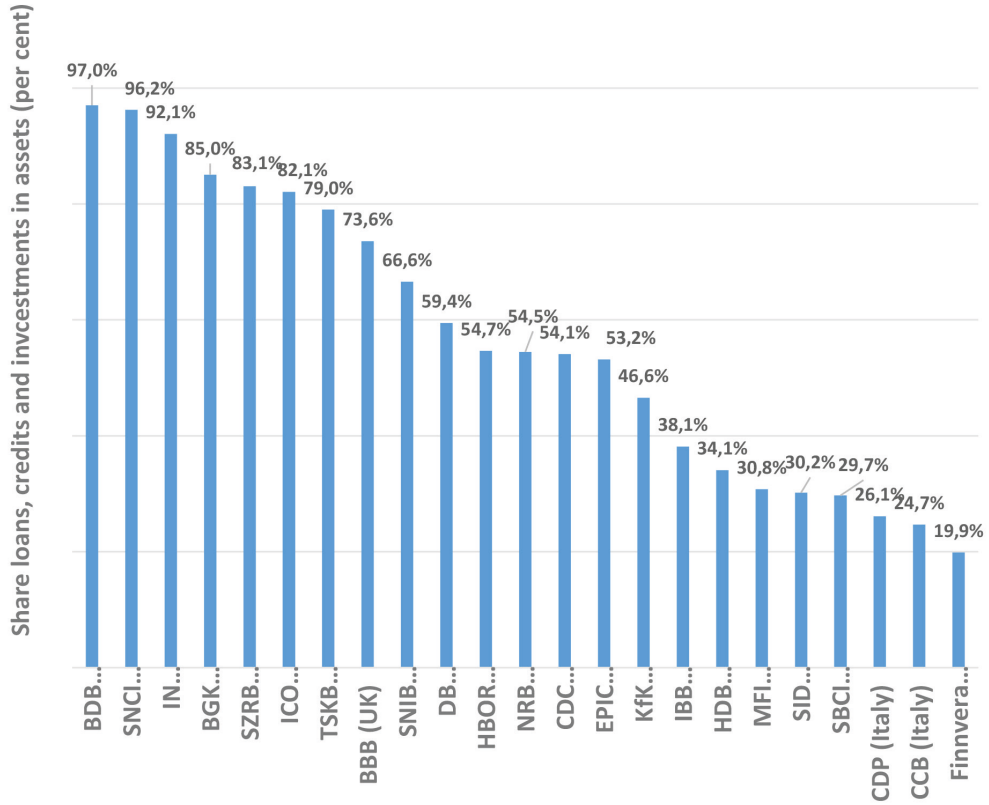

Fig. 5: The share of the loans to customers and banks and direct investments in total assets (in per cent)

Source: comply with the author's calculations based on 2023 annual reports of banks

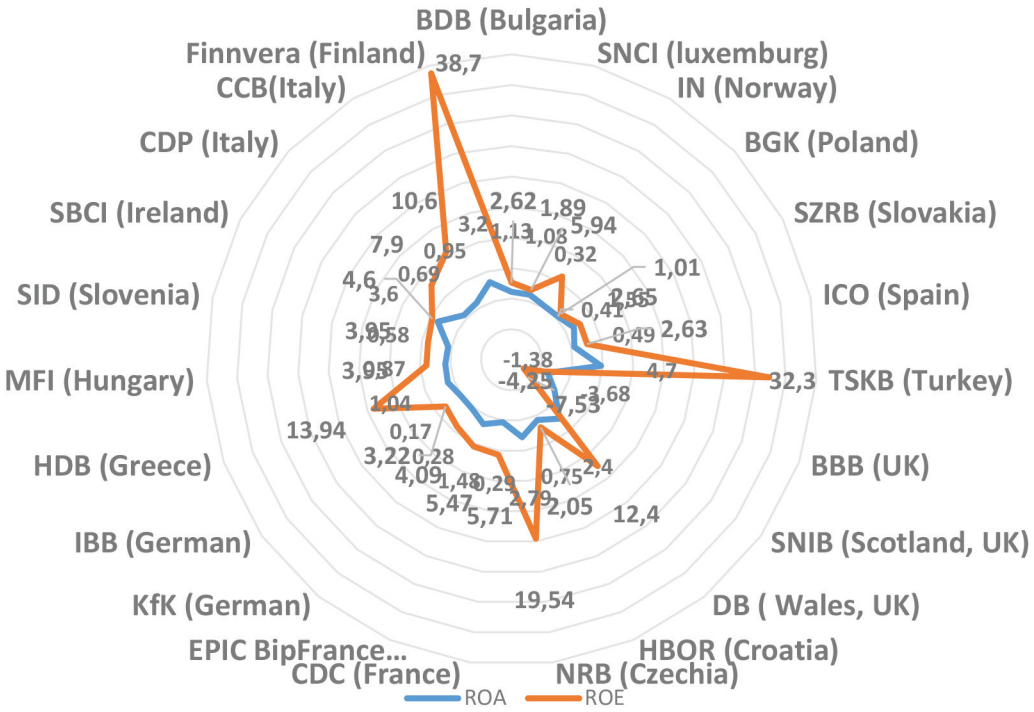

Fig. 6: ROA &ROE indicators of NDBs
Source: Compiled by the author on the Data Fitch rating, 2023 www.fitchratings.com

The final analytical object was ROA & ROE indicators in NDBs activity. As known the events of the last few years have had a negative impact on their behavior. Consequences of COVID-19, and war in Ukraine and other. military conflicts directly or indirectly affected the loss of part of NDBs assets, and with them on the loss of their profits. Thus, BBB Bank (UK) ended FY 2022–2023 with losses and negative ROA & ROE. The same can be said about, the Scottish Development Bank SNIB, which ended the financial year with a negative financial result. Figure 5 illustrates the following picture with these indicators.

The analysis made it possible to discover findings in further research of NDBs.

4 FINDINGS & RESULTS

4.1 Changes in NDBs missions, objectives and cores

Over the last 8–10 years, there have been major changes in the missions, goals and tasks of NDBs by the issues of European cohesion and economic and social development. Both internal factors and external ones are the development vectors of such changes. First, we should emphasize the outstripping needs of the European countries in comparison with available sources of their formation, the impact of scientific and technical progress on the European countries' development, the emergence of breakthrough technologies, wars and conflicts that complicate the pace of European economic development. Under the influence of these factors, the missions, goals and objectives of development banks changed (see Table 2).

Tab. 2 Comparison NDBs missions in 2015 and 2023

NDBs	Missions in 2015	Missions in 2023
Bulgarian development bank (BDB), Bulgaria	BDB's mission is to ensure the implementation and promotion of public economic policies. The Bank has received a public mandate from the national government to finance projects of regional and national importance, encourage the growth of export-oriented companies, help SMEs compete internationally and promote sustainable development	BDB's mission is to provide financing and professional consulting to support the industrial growth of the Bulgarian economy. BDB implements special mandates of the Bulgarian government: anti-crisis measures to overcome the negative consequences of COVID-19; the National Energy Efficiency Program, etc. Implement investments in key sectors of the economy: energy efficiency, infrastructure, agriculture, urban development, exports.
Cassa Depositi e Prestiti (CDP), Italy	CDP Bank's main objective is to promote and support economic growth in Italy	We foster sustainable development in Italy, using savings responsibly to support growth and boost employment, supporting innovation, business competitiveness, infrastructure and local development. Main cores: Climate change and ecosystem protection; Digitization and innovation; Rethinking value chains.
Czech-Moravian Guarantee and Development Bank (CMZRB), Czechia. In 2017 the bank was transformed in **Development Bank (NDB), Czechia (Brno)**	The main mission is to facilitate SMEs' access to funding through specialized banking products and to assist in the development of other economic areas that require public support in accordance with the economic policy objectives of the Czech Republic government and their regions.	NRB's mission, as defined in its mid-term strategy, is based on three pillars. The first is to continue to finance the investment and operational needs of Czech enterprises. The second one is the NRB supports specific segments of the Czech economy in cooperation with ministries, regions or cities/municipalities. The third one focuses on project financing of public infrastructure, particularly transport, social, energy, environmental and digital infrastructure.
Investitionsbank Berlin (IBB) German	Support for Berlin's business companies, including the housing sector, through business development-oriented tools and assistance to companies, taking into account their use of local resources.	Our mission is to make Berlin an even better place to live and work. We help people get started and finance companies so that they can create jobs and housing. Our financial reports give you an insight into our activities. Main areas of focus: Housing and urban development; Public sector (public sector services); Specialized financing; Labor market support (new jobs, etc.)
Banca del Mezzogiorno – MedioCredito Centrale S.p.A., Italy	The Bank has two missions. The first mission is to manage government programs to support and develop businesses in Italy. The Bank acts on behalf of the central and regional governments. The second one is to support investment and economic growth in the Mezzogiorno by providing long-term loans to industrial and agricultural companies and other credit instruments to small and medium-sized enterprises.	Mission is to make a real contribution to the economic, social and cultural development of local communities. Our aim is to promote the wellbeing of our members and of the regions we operate in. Contributing to the common good and creating wellbeing to pass down to future generations, following a sustainable path. With our products and services to meet all the needs of a lifetime.
Strategic Banking Corporation of Ireland, (SBCI), Ireland	The mission is to provide effective financial support to Irish SMEs, as well as timely support to other sectors experiencing difficulties in accessing the credit market, in an environment of increased competition, innovation and efficient use of available EU funds.	Our mission is to support growth, prosperity, and the transition to sustainability by driving competition, enabling innovation, and improving access to finance in the Irish credit market. Our vision: support economic development in Ireland by driving increased access to finance.
SID banka, d.d., Ljubljana, Slovenia	Promotion of Slovenian companies and aid of the country-'s economic growth by providing financing in intermediate market segments. facilitating access of various companies to financing (especially project and infrastructure financing) by implementing national and European policies on green and renewable economy, etc.	The mission of SID Bank is to develop, provide and promote long-term financial services designed to supplement financial markets for the higher competitiveness of economy, creating new jobs and sustainable development of Slovenia.
Slovak Guarantee and Development Bank, Slovakia	Supporting SMEs in Slovakia	The SZRB's mission is to provide funding to support SMEs, agriculture, towns, municipalities and housing in the Slovak Republic.
Bank Gospodarstwa Krajowego (BGK), Poland	Supporting social and economic growth in Poland and public finance sector in process of implementation of their tasks.	The mission of Bank Gospodarstwa Krajowego is to support the sustainable social and economic development of Poland. Positive changes in the economy influence the development of society, and vice versa: an active and integrated society around common goals and values contributes more effectively to economic development.

Source: : Compiled by author on the basis of the Annual reports NDBs 2015, 2017, 2023

From the 2023 Annual Reports, we may find out that NDBs can be "sector banks" focused on specific sectors of the economy, such as SME development banks, merchant banks or universal development banks, and export-import banks. The latter perform traditional trade finance operations. They facilitate trade with foreign countries by providing financing and/or insurance for exports and imports. Most development banks focus on providing services to both the public and private sectors, irrespective of the size of firms and companies, the directions of which are illustrated by the following Figure 2. In some cases, development banks such as the Polish bank BGK (Bank Gospodarstwa Krajowego), the French bank CDC (Central Depositary Company); the Italian bank CDP (Cassa Depositi e Prestiti), the Spanish bank ICO Istituto de Crédito Official) provide a wider range of banking products in relation to export--import transactions.

4.2 What are NDBs now focused on?

Over the 2015 to 2023, shifts in the target concentrations of banks have been occurred which characterized by the following Figure 7.

As we can see there was a shift in the NDBs focuses. If in the last decade the leading focuses of activity were supporting the sustainability of the national economy and its economic growth, promotion SMEs (Periscope, 2015), then they have been replaced by knowledge-intensive areas such as: green economy, digitalization, innovation, support for energy transition, environmental development and zero emissions. Traditionally stable and unchanged companions of NDBs remained: support for SMEs, start-ups, as well as regional. The regional, local, and urban government positions in these ratings are a little down.

Grouping investment focuses by the Western and Northern banks and Central, Eastern and Southern Banks shown the interesting picture (see Fig. 8).

As we see, .in dominating focuses the Central and Eastern banks led more than Western and Northern bank's grope. But in regional local and urban development focuses the situation were totally different.

The inconsistencies and bureaucratic complexities of previous years have been forced by developing banks to manage resources based on short-term criteria have forced. The shift to these criteria was because development banks often showed rather poor reporting on their borrowers. According to a World Bank study provided in 2012 (Jose de Luna-Martinez ***et al***, 2012) both the inability to manage risks based on knowledge and the lack of methods and

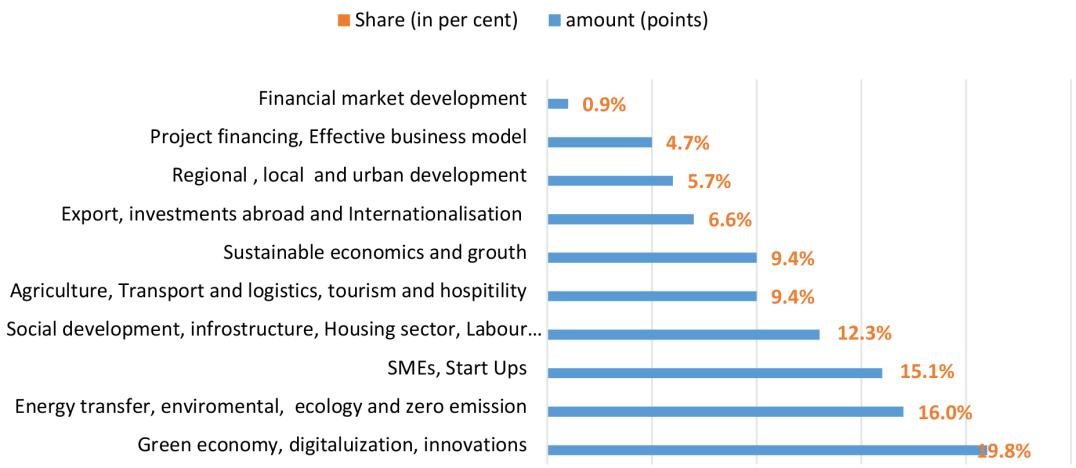

Fig. 7: Investment focuses of European NDBs

Source: Compiled by author on the base of the Annual reports NDBs 2023

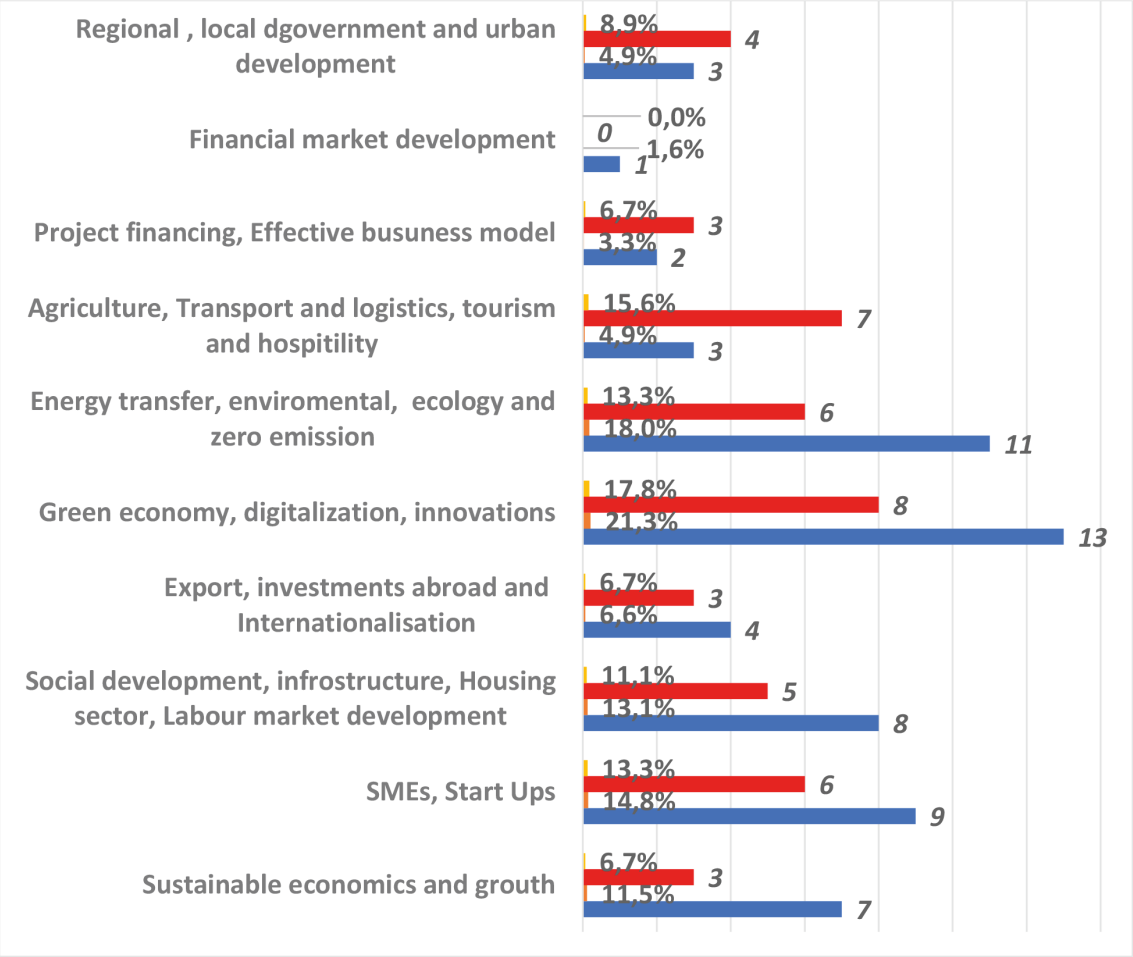

Fig. 8: Investment focuses spread by the NDBs 2023
Source: Compiled by author on the base of the Annual reports NDBs 2023

tools for sustainable development often remain among the main challenges faced by INDs They are: improving risk management capability; maintaining financial sustainable; corporate governance improvement; more flexibles in the recruitment and savement of qualified personal; reducing inappropriate interference.

4.3 Governmental participation extent in the European development banks

Dealing with management issues in development banks with government involvement is a challenge. NDBs are governmental institutions and government influence should be unquestioned. In practice, however, the degree of government involvement in decision-making divides development banks into independent institutions and government sector organizations. A high degree of government involvement in decision-making is noticeable where the government, ministries and banking authorities determine strategy as well as the creation of new products or managing through the Supervisory Board (indirect influence). Examples of such banks are BGK (State Economy Bank, Poland), MFB (Magyar Development Bank, Hungary), SZRB (Slovak Guarantee and Development Bank, Slovakia), NDB (National Development bank, Czech Republic). The degree of government involvement

in decision-making also occurs if the bank prepares a business plan and defines its strategy. In this case, the government only approves it, while the Board of Directors defines the strategy and focuses on the key issues of the business plan. This is subsequently discussed with the government. An example it may be Finnish development bank Finnvera.

The governmental involvement influence tends to increase with the breadth of the mandate given. minimal government involvement in decision-making is typical when the focus is on SMEs. In the case of large deals, action is often supported from a political perspective, which leads to a higher degree of total dependence from government, including profitable orientation as opposed to subsidization.

The degree of involvement of government and for-profit and non-profit oriented organizations is determined by shareholders and usually depends on the institution profile. However, the role of government tends to be greater in Eastern European financial institutions. At the same time, younger institutions from Western Europe have a noticeably low degree of government involvement. Examples are the German bank IBB, the French bank Bpifrance, and the Finnish bank Finnvera. These institutions are profit-oriented and focus on finding the best deal for the taxpayer.

To develop an effective organizational structure, Institutes of National Development (INDs) are controlled by appropriate standards that are divorced from political patronage, lobbying and corruption. Governance and organizational efforts include the establishment and adequate selection of the Board of Directors, as well as a significant degree in decision-making autonomy. Functional committees consisting of board members and senior management should be formed to strengthen control in the IND management.

4.4 NDBs' lending policy and their specifics

Most banks manage a diverse portfolio of assets and, in addition to loans and guarantees, also engage in other activities such as venture capital investments or advisory activities.

Development banks can lend directly to customers (Tier 1 model/retail product sales) or through lending channels to other (private) banks (Tier 2 model/wholesale product sales). There is a difference in whether the bank provides loans and guarantees through its own distribution network, as is the case with NRD bank, (former CMZRB bank), or offers a wide range of value-added services without its own distribution network (BBB). The two-tier model, meanwhile, is based on cooperation with other banks, which tend to apply for loans to end consumers. Many development banks operate on a mixed basis, as is the case with the Magyar Development Bank (MFB). The analytical results shown that Western and Northern bank group more prefer the second channel, and Central and Eastern – the first one. It evidenced by the average indicator of loans and credits to customers by groups (see Fig. 9)

The evolution of development banks in European countries is characterized by cooperation with other institutions to achieve the efficiency of the tasks performed. Cooperation activities create a mutually beneficial situation to improve the distribution network of partners, knowledge of clients, and access to resources and financing. By creating conditions of access (but not guarantees) to development banks, financial inclusion is an opportunity for those firms and companies that are unable to obtain financing on commercial terms from banks or other private financial institutions.

Most financial institutions obtain financing from the capital markets by issuing bonds and debt securities. Unlike regular savings, bonds issued by national development institutions are not always guaranteed by the government, but their issuance is subject to the same financial ratings as other financial institutions in the country, giving them access to financial markets.

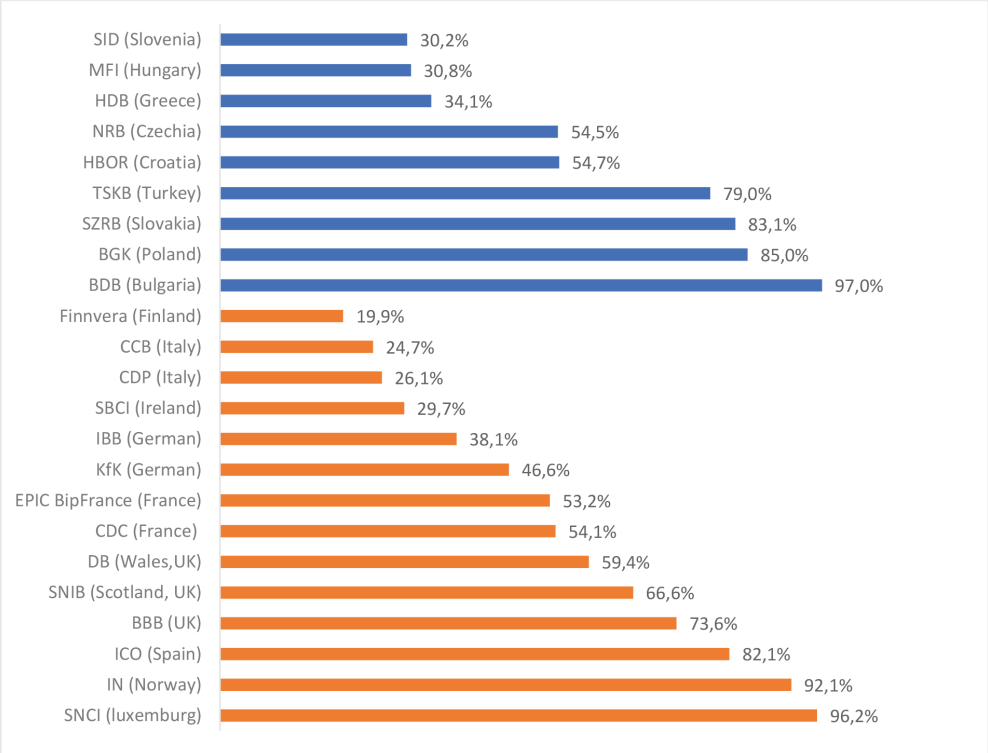

Fig. 9: Share of loans and credits to customers in bank assets by bank groups
Source: Compiled by author on the base of the Annual reports NDBs 2023

4.5 Ratings as a key indicator of NDBs

The most important evaluation indicator of European development banks is their ratings, which are strongly emphasized by consumers, governments and supervisors. Fitch rating provided in 2023 has shown the following picture (Fig. 10).

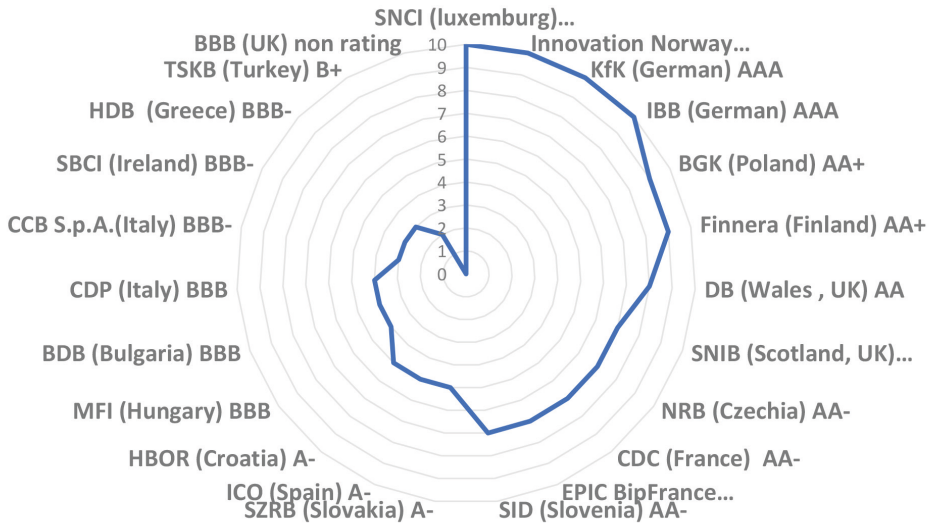

Fig. 10: Fitch rating indicators of the European NDBs
Source: Author's compilation based on reports of Fitch ratings (2023)

As Figure 10 shows, German development banks, SBCI (Luxemburg), IN (Norway) have the highest AAA rating from Fitch. Banks in Central, Eastern and Southern Europe have lower ratings. In comparison with Fitch rations observe 2015 (Nyikos, 2017) Some banks improved their positions in Fitch ratings, for example BGK (Poland) from A– to AA+, ICO (Spain) from BBB+ to AA+, MFB (Hungary) from BBB– to BBB. Nevertheless, some western banks have had their ratings downgraded by CDP (Italy), from BBB+ to BBB– and CDS (France) from AA to AA–. However, this does not prevent them from borrowing to fulfil their missions. It should be noted that Central and Eastern European countries mainly attract EU resources or funds from the European Investment Bank/European Investment Fund (EIB/EIF) and often use Western development banks as seed funding. For example, the German bank KfW provides itself with resources, effectively utilizing its AAA rating and at the same time serving as a refinancing bank for many other financial institutions. Some banks receive very attractive capital market terms through government guarantees.

Concerning ROA&ROE analyses we have found that Central, Eastern and Southern banks get more gaps between ROA and ROA than Western and Northern group which illustrating in Fig. 11.

It can be assumed that the first bank group have more reserves and abilities for lending projects than the second one, because operating profit may cover more operating expediters for enlarge new projects.

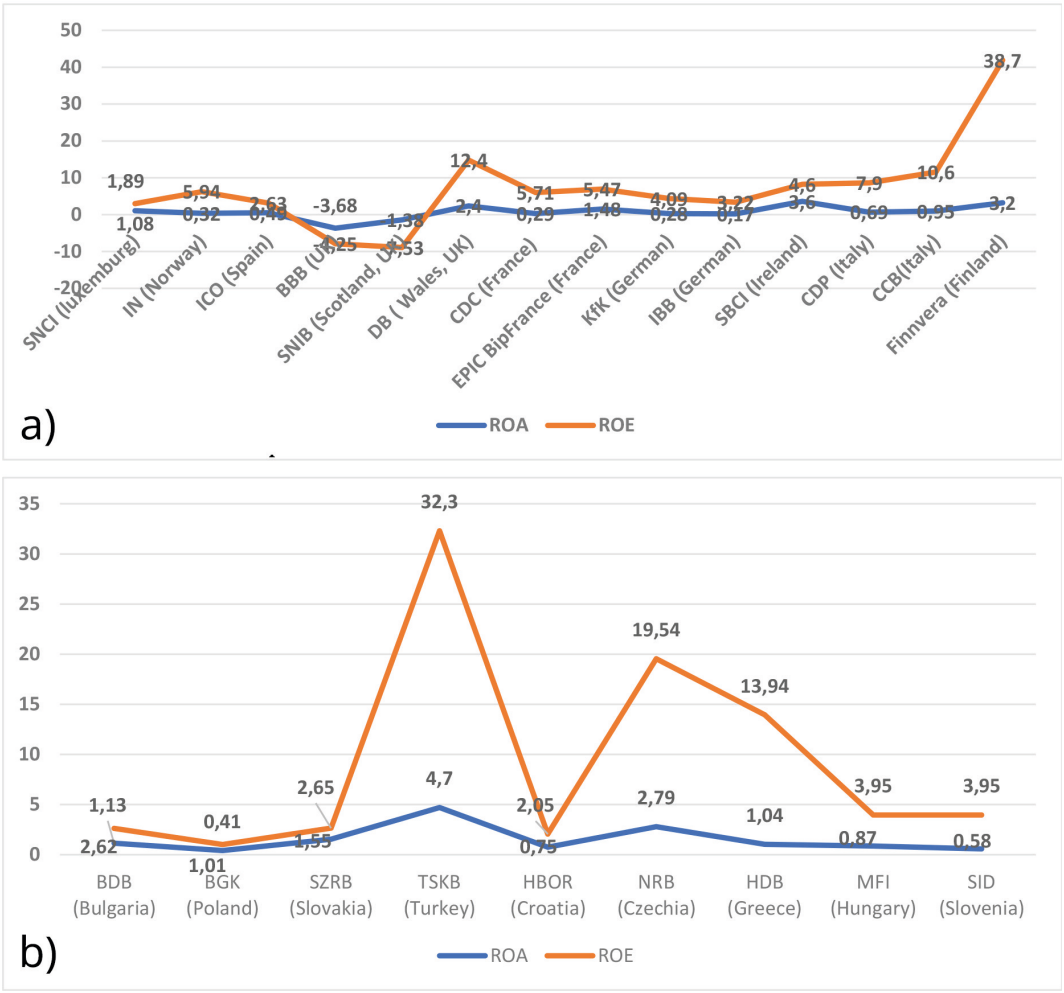

Fig. 11: ROA and ROE indicators by the NDB's groups in 2023; **a)** Western and Northern European countries 2023, **b)** Central, Eastern and Southern European countries in 2023

Source: Author's compilation based on reports of Fitch ratings (2023)

5 DISCUSSIONS

5.1 Focusing on better utilization of governmental support funds and tools

The main questions in the study of European development banks are why development banks should take on the role of drivers in the post-conflict reconstruction of Europe? Whether they can ensure a rapid recovery of the European economy during the transformation of the World Economy? Are there other alternatives? Studies of European economic recovery after the 2008-2009 crisis have shown that the NDBs have successfully managed this task and stabilized the situation in European countries. Another argument in favor of NDBs is their ability to mobilize governmental financial sources on a large scale to support the economy and perform public administration tasks. Of course, such an opportunity cannot be realized by private commercial banks due to high risks of uncertainty in the post-conflict reconstruction period. The ratings achieved by Fitch Ratings may still signal reserves for better utilization of public financial resources.

Other reason in favor of NDBs may best management and lifecycle's specifics. However, given the specifics of product lifecycle management, they should follow the same rules as commercial banks to prevent unnecessary risks and ultimately absolve themselves of the moral responsibility associated with the misuse of government support funds. The requirements for development banks should not differ from commercial banks in terms of their professional approach to risk management and banking operations in general. Development banks can effectively use other sources of financing. Finally, NDBs use public money and more transparent about the way they use it to achieve their objectives.

5.2 Main focuses in post conflict reconstruction?

The challenges of choosing directions and priorities for NDB activities in post-conflict rehabilitation are a debatable issue among practitioners as well. Scattering funds in the existing direction will not lead to the banks' success in stabilizing the economy. It is also clear that the orientation of NDBs towards the former objectives of the European Investment Plan, as laid down in Juncker's plans of ten years ago (MFB Periscope, 2015, p.6), is also no longer in line with the current situation and is being sidelined.

In the context of the poly-crisis, it is also obvious that something has to be abandoned in favor of those links in the chain that can pull the economy through the post-conflict recovery period. Judging by the current investment focus of banks, on the one hand, priority should be given to the energy transition, the green economy, digitalization, and innovation in costly sectors of the economy. On the other hand, regional and local governance (health, education, local development) should not be neglected to prevent the livelihoods of the population from 'drowning'. It can be argued that discussions on the selection and optimization of banks' investment concentrations will be continued.

5.3 Centralization or decentralization?

The current political crisis has seriously affected the cohesion of United Europe, where some countries have found themselves close to intergovernmental co-operation, while others, guided by their national interests, have focused on an isolationist logic and caution. Such different strategies inevitably shape the views of governments and their financial institutions on the centralisation-decentralisation dichotomy. At the same time, some are shifting towards centralization, while others are "overwhelmed" by the decentralization concept. Does this mean that national development banks, with a central government mandate, will push development along a centralized path?

The question is not simple and at the same time not unambiguous. National development banks and their national strategies have never deviated from democratic values, the rule of law and the principles of market economy throughout their operation. And this is an environment that persists now, in the face of recurrent and overlapping crises since the new century. However, being in this environment, it seems inappropriate to follow by rigid concepts of centralization or decentralization for future development. Each country, each government needs to take into account the specific conditions in which they find themselves and clearly understand one flexible rule: where centralization can bring together more benefits than losses, a decision must be made to centralize, and conversely, where decentralization will bring more benefits and effects than centralization, a decision must be made to deconcentrate and devolution.

6 CONCLUSIONS / POLICY RECOMMENDATIONS.

1. Increase the bank capital and liabilities of the National Development Banks (NDBs) in time of post-conflict reconstruction of European countries by the mechanism of State bond issuing. The main bond purchases should MoF and the Central bank, as well as other Public financial institutions. NDB capital and liabilities should be increased, especially for Central, Eastern and Southern European banks, which look weaker than Western and Northern NDBs.
2. Revise outdated and irrelevant missions, goals and visions of NDBs, taking into account support of green economy and green budgets, energy transition, innovation, digitalization, artificial intelligence, and regional and local development and governance as well. Traditional areas of focus: export, import, sustainable growth, project finance, strengthening of financial markets should yield to breakthrough areas of socio-economic development and, if possible, transfer them for lending in commercial banks and other financial institutions under special programs. The commercial banks may be supported by introducing a tax discount, providing an incentive effect on the reduction of taxable income.
3. It is necessary to create a mechanism of preferences for NDBs by reducing reserve funds normative in Central banks and other financial institutions, exemption or mitigation of NDB's taxation and simplification of norms for regulation of their activities.
4. Also need to create a professional staff of highly qualified development bank personnel who are able to deal with social lending projects and hidden risks. Such specialists should be able to calculate the social effect, added value, and VfM, and possess costing methods when designing single banking products.
5. In NDBs, each product or program should be created by objectives similar to those on which the bank focuses. In addition, a normative criterion should be set for the amount of costs required per one project development. The lower the effect-to-cost ratio, the better.

REFERENCE

ABRAHAM, Facundo; SCHMUKLER, Sergio L. . 2017. *A New Role for Development Banks?* Research & Policy Briefs 10. Washington, DC: World Bank Group.

ACEVEDO, Miguel Fernandez; ADEY, Matt; BRUNO, Claudio; DEL BUFALO, Gino; GAZANIOL, Alexandre; LO, Vivien; METZGER BLANCA, Georg; PEREZ, Navarro; VAN DER SCHANS, Dan; THORNARY, Baptiste. 2016. *France, Germany, Italy, Spain and the United Kingdom. Building Momentum in Venture Capital across Europe*. https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-Studien-und-Materialien/Building-Momentum-in-Venture-Capital-across-Europe.pdf

ACHARIA, Viral *et al*. 2011. *Guaranteed to Fail: Fannie Mae, Freddie Mac, and the Debacle of Mortgage Finance*. Princeton, NJ: Princeton University Press.

BECK, Thorsten; HESSE, Heiko; KICK, Thomas; VON WESTERNHAGEN, Natalja. 2009. *Bank Ownership and Stability: Evidence from Germany*. Working Paper Series. Bundesbank, Bonn, Germany.

BERTAY, A. C., DEMIRGUC-KUNT, A., HUIZINGA, H. 2015. Bank Ownership and Credit over the Business Cycle: Is Lending by State Banks Less Procyclical? *Journal of Banking & Finance*. 50, 326–339.

BREI, Michael; SCHCLAREK, Alfredo. 2017. *The Countercyclical Behavior of National Development Banks in Latin America and the Caribbean*. https://ipdcolumbia.org/wp-content/uploads/2024/08/Future_of_National_Development_Banks_-_Countercyclical_Roles.pdf

CHOI, M. J., GUTIERREZ, E., MARTINEZ PERIA, M. S. 2016. Dissecting Foreign Bank Lending Behavior during the 2008–2009 Crisis. *Financial Markets, Institutions & Instruments*. 25(5), 361–98.

DE LA TORRE, Augusto; GOZZI, Juan Carlos; SCHMUKLER, Sergio L. 2017. *Innovative Experiences in Access to Finance: Market-Friendly Roles for the Visible Hand?* Latin American Development Forum. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/27529

DE LUNA-MARTINEZ, Jose; VICENTE, Carlos Leonardo. 2012. *Global Survey of Development Banks*. World Bank Policy Research Working Paper WPS5969. Washington DC: World Bank. http://documents.worldbank.org/curated/en/313731468154461012/Global-survey-of-development-banks

DEUTSCHE BANK RESEARCH. 2015. *Council Directive 98/29/EC sets out provisions for the harmonisation of export credit insurance with medium and long-term cover. Promoting investment and growth: The role of development banks in Europe*. Investitionsbank Berlin. http://www.4-traders.com/DEUTSCHE-BANK-AG-435694/news/Deutsche-Bank-Research-22-Dezember-2015Promoting-investment-and-growth-The-role-of-development-21598901/?iCStream=1

EUROPEAN COMMISSION. 2005. *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: Implementing the Community Lisbon Programme Modern Sme Policy For Growth And Employment*. Document 52005DC0551.

EUROPEAN COMMISSION. 2015. *Working Together for Jobs and Growth: The Role of National Promotional Banks (NPBs) in Supporting the Investment Plan for Europe*. COM(2015) 361 final.

EUROPEAN UNION. 2015. *Communication from the Commission to the European Parliament and the Council. Working Together for Jobs and Growth: The Role of National Promotional Banks (NPBs) in Supporting the Investment Plan for Europe*. COM/2015/0361 final

EUROSTAT. 2014a. *Manual on Government Deficit and Debt. Implementation of ESA 2010*. Eurostat, Luxembourg.

EUROSTAT. 2014b. *Manual on the Changes between ESA 95 and ESA 2010*. Eurostat Manuals and guidelines. http://dx.doi.org/10.2785/52663

Farazi, S., E. Feyen, and R. Rocha. 2013. Bank Ownership and Performance in the Middle East and North Africa Region. *Review of Middle East Economics and Finance*. 9(2), 159-96.

FERRARI, A., MARE, D. S., SKAMNELOS. I. 2017. *State Ownership of Financial Institutions in Europe and Central Asia*. World Bank Policy Research Working Paper 8288. World Bank.

FINANCING FOR DEVELOPMENT OFFICE. 2006. *Rethinking the Role of National Development Banks*. UN Paper, Department of Economic and Social Affairs. Financing for Development Office.

FITCH RATINGS. 2018. *Fitch Upgrades 6 Belarusian Banks to 'B' on Sovereign Action*. Fitch Ratings. Thu 01 Feb, 2018 - 10:06 ET https://www.fitchratings.com/site/pr/10019097

GRIFFITH-JONES, Stephania. 2016. *National Development Banks and Sustainable Infrastructure: The Case of KfW.* GEGI Working Paper 006. Boston University, Boston, MA.

GUTIERREZ, Eva; HEINZ, Rudolph; HOMA, Theodore; BLANCO BENEIT, Enrique. 2012. *Development Banks: Role and Mechanisms to Increase their Efficiency*. Policy Research Working Paper 5729. World Bank, Washington, DC.

HEIDER, Caroline. 2017. *Why Measurement Matters in Development Financial Institutions*. World Bank Group. Blog, September 26. https://ieg.worldbankgroup.org/blog/why-measurement-matters-developmentfinancial-institutions

HUNGARIAN DEVELOPMENT BANK. 2015. *MFB Periscope*. Monthly report, October 2015. https://old.mfb.hu/sites/default/files/mfb_periscope_october_2015.pdf

LA PORTA, R., LOPEZ DE SILANES, F., SHLEIFER, A. 2002. Government Ownership of Banks. *The Journal of Finance*. 57(1), 265–301.

LAZZARINI, Sergio G., MUSACCHIO, Aldo; BANDEIRA-DE-MELLO, Rodrigo; MARCON, Rosilene. 2015. What Do State-Owned Development Banks Do? Evidence from BNDES, 2002–09. *World Development*. 66(February), 237–253. http://dx.doi.org/10.1016/j.worlddev.2014.08.016

MICCO, A., PANIZZA, U., YANEZ, M. 2007. Bank Ownership and Performance. Does Politics Matter? *Journal of Banking & Finance*. 31(1), 219–241.

NYIKOS, Györgyi. 2017. *National development banks for better public spending*. Paper for the 25th NISPAcee Annual Conference, VI. Working Group on Public Finance and Public Financial Management. 22–24, May 2017, Kazan, Russia Federation.

OECD (ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT). 2015. *OECD Guidelines on Corporate Governance of State-Owned Enterprises*. Paris, France: OECD.

ROLAND BERGER EDBB TEAM. 2016. *Development banks*. http://www.cinp.mx/wp-content/uploads/2016/06/2014-GBATA-Readings-Book-Updated.pdf

SANDERSON, Henry. 2013. *China's Superbank: Debt, Oil and Influence: How China Development Bank is Rewriting the Rules of Finance*. Bloomberg Press.

SCHMIT, Mathias; GHEERAERT, Laurent; DENUIT, Thierry; WARNY, Cédric. 2011. *Public Financial Institutions in Europe*. European Association of Public Banks A.I.S.B.L. (EAPB). http://www.adfiap.org/wp-content/uploads/2011/06/2011_03_28_Publ-Fin-Inst-in-Europe_Final.pdf

SMALLRIDGE, Diana *et al*. 2017. *The Role of National Development Banks in Catalyzing International Climate Finance*. Washington, DC: Interamerican Development Bank.

TRIVELLI, Carolina, VENERO, Hildegardi. 2004. *Banca de Desarrollo para el Agro: ¿Qué Podemos Aprender de la Experiencia Latinoamericana?* http://www.cepes.org.pe/debate/debate42/04-trivelli. pdf

UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS FINANCING FOR DEVELOPMENT OFFICE. 2005. *Rethinking the Role of National Development Banks - Background document*. United Nations Department of Economic and Social Affairs Financing for Development Office.

WORLD BANK. 2012. *Global Financial Development Report. 2013: Rethinking the Role of the State in Finance*. Washington, DC: World Bank.

WORLD BANK. 2014. *Corporate Governance of State-Owned Enterprises: A Toolkit*. Washington, DC: World Bank.

WORLD BANK. 2014. *Corporate Governance of State-Owned Enterprises: A Toolkit*. Washington, DC: World Bank.

Abbreviations:
(NDBs) National Development Banks
(BDB): Bulgarian Development Bank, Bulgaria
(HBOR): Croatian Bank for Reconstruction and Development, Croatia
(NRB): Czech Republic: National Development Bank of the Czech Republic
(CDC): Caisse des Dépôts et Consignations, France
(EPIC): Bpifrance, France
(KfW) Kreditanstalt für wiederaufbau, Germany
(HDB) Hellenic Development Bank Greece:
(MFB): Hungarian Development (Bank, Hungary
(SBCI): Strategic Banking Corporation of Ireland: Ireland
(CDP): Cassa Depositi e Prestiti, Italy
(SNCI): Société Nationale de Crédit et d'Investissement), Luxembourg
(IN): Innovation Norway, Norway
(BGK) National Development Bank, Poland
(SZRB): Slovenská záručná a rozvojová banka, Slovakia
(ICO): Instituto de Crédito Oficial, Spain
(TSKB): Development Bank of Turkey (Kalkınma) and Industrial Development Bank of Turkey, Turkey
(BBB): British Business Bank, UK
(SNIB) Scottish National Investment Bank, Scotland, UK
(DBW): Development Bank of Wales, Wales, UK

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ACCEPTANCE AND IMPLEMENTATION OF DIGITAL BUSINESS PLATFORMS: AN ANALYSIS OF EMPLOYEE ATTITUDES IN DIFFERENT INDUSTRIES AND REGIONS

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ABSTRACT

Digitalization has recently sparked a technological revolution by drastically altering how businesses function. These changes have been further hastened by global difficulties, which have led to a rise in the use of digital business platforms. These platforms enable businesses to focus their efforts on distant users and modify their business plans to meet the market's needs. The main goal of this study is to examine employees from various industry sectors and geographical areas' attitudes toward adopting digital networks and using digital business platforms. The employee survey was conducted to understand better their attitude towards these tools and their readiness to integrate digital solutions into everyday work activities. Through cross-tab analysis, the study looked at attitudes regarding adopting and implementing digital business platforms across many industries and geographical areas. The collected data was analyzed using statistical techniques using the SPSS software package. The results obtained provide companies with valuable recommendations for more efficient use of digital tools and improving the digitalization of their business processes.

Keywords: digital business platforms, employee acceptance, behavior, industries, regions

JEL Classification: D85, L21, R11

1 INTRODUCTION

A decade ago, the emergence of Industry 4.0 marked the transition to a new manufacturing era. It integrated modern digital technologies such as artificial intelligence, the Internet of Things (IoT), big data analytics, cyber-physical systems, and other innovations (Yang & Gu, 2021). Since then, Industry 4.0 has remained a key driver of global trends in the development

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of manufacturing systems while simultaneously driving the digital transformation of business practices, models, processes, and routines in the current digital age (Yaqub & Alsabban, 2023).

Modern IT models, paradigms, and control technologies are undergoing rapid changes, driven by urgent applications in practice, which motivates researchers and practitioners to continuously update the basic principles of Industry 4.0 (Gorodecki *et al.*, 2020). One of the more recent innovations is the development of digital business platforms, designed to enable employees to coordinate the management of distributed processes in accordance with the principles of "peer-to-peer" (p2p), which facilitates their acceptance and integration into work processes.

Over time, the platform's work in various business fields has led to numerous employee challenges. Digital platforms enable the coordinated operation of an employee's network through a common information and communication space, ensuring real-time work (Curry & Sheth, 2019). Working conditions depend to a large extent on the impact of digitization.

Furthermore, working on digital platforms replaces the traditional employment contract with a new form of collaboration between employees, platforms and customers, which can lead to both resistance and acceptance of the new work model. The concept of digital business platforms should be expanded for the next generation of enterprises to include proactive behavior, adaptive planning and online re-planning (Curry & Sheth, 2019). In the era of Industry 5.0, digital platforms improve resource management and enterprise integration, allowing employees to access cloud services and data in real time. Their acceptance by employees depends on understanding the benefits they bring in planning and controlling business processes (Gorodetsky *et al.*, 2020).

However, previous research has overlooked the distinct characteristics of digital platforms, which involve various actors on different sides of the platform. This has led to a lack of deeper understanding of how companies using platforms are implementing strategies to encourage the adoption and successful implementation of digital platforms, as well as to minimize employee resistance and facilitate their adaptation to the new work model.

Hence, the main goal of this study is to examine the attitudes of employees from different industry sectors and geographical areas towards adopting and using digital networks and business platforms. The focus is on understanding the key factors influencing their willingness to adopt digital solutions in their daily work activities. This includes a cross-analysis of their perceptions, experiences and expectations regarding adopting and implementing digital platforms across many industries and geographical areas.

2 LITERATURE REVIEW

The platform economy represents a revolutionary change in modern business, transforming business processes, organizational culture, user experience and employee work dynamics (De Reuver *et al.*, 2018). Key drivers of this transformation include the rapid spread of mobile devices, decentralized information networks and big data analytics, which have enabled the development of digital platforms. These platforms have facilitated the provision of work and given workers access to new forms of income via the Internet, which has accelerated changes in global work practices. Digitalization has radically changed the functioning of enterprises, the structure of work, and how work is done (Piasna *et al.*, 2022). This process has raised significant questions about the relevance of traditional worker protection mechanisms in the new circumstances. With the rise of platform work, the sector's revenue has grown from €3 billion in 2016 to approximately €14 billion in 2020. The number of workers relying on platforms is expected to reach 43 million by 2025 (O'Farrell *et al.*, 2020). These figures point to a profound transformation of the work environment, bringing new opportunities and significant challenges.

Digital transformation has also influenced the operating strategies of organizations, setting new standards for business agility and competitiveness in a rapidly changing environment (Škare & Soriano, 2020). Companies have had to abandon traditional methods and adapt their operations to digital platforms, which has created challenges for both organizations and employees (Woodside *et al.*, 2021). The introduction of digital technologies, however, is not enough on its own – it must be accompanied by the definition of comprehensive digital strategies aligned with the needs of platform workers (Woodside *et al.*, 2021; Weile *et al.*, 2022).

However, platform work brings specific challenges regarding workers' rights and protections. The categorization of platform workers as self-employed or independent contractors often deprives them of traditional rights and protection mechanisms, significantly reducing their bargaining power to improve working conditions (Aloisi & Gramano, 2019). This status of workers, combined with the rapid expansion of paid work platforms, has raised significant expectations about their resistance and possible mobilization for better working conditions (Vandaele, 2018).

Research, such as Benkler (2011), points to strategic measures that individual workers can take to improve their working conditions. However, broader institutional support is needed to ensure that the digital transformation, while significant for the economy, does not lead to degrading workers' rights and working conditions (Vandaele, 2018). In this context, digitalization has become not only a technological but also a social phenomenon that shapes contemporary working realities, raising the question of how to balance innovation with sustainable and fair working practices (Aloisi & Gramano, 2019).

3 METHODOLOGY AND DATA

The research used an online questionnaire distributed to employees in companies of various industries and geographical regions via personal email and the LinkedIn platform. The survey included two sets of questions. The initial group concentrated on the demographic information of the respondents, including age, gender, education level, work experience, job position, country, and industry. The second set of questions explored the readiness of the respondents to embrace digital business platforms in their business activities. The research covered countries such as the Republic of Serbia, Hungary, Poland, Slovakia, the Czech Republic and Bulgaria, and the questionnaire was adapted to small and medium-sized enterprises and their openness to the use of digital platforms. 636 correctly completed questionnaires were analyzed using a five-point Likert scale. The statistical software SPSS v.25 was used for data processing and analysis.

4 RESULTS

After data collection, incomplete responses were excluded from the sample, and a data set was then selected for further statistical processing. Out of 825 questionnaires sent, 636 were fully completed and valid for processing, which makes up 77.1% of the representative sample. Demographic characteristics of the respondents are shown in Table 1.

Two main age trends can be deduced from the data in Table 1. The age group 31 to 45 years old makes up the largest part of the data set with (36.3% of respondents), followed by 18–30 years old (23.6%) and those older than 46 (32.3%). Male respondents had a higher share in the sample at 61.8%, while women made up only 37.1% of the sample. Most respondents had a master's degree (47.0%), while the rest had a bachelor's degree (24.7%). The collected data show that the working population with work experience of 6 to 20 years makes up the largest part of the sample, with younger and older workers being less represented. For the positions of the company 30.7% of respondents worked as owners or employees, and a significant part

Tab. 1 Demographic characteristics

Variables	Category	Frequency	Percent
Age	18–30	152	23.6
	31–45	230	36.3
	46–60	205	32.3
	> 61	49	7.8
Gender	Male	393	61.8
	Female	236	37.1
	Do not wish to answer	7	1.1
Education Level	High school	139	21.9
	Bachelor	157	24.7
	Master	299	47.0
	PhD	31	4.9
	Other	10	1.5
Years of Work Experience	Up to 5 years	178	28.0%
	From 6 to 10 years	109	17.1%
	From 11 to 20 years	149	23.4%
	More than 20 years	196	30.8%
	Missing	4	0.6%
Position in Company	Owner	195	30.7%
	Senior manager	101	15.9%
	Manager	145	22.8%
	Employees	195	30.7%
Country of Operation	Czech Republic	89	14.0%
	Hungary	110	17.3%
	Slovakia	100	15.7%
	Poland	101	15.9%
	Serbia	135	21.2%
	Bulgaria	101	15.9%
Industry of Business Activity	Agriculture	29	4.6%
	Mining and quarrying	14	2.2%
	Machinery and equipment	39	6.1%
	Construction and developers	56	8.8%
	Wholesale and retail trade	79	12.4%
	Information and communications	65	10.2%
	Manufacturing	104	16.4%
	Finance and insurance	37	5.8%
	Energy	36	5.7%
	Other sectors	177	27.8%

were still managerial workers. Most respondents come from Serbia, Hungary and Poland, with industries such as manufacturing at 16.4%, trade at 12.4% and communication and information at 10.2%.

4.1 Cross-tabulation Analysis of Factors Influencing the Adoption and Implementation of Digital Platforms

For further analysis, a crosstab was employed for additional analysis to assess how various categories like age, gender, education level, work experience, job position, country of origin, and industry affect employees' views and expectations about the adoption and implementation of digital platforms. Crosstab analysis allows for comparing and identifying patterns in responses to different categories and determining statistically significant differences between different groups in the respective variant.

The crosstab analysis shows the distribution of responses to the question about the adoption and use of digital platforms depending on the age group. The obtained values indicate that the largest number of respondents from the age groups 31–45 and 46–60 consider the platforms to be a good or very good choice for their business. In contrast, the number of respondents older than 61 who positively assessed digital platforms is significantly lower. The results from the chi-square test show a statistically significant difference between age groups regarding the adoption of digital platforms (Pearson Chi-Square = 36.248, $p < 0.001$). This indicates that age has a significant impact on attitudes towards digital platforms. The Linear Association results also confirm this difference ($p = 0.006$), meaning that younger age groups tend to have more positive attitudes towards digital platforms.

However, the analysis indicates that respondents' gender does not show a statistically significant response difference.

Further analysis examined the relationship between the country where the respondents' company operates and their perceptions of adapting and using digital platforms. The results show significant differences across countries, as confirmed by the Pearson chi-square test value (129.855, $p < 0.001$). Respondents from Serbia show the highest percentage of strong agreement with adapting and using digital platforms (score 5, with 38 responses), while the Czech Republic, Hungary and Bulgaria have a smaller number of respondents in this category. Slovakia has a more even distribution, with a significant number of responses in the middle range (score 4, with 30 responses). This analysis suggests that national context influences the adoption of digital platforms, with some countries showing a greater propensity for adaptation than others.

The relationship between the position in the company where employees work and perceptions of adapting to and using digital platforms was also examined. The results show statistically significant differences between groups, as confirmed by the value of the Pearson chi-square test (50.031, $p < 0.001$). Company owners comprise the largest percentage of respondents with low scores for adapting to digital platforms (score 1, with 116 responses). In contrast, managers and employees show a relatively even distribution of responses with higher scores, indicating greater openness towards digital platforms. Senior managers have the fewest responses in the high-score categories (4 and 5). This analysis suggests that position in the company significantly influences attitudes towards digital platforms, with company owners showing greater scepticism while employees and managers demonstrate greater readiness to accept them.

Cross-sectional analysis shows a correlation between employees' education level and their perception and willingness to adapt to digital platforms. Pearson's chi-square test shows statistically significant differences ($\chi^2 = 63.667$, $p < 0.001$), indicating that the level of education significantly influences attitudes towards digital platforms. Respondents with a high school diploma dominate the category with the lowest grades, while those with a master's or doctorate degree show a higher representation in the category with higher grades. In particular, respondents with a master's degree have the most responses in categories 4 (45 responses)

and 5 (32 responses), indicating a positive attitude towards digital platforms. On the other hand, respondents with a lower level of education generally show a lower willingness to adapt to these technologies. This analysis highlights the importance of education as a factor contributing to adopting digital platforms.

A statistically significant difference can be observed in the attitudes of employees from different sectors of business activities towards the adoption and application of digital platforms. Pearson's chi-square test shows statistical significance ($\chi^2 = 63.014$, $p = 0.004$), indicating that the sector in which companies operate affects the readiness of their employees to adapt to digital platforms. The largest number of respondents who opted for high scores come from sectors such as wholesale and retail trade, information and communication, and manufacturing. In contrast, some sectors such as mining and quarrying, and agriculture, show a higher representation of responses with lower scores, indicating a lower readiness to accept digital platforms. This analysis highlights the importance of the business sector as a factor shaping the attitudes and readiness of companies to adapt to digital innovations

5 DISCUSSION AND CONCLUSIONS

This study aimed to explore how different elements, such as age, gender, education, work experience, job role, geographic area, and industry sector, influence employees' readiness to embrace and utilize digital networks and business platforms. Consequently, a cross-analysis was performed to better comprehend the distinctions among various employee groups regarding their views on digitalization.

The results indicate a significant influence of age group on attitudes towards digital platforms, with the most positive responses among employees aged between 31 and 60, while those over 61 showed less willingness to adopt these technologies. Geographical differences also play a key role, with employees from Serbia showing a greater willingness to adopt digital platforms compared to countries such as the Czech Republic, Hungary and Bulgaria, while employees in Slovakia had a more balanced response. In addition, position in the company significantly influences attitudes towards digital solutions; business owners showed more scepticism compared to managers and employees, who generally showed more openness to digitization. The education level was also important since employees with advanced degrees, like a master's or doctorate, exhibited a stronger readiness to embrace digital technologies.

Theoretically, this paper enhances the comprehension of the complexities of adopting digital platforms across various industries and locations, pinpointing essential elements influencing employee perceptions of digital transformation. Practical implications include recommendations for identifying specific barriers and factors that hinder or encourage the adoption of digital solutions depending on the sector, country, and level of education of employees. Based on these findings, organizations should create strategies encompassing training, education, and infrastructure adjustments to enhance employees' readiness to embrace and incorporate digital solutions into their everyday tasks.

In light of these results, organizations should develop strategies that address the unique requirements of their employees, intending to enhance digital transformation and streamline business operations through the successful implementation of digital technologies and digital business platforms.

REFERENCES

ALOISI, A., GRAMANO, E. 2019. Workers without workplaces and unions without unity: Non-standard forms of employment, platform work and collective bargaining. In: *Employment Relations for the 21st Century, Bulletin of Comparative Labour Relations*. 107.

ALQAYED, Y., FOROUDI, P., KOOLI, K., FOROUDI, M. M., DENNIS, C. 2022. Enhancing value co-creation behaviour in digital peer-to-peer platforms: An integrated approach. *International Journal of Hospitality Management*. 102, 103140.

CURRY, E., SHETH, A. 2018. Next-generation smart environments: From system of systems to data ecosystems. *IEEE Intelligent Systems*. 33(3), 69–76.

DE REUVER, M., SØRENSEN, C., BASOLE, R. C. 2018. The digital platform: A research agenda. *Journal of Information Technology*. 33(2), 124–135.

KENNEY, M., ZYSMAN, J. 2016. The Rise of the Platform Economy. *Issues in Science and Technology*. 32(3), 61–69.

GORODETSKY, V., LARUKCHIN, V., SKOBELEV, P. 2020. Conceptual model of digital platform for enterprises of industry 5.0. In: *Intelligent Distributed Computing XIII*. Springer International Publishing, pp. 35-40.

LUND, B. 2021. Predictors of use of digital technology for communication among older adults: analysis of data from the health and retirement study. *Working with Older People*. 25(4), 294–303.

O'FARRELL, R., MONTAGNIER, P. 2020. Measuring digital platform-mediated workers. *New Technology, Work and Employment*. 35(1), 130–144.

PIASNA, A., ZWYSEN, W., DRAHOKOUPIL, J. 2022. *The platform economy in Europe*. Results from the Second ETUI Internet and Platform Work Survey (IPWS), 57.

ŠKARE, M., SORIANO, D. R. 2021. A dynamic panel study on digitalization and firm›s agility: What drives agility in advanced economies 2009–2018. *Technological Forecasting and Social Change*. 163, 120418.

VANDAELE, K. 2018. *Will trade unions survive in the platform economy? Emerging patterns of platform workers' collective voice and representation in Europe*. Emerging Patterns of Platform Workers' Collective Voice and Representation in Europe (June 19, 2018). ETUI Research Paper-Working Paper.

VEILE, J. W., SCHMIDT, M. C., VOIGT, K. I. 2022. Toward a new era of cooperation: How industrial digital platforms transform business models in Industry 4.0. *Journal of Business Research*. 143, 387–405.

WOODSIDE, J., VINODRAI, T., MOOS, M. 2021. Bottom-up strategies, platform worker power, and local action: Learning from ride-hailing drivers. *Local Economy*. 36(4), 325–343.

YANG, F., GU, S. 2021. Industry 4.0, a revolution that requires technology and national strategies. *Complex & Intelligent Systems*. 7, 1311–1325.

YAQUB, M. Z., ALSABBAN, A. 2023. Industry-4.0-Enabled digital transformation: prospects, instruments, challenges, and implications for business strategies. *Sustainability*. 15(11), 8553.

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CHANGING THE CONSUMER BEHAVIOR IN FOOD PRODUCT PURCHASING ACCORDING TO THE CONCEPT OF SUSTAINABLE FOOD CONSUMPTION

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ABSTRACT

The limited natural resources with the growth of the population make the problem of sustainable food consumption very relevant and important, as it affects the environmental, economic and social aspects of life. The purpose of the study is to develop recommendations for shaping the behavior of food consumers based on the concept of sustainable consumption. The information base of the study was formed by interview data, official statistical materials, and the results of our own research. The research methods used were a systematic approach, an economic and statistical method, and an expert evaluation method. As a result of the study, the components of the sustainable food consumption system were determined in accordance with the concept of rational consumption; the motivators that guide the purchase of food products were characterized, as well as the demotivators that prevent consumers from sustainably consuming food products; proposals were made for changing consumption behavior in accordance with the concept of more sustainable food consumption.

Keywords: sustainable food consumption, consumer behavior, sustainability

JEL Code: Q50, Q56, M31

1 INTRODUCTION

Today, in a global context, the food system faces problems related to both meeting the population's food needs and environmental issues related to saving and preserving natural resources and protecting the environment. On the one hand, globalization, industrialization of production, and the growth of food production and sales are destroying natural resources and harming the environment. On the other hand, the population of some countries has a lack of food and hunger problems, and there is also a problem of obesity due to unbalanced nutrition, *etc*. Recent studies (Genova and Allegretti, 2024) emphasize the interdisciplinary nature

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of sustainable food consumption. That is, the issue of responsible nutrition and sustainable food consumption is interdisciplinary, related to economics, ecology, food production, nutrition, marketing, *etc*. Responsible consumer nutrition aims to improve food sustainability. Not only government regulation, but also marketing strategy has a significant impact on responsible nutrition. A well-formed marketing strategy should promote sustainable consumption by influencing environmental awareness and a new lifestyle of consumers, combining the social responsibility of business and economic incentives. A key role in this is played by information policy, which pushes businesses and consumers to sustainable behavior. Business can promote sustainable consumption by expanding the range of environmentally friendly and eco-efficient food products, adhering to ethical behavior, influencing consumer behavior through eco-labeling and advertising campaigns aimed at responsible nutrition.

The main aspects of sustainable consumption are environmental protection, reasonable satisfaction of basic needs and consideration of the needs of future generations. Regarding the definition of sustainable food consumption, the Sustainable Development Commission (2009) notes that it should meet environmental requirements and provide safe, healthy and nutritious food; contribute to the protection of the environment, animal welfare and biodiversity, promote energy conservation, minimize waste, *etc*.

Ensuring sustainable food consumption correlates with many sustainable development goals, primarily, overcoming hunger, good health, and quality education. The goal of overcoming hunger will be realized through rational consumption and minimizing food waste (Tekinbas Ozkaya, *et al*., 2021). The goal of achieving good health is indisputably linked to quality and balanced nutrition (Genova and Allegretti, 2024). Spreading awareness about conscious consumption and, through this, environmental protection will influence the change in consumer behavior, as well as the implementation of the goal of quality education. Therefore, ensuring sustainable food consumption is a complex task that is achieved through healthy and balanced nutrition, reducing food waste, and raising consumer awareness about responsible food consumption.

Theoretical and practical approaches to studying sustainable food consumption are very diverse. Thøgersen (2010) focuses on sustainable consumption on organic food, Austgulen (2014), Vinnari (2008), Clonan *et al*., (2015) studied the impact of sustainable meat consumption. Gorissen and Weijters (2016) primarily assess sustainable consumption from the perspective of ecology and environmental impact. Research by Alsaffar (2016), Friel *et al.* (2014), Meybeck *et al.* (2017) focuses on issues of balanced nutrition and health. Vassallo *et al.* (2016) sees sustainable consumption as having psychological and social impacts, and Barling (2011), Reisch *et al.* (2013) study barriers that limit the rapid transition to the concept of responsible nutrition.

Of particular note are works that study consumer behavior, which study influencing factors, primarily product availability, as well as cultural norms and traditions, physiological needs, fashion, tastes, community influence, health, *etc*. Thus, Wongprawmas *et al.* (2021) classified the factors of consumer food choice into psychological (mood, stress, and guilt), physiological (availability, education, and time), biological (hunger, appetite, and taste), social (culture, family, and peers), and economic (e.g., cost, income, and availability). Kamenidou *et al.* (2019) outlined the primary drivers that contribute to the consumer's transition to sustainable consumption, such as green consumption and local consumption. Genova *et al.* (2024) substantiate consumer behavior in choosing a consumption strategy by demographic characteristics of consumers, such as differences in age, gender, *etc*. Barcellos *et al.* (2011) formulated a typology of consumers regarding sustainable consumption, dividing them into clusters, namely indifferent to sustainability, environmentally conscious consumers and consumers oriented towards sustainable development.

Tobler *et al.* (2011), Vitterso *et al.* (2015), Yadav *et al.* (2019) analyze motivators and demotivators of sustainable food consumption, to which they attribute health concerns, ethical issues, food safety, seller reputation, social identity, concern for agricultural producers, concern

for animals, perceived accessibility, availability of environmentally friendly food products, excessive prices, time constraints, lack of information about eco-products, eco-labeling, limited marketing communication, ignorance of the impact of agricultural production on the environment. Sidali *et al.* (2016) substantiated the main motives of consumers when buying sustainable food products, which included naturalness, health impact, ethical issues, and innovation. Gorgitano and Sodano (2014) identified demotivators of sustainable consumption, namely the rebound effect, the gap between knowledge and action, and the gap in behavior and influence, which limit sustainable food consumption. In general, cultural and social norms, as well as individual consumer habits, are quite difficult to change. The reorientation of consumers towards sustainable food consumption is no exception.

A global index that allows you to assess the level of food sustainability of a country according to the criteria of sustainable agriculture, nutrition problems, and food losses is the Food Sustainability Index. This index simultaneously indicates the environmental, economic, and social problems that affect the nutrition of the population. The latest calculations of the index were carried out in 2021, 78 countries of the world were studied according to 95 indicators, covering 92% of the world's population and 92% of global GDP. Countries such as Sweden, Japan, Canada, Finland, Austria received a very high level of index value. Ethiopia, Morocco, Pakistan, Ghana, Kenya have low levels of the index (Food Sustainability Index, 2021).

In the process of shaping the behavior of food consumers based on the concept of sustainable consumption, the level of consumer awareness of the concept of rational consumption was investigated; motivators that guide food purchases were identified, as well as demotivators that prevent consumers from consuming food products sustainably; suggestions were made for changing consumption behavior in accordance with the concept of more sustainable food consumption.

The main goal of the study is to develop recommendations for shaping the behavior of food consumers based on the concept of sustainable consumption. To achieve this, the study addresses the following research questions: What are the main motivators and demotivators affecting sustainable food consumption? How do demographic factors influence sustainable food purchasing behavior? What strategies can be implemented to support sustainable consumption among different consumer clusters?

2 METHODOLOGY AND DATA

The information base of the study was made up of interview data, official statistical materials, and the results of our own research. The data collection process was carried out using an interview format based on questions regarding sustainable food consumption.

Questionnaire survey conducted online during August–September 2024 in Slovakia. It covered 117 respondents representing various age groups, genders, education levels, and income levels. Topics included consumption habits, awareness of sustainable food, motivations and barriers, influence of marketing, and social norms.

The study aims to identify factors influencing consumer behavior, their awareness of sustainable consumption principles, and their willingness to make more conscious decisions when choosing food products, taking into account environmental and social factors. The demographic profile of the respondents is presented in Table 1.

The diversity of respondents in terms of education, age, gender, and socio-economic status reveals different aspects of consumer habits, as well as factors that may influence attitudes to-wards sustainable consumption and nutrition. The questions to the respondents concerned consumer habits, awareness of the principles of sustainable consumption, willingness to change one's own behavior in favor of sustainable consumption, the influence of marketing factors on consumer behavior, social and cultural aspects of consumption. For quantitative processing of data, correlation analysis was used, which made it possible to determine the

Tab. 1 Demographic profile of respondents

Characteristics	Specific weight (%)	Characteristics	Specific weight (%)
Age of respondents		Educational level	
18–24	21	Higher education	65
25–35	29	Secondary education	35
36–44	27	Income level	
Over 45	23	Middle	69
Gender of respondents		High	19
Men	42	Low	12
Women	58		

Source: own research

relationships between variables.

3 RESULTS

The survey yielded the following results. The majority of respondents (45%) buy organic products occasionally, and 30% do so regularly. Only 15% buy organic products always, indicating a high level of awareness and interest in organic products, but a certain part of respondents still has limited experience. The greatest attention is paid to quality (75%) and environmental impact (60%). Price is the most important factor for 60% of respondents, indicating existing economic barriers to sustainable consumption. Most respondents (80%) are familiar with the concept of sustainable consumption. 85% say they have heard of certifications such as organic and eco-friendly. Most respondents (50%) are willing to pay more for organic products depending on the price difference, indicating sensitivity to price factors. Only 30% are willing to pay more regardless of cost. The main motives for buying organic products are lower prices and better accessibility. This shows that many consumers want to make sustainable choices, but are looking for a more economical option. The high price of organic products is the main obstacle for 70% of respondents. Insufficient consumer awareness (40%) and limited assortment (20%) may be other barriers. Marketing campaigns have a much smaller influence on the choice of eco-products: only 25% of respondents recall

Tab. 2 Generalized results of the survey of respondents

Factor	Average value (on a scale of 1–5)
Product price	4.7
Environmental awareness	4.3
Availability of goods	4.1
Certification	3.8
Marketing attractiveness	3.4
Socio-cultural component	3.0

Source: own research

Tab. 3 Correlation matrix (level of correlation with demand)

Factor	Level of correlation with demand	Description of the relationship
Product price	−0.68	High price may deter demand, especially among lower-income populations
Environmental awareness	+0.81	High environmental awareness stimulates demand for organics.
Availability of goods	+0.75	The more easily available organic products are, the higher the demand
Certification	+0.72	The presence of certificates increases trust and stimulates demand.
Marketing attractiveness	+0.52	Bright and correct positioning influences consumer choice.
Socio-cultural component	+0.64	Social trends and fashion have a positive impact on a healthy lifestyle.

Source: own research

advertising that convinced them to buy sustainable products. Consumers (50%) are moderately influenced by the behavior of their loved ones (friends, family) when choosing products. Generalized results of the survey of respondents presented in Table 2.

High price sensitivity indicates the need for government or business incentives (subsidies, discounts). Consumer awareness comes in second place, confirming the need for information campaigns. Certification has weight, but is considered secondary without the context of price or awareness. Marketing and social impact are important, but are considered supporting factors. Correlation matrix of sustainable consumption factors presented in Table 3.

Statistical methods can be used to analyze the correlation between different variables. Thus, the highest positive correlation with the demand for organic products was found in the factor of environmental awareness of the population (r = +0.81), which confirms the key role of the level of awareness of citizens regarding the consequences of consumption and environmental safety in the process of forming consumer preferences. Factors such as the availability of product certification (r = +0.72), the availability of organic products (r = +0.75), as well as socio-cultural attitudes (r = +0.64), which reflect the influence of values, norms of behavior and dominants in lifestyle, also correlate significantly positively with demand. This indicates the need to support the development of local organic producers, expand the distribution network and cultural adaptation of marketing strategies. The factor of marketing attractiveness demonstrated an average level of positive dependence (r = +0.52), which allows us to interpret it as an auxiliary tool for influencing the consumer, especially at the stage of familiarization with the product. The price factor showed a negative correlation with demand (r = -0.60), which indicates the deterrent effect of high prices on the decision to purchase organic goods. Therefore, the results of the correlation analysis indicate the multifactorial nature of consumer behavior in the organic products market.

The survey results show that the ways to change consumer behavior in accordance with the concept of sustainable food consumption are to reduce the volume of production and, accordingly, the consumption of food products of animal origin, which have the most negative impact on the environment. The transition to sustainable consumption requires changing the eating habits of consumers, which is a complex combined issue. Rational nutrition involves increasing the consumption of cereals, legumes, vegetables and fruits, and reducing the volume of consumption of animal food. That is, such adjustments are associated not

only with consumers, but also with producers who must provide the population with these products. Packaged and processed food products are also harmful to the environment, that is, minimizing sales of such goods will negatively affect sustainable consumption, although it requires changing the habits of consumers who will buy the corresponding products due to workload. The absence of fast food consumption, preference for purchasing locally produced food, consumer orientation towards the consumption of seasonal products, the habit of planned purchases, and increased well-being of the population and, accordingly, increased access to high-quality ecological food products, balanced nutrition, the possibility of reuse, and waste reduction will have a positive impact on sustainable food consumption.

The behavior of food consumers is influenced by economic, social and environmental aspects. The consumer wants to eat healthy, inexpensive, environmentally friendly, healthy food products. The environmental components of sustainable food consumption are the use of land resources, energy conservation, food waste management, minimizing carbon and water effects in food production, the use of recyclable packaging, the impact of local farmers on the environment, *etc*. Environmental components are associated with high-quality and healthy food, which ensures better health and minimizes morbidity. The economic component is primarily the price of food, i.e. the availability of high-quality and healthy food products for all segments of the population. The social component is consumer awareness of the importance of rational food consumption, as well as the level of development of society, values, quality of life, *etc*.

A significant problem in changing the behavior of food consumers according to the concept of sustainable food consumption is the lack of sufficient awareness of consumers about the importance and significance of sustainable and rational food consumption. The main mistakes that consumers make when buying food that affect sustainable consumption are excessive purchases, unconscious purchases, and incorrect behavior after consumption. These mistakes lead to such consequences as food spoilage, expiration date, losses during cooking, and not knowing what to do with leftovers, which is a negative side of sustainable food consumption.

Changing the behavior of food consumers depends on personal and external factors that can be influenced by society, the manufacturer, government institutions, or other consumers. Personal factors include personal psychological habits, consumption culture, income, lack of information about proper and rational nutrition, lack of time to cook, and lifestyle. External factors include population size and, accordingly, the availability of food products, and the marketing strategy of enterprises to influence consumers.

Effective strategic steps towards sustainable consumption include increasing the possibility of recycling food waste, information policy on motivating healthy eating and a sustainable lifestyle. Marketing communication tools are of great importance in changing consumer behavior towards sustainable consumption. Priority communication channels are public advertising, social networks, television advertising, and visual advertising. Planning purchases can also change consumer behavior, which will limit unexpected purchases, unnecessary and unnecessary food purchases. Local producers should focus on their own products, their freshness, longer shelf life, *etc*. The difficult task is to minimize waste after food consumption. Here, the appropriate consumer behavior would be not to throw away waste, but to give excess products to those who need them, if they are not subject to consumption, to sort waste, and accordingly use them either as fertilizers or for energy production.

Therefore, sustainable food consumption can be implemented by changing consumer behavior. Changing consumer behavior will contribute to improving the standard of living and the availability of environmentally friendly products.

4 DISCUSSION AND CONCLUSIONS

The results of this study provide valuable insights into the drivers and barriers of sustainable food consumption, offering both a theoretical basis and practical implications. The study confirms that the transition to sustainable consumption must take into account economic, environmental and social aspects simultaneously (Meybeck & Gitz, 2017; Barling, 2011). One of the key findings is the low level of consumer awareness, which remains a central barrier to behavior change. Many respondents are not fully aware of the importance of sustainability in their daily food choices. This finding echoes the findings of Gorgitano and Sodano (2014). Furthermore, the study identifies both motivating and demotivating factors influencing consumer behavior. Health, environmental concerns and ethical responsibility were identified as key motivating factors, which is consistent with the findings of Tobler, Visschers and Siegrist (2011) and Alsaffar (2016). However, demotivating factors such as lack of reliable sustainability labelling, higher prices and limited access to sustainable products are consistent with concerns raised by Yadav *et al.* (2019).

This study deepens the understanding of the factors shaping consumer behavior in the context of sustainable food consumption. One of the problems of the slow transition of society to sustainable food consumption is the lack of awareness of this issue, which is not perceived as important today. Unsustainable consumer behavior is associated with unplanned, unnecessary and incorrect purchases, unconscious consumption and post-purchase mistakes in dealing with surpluses and waste. The study allowed to form the components of the sustainable food consumption system in accordance with the concept of rational consumption; to identify motivators that guide food purchases, as well as demotivators that prevent consumers from sustainable food consumption; to provide suggestions for changing consumer behavior in accordance with the concept of more sustainable food consumption.

Despite its contribution, the study has several limitations. First, the sample, although demographically diverse, may not fully represent all consumer groups. Second, the data are based on self-reported responses, which may be influenced by social desirability bias or discrepancies between attitudes and actual behavior. In addition, although the study examined several demographic and socioeconomic indicators, more detailed psychographic or cultural variables (e.g., values, identity, media exposure) could enrich future analyses.

Future research could delve into specific consumer segments, such as youth, families, or the elderly, to identify individual strategies that respond to their unique motivations and barriers. Expanding the geographical scope or conducting comparative studies across countries could also help to illuminate cultural or political differences that influence sustainability-related behaviors. The transition to sustainable food consumption is a multifaceted task that requires interdisciplinary collaboration and long-term commitments from both consumers and producers.

REFERENCES

ALSAFFAR, A. A. 2016. Sustainable Diets: The Interaction Between Food Industry, Nutrition, Health and the Environment. *Food Sci. Technol. Int.* 22(2), 102–111. https://doi.org/10.1177/1082013215572029

AUSTGULEN, M. H. 2014. Environmentally Sustainable Meat Consumption: An Analysis of the Norwegian Public Debate. *J. Consum. Policy.* 37, 45–66.

BARCELLOS, M. D., KRYSTALLIS, A., DE MELO SAAB, M .S., KÜGLER, J. O., GRUNERT, K. G. 2011. Investigating the Gap Between Citizens' Sustainability Attitudes and Food Purchasing Behaviour: Empirical Evidence from Brazilian Pork Consumers. *Int. J. Consum. Stud.* 35, 391–402. https://doi.org/10.1111/j.1470-6431.2010.00978.x

BARLING, D. 2011. The Challenges Facing Contemporary Food Systems: European Policy and Governance Pathways to Sustainable Food Consumption and Production. *Agron. Environ. Soc.*1(2), 15–25.

THE ECONOMIST. 2021. About the Food Sustainability Index. *Economist Impact*. [Accessed: 2024-12-17] https://impact.economist.com/projects/foodsustainability/fsi/about-the-food-sustainability-index/

FRIEL, S., BAROSH, L. J., LAWRENCE, M. 2014. Towards Healthy and Sustainable Food Consumption: An Australian Case Study. *Public Health Nutr.* 17(5), 1156–1166. https://doi.org/10.1017/S1368980013001523

GENOVA, C., ALLEGRETTI, V. 2024. Sustainable Food Consumption: Social Representations of Definitions, Drivers, and Obstacles. *Sustainability*. 16(4), 1415. https://doi.org/10.3390/su16041415

GORGITANO, M. T., SODANO, V. 2014. Sustainable Food Consumption: Concept and Policies. *Calitatea*. 15, 207. [Accessed: 2024-11-25] https://www.researchgate.net/publication/286020550_Sustainable_food_consumption_Concept_and_policies

GORISSEN, K., WEIJTERS, B. 2016.The Negative Footprint Illusion: Perceptual Bias in Sustainable Food Consumption. *J. Environ. Psychol.* 45, 50–65. https://doi.org/10.1016/j.jenvp.2015.11.009

KAMENIDOU, I. C., MAMALIS, S. A., PAVLIDIS, S., BARA, E.-Z. G. 2019. Segmenting the Generation Z Cohort University Students Based on Sustainable Food Consumption Behavior: A Preliminary Study. *Sustainability*. 11(3), 837. https://doi.org/10.3390/su11030837

MEYBECK, A., GITZ, V. 2017. Sustainable Diets within Sustainable Food Systems. *Proc. Nutr. Soc.* 76, 1–11. https://doi.org/10.1017/S0029665116000653

REISCH, L., EBERLE, U., LOREK, S. 2013. Sustainable Food Consumption: An Overview of Contemporary Issues and Policies. *Sustain. Sci. Pract. Policy*. 9, 7–25. https://doi.org/10.1080/15487733.2013.11908111

SIDALI, K. L., SPILLER, A., MEYER-HOEFER, M. 2016. Consumer Expectations Regarding Sustainable Food: Insights from Developed and Emerging Markets. *Int. Food Agribus. Manag. Rev.* 19, 141–170.

SUSTAINABLE DEVELOPMENT COMMISSION. 2009. *Setting the Table: Advice to Government on Priority Elements of Sustainable Diet*. SDC, London. [Accessed: 2024-12-17] http://www.sd-commission.org.uk/publications.php?id=1033

TEKINBAS OZKAYA, F., DURAK, M. G., DOGAN, O., BULUT, Z. A., HAAS, R. 2021. Sustainable Consumption of Food: Framing the Concept through Turkish Expert Opinions. *Sustainability.* 13(7), 3946. https://doi.org/10.3390/su13073946

TOBLER, C., VISSCHERS, V. H., SIEGRIST, M. 2011. Eating Green. Consumers' Willingness to Adopt Ecological Food Consumption Behaviors. *Appetite*. 57, 674–682. https://doi.org/10.1016/j.appet.2011.08.010

THOGERSEN, J. 2010. Country Differences in Sustainable Consumption: The Case of Organic Food. *J. Macromarketing*. 30, 171–185. https://doi.org/10.1177/0276146710361926

VASSALLO, M., SCALVEDI, M. L., SABA, A. 2016. Investigating Psychosocial Determinants in Influencing Sustainable Food Consumption in Italy. *Int. J. Consum. Stud*. 40, 422–434. https://doi.org/10.1111/ijcs.12268

VINNARI, M. 2008. The Future of Meat Consumption—Expert Views from Finland. *Technol. Forecast. Soc. Chang.* 75, 893–904. https://doi.org/10.1016/j.techfore.2007.02.001

VITTERSO, G., TANGELAND, T. 2015. The Role of Consumers in Transitions Towards Sustainable Food Consumption. The Case of Organic Food in Norway. *J. Clean. Prod.* 92, 91–99. https://doi.org/10.1016/j.jclepro.2014.12.055

WONGPRAWMAS, R., MORA, C., PELLEGRINI, N., GUINÉ, R. P. F., CARINI, E., SOGARI, G., VITTADINI, E. 2021. Food Choice Determinants and Perceptions of a Healthy Diet among Italian Consumers. *Foods.* 10, 318. https://doi.org/10.3390/foods10020318

YADAV, R., SINGH, P. K., SRIVASTAVA, A., AHMAD, A. 2019. Motivators and Barriers to Sustainable Food Consumption: Qualitative Inquiry About Organic Food Consumers in a Developing Nation. *Int. J. Nonprofit Volunt. Sect. Mark.* 24, 1650. https://doi.org/10.1002/nvsm.1650

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SUSTAINABLE COMPETITIVENESS: THE ROLE OF ENVIRONMENTAL PERFORMANCE IN ECONOMIC RANKINGS

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ABSTRACT

This study examines the relationship between competitiveness and sustainability, demonstrating a positive correlation between high national competitiveness and strong environmental performance. Using data from the Environmental Performance Index (EPI) and the IMD World Competitiveness Ranking, the analysis highlights those sustainable practices that contribute significantly to long-term competitive advantage. The results show that countries excelling in economic infrastructure, innovation, and governance often prioritize environmental policies, enhancing both competitiveness and sustainability. These findings underscore the importance of integrating sustainable practices into economic strategies to foster balanced and resilient growth.

Keywords: Competitiveness, Sustainability, 21st Century, Environmental Performance Index (EPI), IMD World Competitiveness Ranking, Resource-Based View (RBV), Economic Growth

JEL Codes: Q56, F63, O44, Q01, O11

1 INTRODUCTION

The intersection of competitiveness and sustainability has emerged as a critical area of study, as companies increasingly strive to achieve economic growth while addressing environmental and social imperatives. The literature reveals a growing convergence of these concepts, highlighting that long-term competitiveness is increasingly dependent on sustainable practices. This convergence between the two concepts is essential in contemporary business and economic discourse.

Competitiveness generally refers to a firm's ability to maintain an advantageous position in the market, whereas sustainability emphasizes the responsible use of resources to meet current needs without compromising future generations' ability to meet theirs. And is traditionally defined as a firm's capacity to maintain an advantageous position within a market by enhancing productivity, efficiency, and profitability (Porter, 1990). Sustainability, on the other

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hand, focuses on the long-term stewardship of resources, balancing present needs with the future welfare of society and the environment (WCED, 1987). Scholars argue that competitive advantage is increasingly derived from sustainable practices, as these address the social and environmental expectations that define modern markets.

The present article has as its main aim to investigate the current relationship between the two concepts and how sustainability contributes to maintaining and increasing the competitiveness of companies and countries. And is structured as follows: after this introduction, section 2 presents a literature review of the theoretical framework and the relation between the two concepts, considering the seminal papers and the state of the art, and the main contributions.

2 LITERATURE REVIEW

Early theories on competitiveness, rooted in classical economic thought, primarily focused on productivity and innovation as drivers of competitive advantage (Porter, 1990; Pereira, 2005). Porter's Diamond Model outlines key determinants of national competitive advantage, including factor conditions, demand conditions, related industries, and firm strategy. However, Porter's later work on the concept of "shared value" (Porter & Kramer, 2011) marks a shift towards a broader view, suggesting that firms can create economic value by addressing social and environmental challenges and is near the Resource Based View (RBV) (Barney, 1991; Penrose, 1958). This perspective is related to the business analysis framework for strategic management based on value, rarity, imitability, and organization (VRIO). Proposed by Barney (1991), VRIO is a form of internal analysis that evaluates all the resources and capabilities of a firm.

The RBV is a strategic framework that focuses on how a firm‘s internal resources contribute to sustaining competitive advantage. Recent scholarly work has expanded and critiqued this perspective, offering deeper insights into its applications and limitations. The integration with international business, developed by Peng (2001), examines the diffusion of RBV within international business research, highlighting its influence on areas such as multinational management and strategic alliances. The study underscores the RBV‘s role in understanding firm strategies across diverse markets. On the other side, addressing some critiques of RBV, Kraaijenbrink, Spender, and Groen (2010) provide a comprehensive review of critiques against RBV, addressing concerns about its theoretical underpinnings and practical applicability. They propose enhancements to strengthen RBV‘s explanatory power in strategic management. And a renewed RBV applied to contemporary contexts by Devinney, Schwalbach and Leitner (2022) introduced a renewal version of RBV by incorporating new contexts such as artificial intelligence and digitization. This work emphasizes the need for RBV to evolve in response to technological advancements and changing business environments. Considering some practical implications and applications, Bresser and Powalla (2012) investigate the practical applications of RBV, particularly through the VRIO framework, in strategic decision-making. Their research compares the effectiveness of theory-based tools with alternative heuristics, providing insights into the RBV‘s utility in managerial practice. These articles collectively advance the understanding of RBV by integrating it with international business strategies, addressing theoretical critiques, adapting it to modern technological contexts, and exploring its practical applications. They offer valuable perspectives for both scholars and practitioners aiming to leverage internal resources for competitive advantage.

Sustainability, on the other hand, draws from environmental science, ethics, and development studies, with frameworks like the Triple Bottom Line (Elkington, 1997), which advocates for the integration of social, environmental, and economic performance measures. Combining these perspectives, Hart (1995) introduced the "natural-resource-based view" of the firm, suggesting that sustainable resource management can be a source of competitive advantage.

2.1 Competitiveness through Sustainable Practices

The Sustainable Value Framework proposed by Hart and Milstein (2003) provides a strategic blueprint for aligning sustainability with business performance. This model emphasizes that sustainable development strategies can generate long-term profitability by fostering innovation, resource efficiency, and stakeholder engagement. By balancing environmental, social, and economic concerns, firms can achieve resilience and flexibility, essential for maintaining competitiveness in an evolving market.

Resource efficiency and strictly related to cost savings. Research indicates that sustainable practices such as energy efficiency, waste reduction, and resource conservation can lower operational costs and increase competitiveness. Studies by Schaltegger and Wagner (2011) have shown that firms adopting eco-efficiency measures often enjoy both environmental and economic benefits, suggesting that sustainability can drive profitability through efficiency.

Sustainability-driven innovation is another critical component of competitiveness, as innovation is a critical factor of competitive advantage (Pereira, 2005). The development of green products, circular economy models, and sustainable supply chains not only meets regulatory and consumer demand for sustainable solutions but also differentiates companies within their markets. A study by Nidumolu, Prahalad, and Rangaswami (2009) argued that sustainability challenges spur innovation, leading companies to rethink business models and design processes that contribute to lasting competitive advantage.

Sustainable practices can enhance brand reputation, build customer loyalty, and increase market share. According to Luo and Bhattacharya (2006), firms with strong corporate social responsibility (CSR) records tend to enjoy a "reputation premium", which can lead to improved financial performance. Consumers increasingly favor brands that demonstrate commitment to environmental and social issues, making sustainability a key differentiator.

2.2 Integrating Competitiveness and Sustainability in Strategy

Academic literature suggests several strategic frameworks for aligning competitiveness and sustainability. The Sustainable Value Framework (Hart & Milstein, 2003) provides a strategic approach that aligns sustainability with business performance, proposing that sustainable development strategies are beneficial not only to the environment but also to firm profitability and growth.

Ghisellini, Cialani, and Ulgiati (2016) indicate that circular economy models, which emphasize resource reuse and product life-cycle extension, can enhance competitiveness by reducing dependency on raw materials and minimizing waste. By adopting these principles, firms can achieve cost savings, enhance resource security, and build sustainable value chains, thus strengthening their market position and contributing to competitive advantage

The stakeholder's theory (Freeman, 1984) suggests that addressing the needs of all stakeholders—including customers, employees, suppliers, and the environment—can lead to stronger competitive positioning. By adopting this perspective, firms can mitigate risks, build stronger relationships, and enhance long-term viability.

The concept of dynamic capabilities (Teece, Pisano, & Shuen, 1997) has been extended to sustainability, where firms must continuously adapt and innovate to respond to changing environmental and social expectations. This view supports the notion that sustainability-oriented firms develop unique capabilities that enhance adaptability and competitiveness.

2.3 Challenges in Achieving Sustainable Competitiveness

Despite the apparent benefits, firms face significant barriers in integrating sustainability with competitiveness:

I. Cost and Investment Requirements: Sustainability initiatives often require upfront investments in technology, training, and infrastructure, which may impact short-term profitability. Not all firms have the capital or incentives to adopt sustainable practices fully, particularly in highly competitive industries with thin margins.
II. Regulatory and Market Constraints: Variability in environmental regulations and market conditions can create uncertainty, complicating the alignment of competitiveness and sustainability strategies. Inconsistent standards and the lack of a global regulatory framework can limit firms' ability to standardize and scale sustainable practices.
III. Greenwashing and Authenticity Risks: Firms that attempt to project a sustainable image without substantive actions (greenwashing) risk damaging their reputation and customer trust. A study by Delmas and Burbano (2011) found that such deceptive practices can backfire, leading to consumer skepticism and competitive disadvantages for genuinely sustainable firms.

2.4 Recent Trends and Future Directions in Research

Recent research suggests a shift towards a more integrated view of competitiveness and sustainability. For instance, attention has turned to sustainable finance, where investment funds increasingly evaluate companies based on Environmental, Social, and Governance (ESG) criteria, linking capital availability to sustainable performance (Friede, Busch, & Bassen, 2015). Digitalization is also playing a key role; digital technologies, such as blockchain, AI, and big data, enable firms to track, measure, and optimize sustainable practices, enhancing transparency and accountability in supply chains.

Future Directions: Emerging areas of research explore the potential for sustainability to become a foundational aspect of competitive advantage. Scholars such as Bansal and DesJardine (2014) suggest that rather than viewing sustainability as an isolated component, firms should integrate it across all levels of strategy, enabling them to respond to societal pressures and shifting stakeholder expectations.

3 METHODOLOGY AND DATA

Competitiveness and sustainability are critical metrics for assessing the economic and environmental health of nations. Various indices provide insights into these areas, highlighting global and European standings. Some of these, the most well-known, are:

a) For global competitiveness: The World Economic Forum's Global Competitiveness Index (GCI), which evaluates the competitiveness landscape of economies worldwide. The latest available data indicates that Singapore ranks first, followed by Switzerland and Denmark. These rankings reflect factors such as infrastructure, macroeconomic
b) For the European competitiveness: The IMD World Competitiveness Ranking. Within Europe, countries like Switzerland and Denmark consistently perform well in competitiveness rankings. The IMD World Competitiveness Ranking 2024 places Switzerland second and Denmark third among 67 economies, highlighting their robust economic performance and efficient governance structures. (IMD World Competitiveness Center, 2024).
c) For global sustainability, the Environmental Performance Index (EPI) assesses the environmental health and ecosystem vitality of countries. In the 2024 EPI, Estonia achieved the top position, reflecting significant progress in reducing emissions and

enhancing environmental policies. Denmark, previously a leader, ranked 10th, indicating challenges in maintaining its earlier environmental performance levels (Yale Center for Environmental Law & Policy, & Center for International Earth Science Information Network, 2024).

In Europe, considering European sustainability, several countries demonstrate strong commitments to sustainability. The 2024 EPI highlights Estonia's leading position, with Luxembourg and Germany also performing well. These rankings underscore effective environmental policies and practices within these nations (Yale Center for Environmental Law & Policy & Center for International Earth Science Information Network, 2024).

These indices provide valuable insights into how countries balance economic competitiveness with environmental sustainability, offering benchmarks for policy development and international comparisons.

Given sustainability by EPI scores that reflect environmental health and ecosystem vitality, the IMD Competitiveness Rank assesses economic performance, government efficiency, business efficiency, and infrastructure. Analysing the relationship between national competitiveness and environmental sustainability reveals a positive correlation, indicating that countries excelling in competitiveness often demonstrate strong environmental performance.

Many applied studies highlight a significant correlation between Competitiveness and Environmental Performance. These studies have shown that nations ranking high on the Global Competitiveness Index (GCI) also tend to perform well on the Environmental Performance Index (EPI). An empirical analysis done by Santos and Siquiera (2014), based on a canonical correlation analysis examining the relationship between competitiveness and environmental sustainability, found a significant interrelation between these dimensions. The study analysed indicators from both the EPI and GCI across 117 countries, revealing that strong environmental performance is associated with higher competitiveness. Esty and Charnovitz (2012) explored the empirical association between environmental performance and national competitiveness, emphasizing that countries with better environmental performance often occupy top positions in global competitiveness indices. Dima *et al.* (2018) investigated the influence of the Global Competitiveness Index on economic performance, concluding that factors such as innovation and environmental sustainability are significant determinants for enhancing an economy's competitiveness. Zhang *et al.* (2021) investigated how environmental performance impacts competitiveness and economic growth, highlighting that those nations with high human development indices are better able to balance environmental sustainability with economic competitiveness.

For the empirical analysis in this paper, to examine the relationship between competitiveness and sustainability, data from the Environmental Performance Index (EPI) and the IMD World Competitiveness Ranking were used. The EPI is published every two years, and in 2024 it was not been published yet. The IMD Competitiveness Rank is annually published, being the most recent edition published in 2024. So, considering this data constraint, the period considered was the years 2022 and 2024. Analysing the way the sustainable performance was verified in 2022, reflected in competitiveness two years after, like it was an investment made in 2022 to be reflected in the competitiveness two years after. A Pearson correlation analysis was applied to a better analysis.

The sample of countries was based on the choice of the 20 best-ranked countries in the EPI index in 2022, for a comparison with their positions in the IMD Competitiveness Rank in 2024. This intends to analyse the sustainable competitiveness in terms of the role of environmental performance reflected in a lagged way in economic competitiveness rankings.

4 RESULTS

Table 1 illustrates the relationship between national competitiveness and environmental sustainability data, using the 2022 Environmental Performance Index (EPI) and the 2024 IMD World Competitiveness Ranking for the 20 selected countries.

The data collected were inserted into the Stata software to calculate the correlation between the positions of the 20 countries in the two rank's indicators.

This data analysis shows a positive correlation between these two dimensions, demonstrating that the relationship between environmental sustainability and national competitiveness is moderately aligned, suggesting that countries with higher environmental performance (lower EPI ranks) tend to have better competitiveness rankings (lower IMD ranks) (Table 1 and Figure 1). The Pearson correlation coefficient between the EPI ranks (2022) and IMD Competitiveness ranks (2024), for the top 20 countries, is 0.521, which indicates a moderate positive correlation, with a p-value of 0.018, indicating that the correlation is statistically significant. This correlation between competitiveness and sustainability has been increasing over time.

The analysis reveals a moderate positive relationship between competitiveness and sustainability, this given by the EPI. Countries with higher competitiveness rankings, such as Switzerland, Denmark, and Singapore, consistently demonstrate strong environmental performance, reflected in their EPI scores.

Tab. 1 Countries' ranked position between national competitiveness and environmental sustainability

Country	EPI Rank (2022)	IMD Competitiveness Rank (2024)
Denmark	1	3
United Kingdom	2	29
Finland	3	11
Malta	4	36
Sweden	5	6
Luxembourg	6	12
Slovenia	7	40
Austria	8	25
Switzerland	9	2
Iceland	10	13
Spain	11	30
Estonia	12	31
Portugal	13	33
France	14	31
Germany	15	24
Ireland	16	7
Cyprus	17	37
Italy	18	41
Slovakia	19	50
Latvia	20	38

Sources: 2022 Environmental Performance Index (EPI), IMD World Competitiveness Ranking 2024

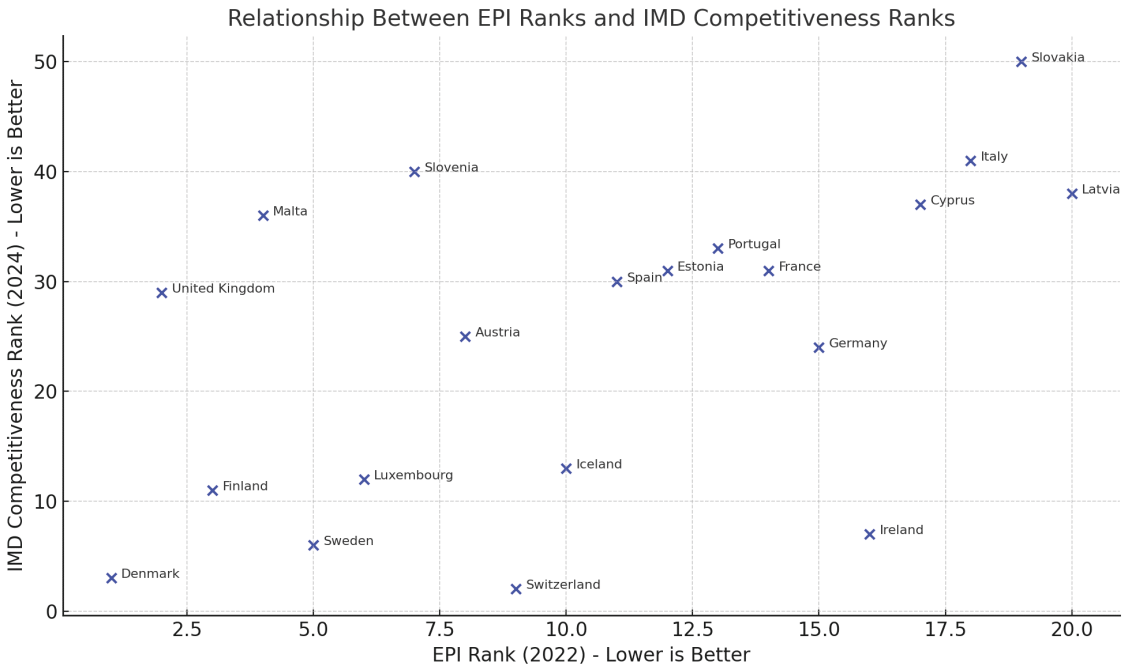

Fig. 1: Competitiveness versus Environmental Performance
Sources: 2022 Environmental Performance Index (EPI), IMD World Competitiveness Ranking 2024

- This relationship suggests that nations excelling in economic infrastructure, innovation, and governance (key components of competitiveness) often prioritize sustainable practices and policies. The alignment underscores the potential for integrating environmental performance as a strategic driver of competitiveness, emphasizing that economic growth and environmental sustainability can complement rather than conflict with one another.
- These findings highlight the importance of fostering policies that balance economic and environmental objectives, demonstrating that competitiveness and sustainability are mutually reinforcing goals for long-term national development and for the sustainable economic growth of nations.

5 DISCUSSION AND CONCLUSIONS

Countries with high competitiveness rankings, such as Switzerland, Denmark, and Singapore, consistently demonstrate strong environmental performance, as reflected in their EPI scores (Environmental Performance Index, 2022; IMD World Competitiveness Center, 2024). This finding aligns with previous research, which has shown that nations excelling in economic infrastructure, innovation, and governance—key components of competitiveness—often prioritize sustainable practices and policies (Porter & van der Linde, 1995; Atici *et al.*, 2021).

The alignment between competitiveness and environmental sustainability underscores the potential for integrating environmental performance as a strategic driver of national competitiveness, emphasizing that economic growth and environmental sustainability can be complementary rather than conflicting objectives (IMD World Competitiveness Center, 2024; Yale Center for Environmental Law & Policy, 2022). This perspective is further supported by studies indicating that robust institutions, effective governance, and innovation capacity are strongly associated with both higher competitiveness and better environmental outcomes (Atici *et al.*, 2021; Porter & van der Linde, 1995).

The literature on competitiveness and sustainability indicates that the positive relationship between Competitiveness and Sustainability is increasingly intertwined in the 21st century. While traditional views positioned them as potentially conflicting objectives, contemporary research reveals that sustainable practices can contribute significantly to competitive advantage by driving efficiency, fostering innovation, and enhancing brand loyalty. However, significant challenges remain, particularly in aligning short-term financial goals with long--term sustainability outcomes. Continued research and strategic innovation are essential for firms seeking to achieve sustainable competitiveness, which is likely to become a defining feature of successful businesses in the years to come. As well, additional research on these topics must be developed, for example, a regression analysis and a Granger causality model, in addition to correlation analysis, with the purpose of showing causality between the two indicators.

REFERENCES

ATICI, K. B., SIMÕES, P., and DIAS, M. F. 2021. The relationship between environmental performance and competitiveness: Evidence from European countries. *Environmental Science & Policy.* 120, 29–41. https://doi.org/10.1016/j.envsci.2021.02.009

BANSAL, P., DESJARDINE, M. R. 2014. Business sustainability: It is about time. *Strategic Organization*. 12(1), 70–78.

BARNEY, J. 1991. Firm resources and sustained competitive advantage. *Journal of Management*. 17(1), 99–120. https://doi.org/10.1177/014920639101700108

BRESSER, R. K. F., POWALLA, M. 2012. Practical implications of resource-based theory in strategic decision-making: Assessing the VRIO framework against alternative heuristics. *Zeitschrift für Betriebswirtschaft*. 82, 335–359. https://doi.org/10.1007/s11573-012-0553-4

DELMAS, M. A.,BURBANO, V. C. 2011. The drivers of greenwashing. *California Management Review*. 54(1), 64–87.

DEVINNEY, T. M., SCHWALBACH, J., LEITNER, K.-H. 2022. *Renewing the resource-based view: A special issue on contemporary contexts such as artificial intelligence and digitization*. Wharton Faculty Papers. https://faculty.wharton.upenn.edu

DIMA, A. M., GRABARA, J., VLĂDUŢESCU, S. 2018. Sustainable competitiveness: How does global competitiveness index relate to economic performance? *Journal of Competitiveness.* 10(4), 5–20. https://doi.org/10.7441/joc.2018.04.01

ELKINGTON, J. 1997. *Cannibals with forks: The triple bottom line of 21st century business.* Capstone.

ESTY, D. C., CHARNOVITZ, S. 2012. *Environmental sustainability and competitiveness: Policy imperative and corporate opportunity*. Harvard Business School Working Paper. https://www.hbs.edu/competitiveness/Documents/USComp-EstyCharnovitz-WorkingPaper.pdf

ENVIRONMENTAL PERFORMANCE INDEX. 2022. *2022 EPI Results*. Yale Center for Environmental Law & Policy. https://epi.yale.edu/epi-results/2022/component/epi

FREEMAN, R. E. 1984. *Strategic management: A stakeholder approach.* Pitman.

FRIEDE, G., BUSCH, T., BASSEN, A. 2015. ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment*. 5(4), 210–233.

GHISELLINI, P., CIALANI, C., ULGIATI, S. 2016. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*. 114, 11–32.

HART, S. L. 1995. A natural-resource-based view of the firm. *Academy of Management Review*. 20(4), 986–1014.

HART, S. L., MILSTEIN, M. B. 2003. Creating sustainable value. *Academy of Management Perspectives*. 17(2), 56–67.

IMD WORLD COMPETITIVENESS CENTER. 2024. IMD World Competitiveness Ranking 2024. https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/

KRAAIJENBRINK, J., SPENDER, J.-C., GROEN, A. J. 2010. The resource-based view: A review and assessment of its critiques. *Munich Personal RePEc Archive*. [Accessed: 28 October 2024] https://mpra.ub.uni-muenchen.de/21442/

LUO, X., BHATTACHARYA, C. B. 2006. Corporate social responsibility, customer satisfaction, and market value. *Journal of Marketing.* 70(4), 1–18.

NIDUMOLU, R., PRAHALAD, C. K., RANGASWAMI, M. R. 2009. Why sustainability is now the key driver of innovation. *Harvard Business Review*. 87(9), 56–64.

PENG, M. W. 2001. The Resource-Based View and International Business*. Journal of Management. 27, 803-829. http://dx.doi.org/10.1177/014920630102700611*

PEREIRA, E. T. 2005. *Factors of competitiveness and business performance: A study applied to the ceramics sector in Portugal.* Doctoral dissertation. University of Aveiro.

PORTER, M. E. 1990. *The competitive advantage of nations.* Free Press.

PORTER, M. E., KRAMER, M. R. 2011. Creating shared value. *Harvard Business Review*. 89(1/2), 62–77.

PORTER, M. E., VAN DER LINDE, C. 1995. Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*. 9(4), 97–118. https://doi.org/10.1257/jep.9.4.97

SANTOS, S. F., SIQUEIRA, H. B. 2014. A canonical correlation analysis of the relationship between sustainability and competitiveness. *Clean Technologies and Environmental Policy*. 16(8), 1735–1746. https://doi.org/10.1007/s10098-014-0755-2

SCHALTEGGER, S., WAGNER, M. 2011. Sustainable entrepreneurship and sustainability innovation: Categories and interactions. *Business Strategy and the Environment*. 20, 222-237. https://doi.org/10.1002/bse.682

TEECE, D. J., PISANO, G., SHUEN, A. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal.* 18(7), 509–533.

WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT (WCED, 1987). *Our Common Future.* Oxford University Press.

WORLD ECONOMIC FORUM (2019). *The Global Competitiveness Report 2019*. [Accessed: 28 October 2024] https://www.weforum.org/reports/the-global-competitiveness-report-2019

YALE CENTER FOR ENVIRONMENTAL LAW & POLICY, & CENTER FOR INTERNATIONAL EARTH SCIENCE INFORMATION NETWORK. 2024. *Environmental Performance Index*. [Accessed: 28 October 2024] https://epi.yale.edu/

ZHANG, X., WANG, H., LI, X. 2021. The effects of environmental performance on competitiveness and economic growth: The moderating role of human development. *Environment, Development and Sustainability.* 23(10), 14523–14540. https://doi.org/10.1007/s10669-021-09828-w

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THE SUSTAINABILITY TRAJECTORY IN BUSINESS: EXPERIENCES FROM THE SLOVAK REPUBLIC

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ABSTRACT

Sustainable business is one of the main strategic factors for businesses that are trying to strengthen their competitiveness and ensure long-term prosperity in a dynamically changing market environment. Business activities in the field of sustainability include specific steps supporting economic, environmental and social balance, while addressing global challenges of sustainable business. Initiatives in sustainable business also strengthen the reputation of businesses and increase their long-term competitive advantage in the market. The presented study focuses on the analysis of sustainable business in the Slovak Republic, examining selected sustainable activities implemented by businesses. Based on a questionnaire survey that included 402 businesses of various sizes and sectors, it was found that the most frequently implemented activities are recycling and waste minimization, as well as the reduction of water and energy consumption. Sustainable activities bring benefits to businesses, such as reduced operating costs, increased image and access to new markets. Despite positive trends in sustainability, differences persist in the intensity of their application in practice. The paper emphasizes the need for a systematic approach to sustainability and the importance of involving employees in the transformation process. The findings provide a basis for further research into effective sustainable business strategies.

Keywords: enterprise, sustainable business, sustainability, sustainable activities, competitive advantage, ecology, Slovak Republic

JEL Classification: L26, M14, Q56, Q57

1 INTRODUCTION

The business environment around the world is currently extremely unstable, as it is affected by financial crises, digitalization, military conflicts, political situations, climate change, depletion of natural resources and growing demands to minimize negative impacts on the environment (Vrabcová, 2021). Sustainability has become an essential part of business over time and

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should be a key element of corporate strategy, not only in the private sector, but also in public organizations. The issue of sustainability in business is more relevant and important than ever before (Nosratabadi, 2019). Sustainable socially responsible business is becoming a starting point for businesses in making effective decisions about their future direction (Musová and Drugdová, 2021). Schaltegger and Wagner (2011) describe sustainable business as contributing to solving social and environmental problems by implementing successful business and supporting sustainable development through business activities. According to Cavagnoro and Curiel (2022), sustainable business is a way of managing a business that emphasizes a long-term balance between economic growth, environmental protection and positive social impact. The goal is not only to generate maximum profit, but also to minimize negative impacts on the planet and contribute to the well-being of society. While in Western European countries, environmental, social and governance (ESG) activities are increasingly integrated into the strategic management of companies, Slovak companies are often limited to basic environmental measures, such as recycling and reducing energy consumption. Advanced forms of sustainability, such as the development of green products, the application of circular models or the systematic integration of ESG, remain marginal (Gazzola *et al.*, 2024; Laureti *et al.*, 2024). This delayed transition can be explained by a combination of factors: weaker legislative and institutional support, lower levels of ESG awareness in business practice, as well as limited resources and a cautious approach to investments in eco-innovations (Ahmadi-Gh & Bello-Pintado, 2022; Raimo *et al.*, 2021). In this context, the presented study provides an original empirical insight into the state of sustainability in the Slovak business environment. Its aim is not only to identify the most frequently implemented activities and their perceived benefits, but also to point out the differences that distinguish the Slovak context from advanced EU member states. This knowledge is crucial for the creation of more targeted policies and adaptation strategies in the conditions of the Central European space. Chavalittumrong and Speece (2022) state that many businesses implement sustainable practices and focus on building an image that speaks of the sustainability of the business. According to Litvaj *et al.* (2023), up to 62% of European entrepreneurs consider a sustainable development strategy important because it is essential for the competitiveness of the business. Another 22% of European businesses believe that a sustainability strategy will become essential for competitiveness in the future. Laureti *et al.* (2024) argue that sustainable business requires forward thinking that seeks to integrate three dimensions of sustainability:

- Economic sustainability – emphasizes job creation, ensuring profitability and taking ecosystem services into account when assessing costs and benefits. Key aspects include innovation, research and development, efficient use of resources, transparent reporting and evaluation of results, risk management and active cooperation with stakeholders (Monir and Gebremeskel, 2024).
- Social sustainability – includes aspects of environmental justice, health protection, ensuring the availability of resources and lifelong learning of employees. In promoting social sustainability, companies should give priority to the needs of employees, prioritizing their well-being over the economic goals of the companies (Morais and Silvestre, 2018).
- Environmental sustainability – primarily focuses on protecting the environment, including water quality, air quality, innovative technologies in production processes, separation and reduction of environmental burdens. Minimizing negative impacts on the environment also benefits residents, because the quality of human health is closely linked to the quality of the environment in which residents of the region in which the company is located live (Gazzola *et al.*, 2024).

Corporate sustainability activities are concrete steps and initiatives that companies implement to promote economic, environmental and social sustainability. Activities allow companies not only to contribute to solving global challenges such as climate change or social inequality, but also to strengthen their reputation and long-term competitive advantage in the

market (Kajanová *et al.*, 2022). Corporate sustainability strategies include diverse measures that promote responsible behavior towards the environment, employees, communities and society as a whole. Table 1 provides an overview of the main activities in the three key areas of sustainability.

Tab. 1 Sustainable business activities

Business activities in three areas of sustainable business:	
Social sustainability	creating employee comfort, eliminating poverty, combating discrimination, employee education and training, safety and health protection, donation, volunteering, assistance to disadvantaged groups, employment development, supporting education and consumer protection, etc.
Economic sustainability	economic activities, interaction of economic activities and interaction of the environment with the organization, rejection of corruption, transparency, protection of intellectual property, respect for the rules of competition, ecological technology, investments in sustainable projects, etc.
Environmental sustainability	consumption of renewable resources, water and energy consumption, air quality, modern technologies, reducing greenhouse gas emissions, ecological footprint, carbon footprint, biodiversity protection, creation of ecological policy, green logistics, circular economy, etc.

Source: Own research based on Kunz (2012)

Activities in the three dimensions of sustainability significantly contribute to the creation of a sustainable and prosperous enterprise. Established enterprises that have already implemented some elements of sustainability into their processes need to continuously improve or maintain these activities. Enterprises that have chosen the path of sustainability should regularly evaluate their practices, identify their strengths and, conversely, eliminate weaknesses in the future. Every enterprise initiative in the field of sustainability requires the support of employees, who must understand their role and must be identified with the enterprise's goal regarding sustainability (Danciu, 2013).

The main goal of the presented study is to analyze the issue of sustainability in business in the context of selected sustainable activities through empirical research in the form of a questionnaire in enterprises in the Slovak Republic.

To achieve the set goal, the following scientific questions were formulated:

(1) Which environmentally sustainable activities do businesses in Slovakia most often implement?
(2) What benefits do businesses in Slovakia most often perceive when implementing sustainable activities?

In order to fulfill the scientific objective of the article as well as the established scientific questions, this study further works with scientific hypotheses that further analyze the identified condition. As a result, statistical verification of the hypotheses was performed using a two-sided confidence interval.

2 METHODOLOGY AND DATA

To ensure a clear structure and logical continuity, the methodology of the scientific contribution was divided into three phases. The study focuses on the theoretical and practical analysis of the research issue. To achieve the set scientific goal, a detailed analysis of secondary sources related to the issue of sustainable and socially responsible business and activities within

sustainable business was carried out in the first phase. The theoretical analysis drew primarily from foreign scientific sources, which were subsequently supplemented by domestic literature. The main attention was focused on relevant studies published in renowned electronic databases, such as Web of Science (WoS), Science Direct and ProQuest. The methods of analysis, synthesis, induction, deduction, comparison, description and concretization were used in the processing of the theoretical part of the study.

After analyzing the theoretical information, the survey method was used – a questionnaire form of the survey, which appeared to be the most appropriate method of obtaining the necessary data to achieve the main goal of the presented study. The survey method served as the primary source of information for the research part of the work. Based on the obtained theoretical foundations of the given issue, a questionnaire was compiled, which was anonymous and the target group of the research was business entities operating in the territory of the Slovak Republic. The complete questionnaire consisted of two parts. Part A contained basic identification questions. This part of the questionnaire contained three identification questions, the task of which was to determine the size of the company, the industry in which the company operates and the length of time it has been on the market. In part B, attention was paid to the assessment of sustainable business and specific sustainable activities that companies carry out as part of their activities. The preparation and distribution of the electronic questionnaire was ensured using the free Google Forms platform from September 2024 to November 2024. According to the Finstat portal (2024), there are 576,508 enterprises in Slovakia. These enterprises represent the basic set. The research sample consisted of 6,781 randomly selected enterprises. One of the main criteria was that enterprises must be selected randomly from all regions of the Slovak Republic. The selection was carried out using a random number generator, which guaranteed equal chances and a high degree of randomness in the selection of the enterprises we addressed.

The variables selected for hypothesis testing are based on the theoretical framework identified in the introduction (through literature sources) and the most frequently cited areas of environmental activities and their expected benefits. Reducing water and energy consumption is among the most frequently implemented environmental measures with a direct impact on costs and efficiency (Ekins, Zenghelis, 2021; Ahmadi-Gh, Bello-Pintado, 2022). At the same time, several studies report that lower operating costs are one of the main motivations for companies to implement sustainable measures (Raimo *et al.*, 2021). The selection of these variables also reflects, among other things, their high practical relevance for companies in the Slovak economic context.

After collecting, processing and analyzing the obtained data, the questionnaire survey was evaluated statistically, numerically, graphically and the results were presented using a descriptive method. All types of tests performed, analysis and processing of the obtained data were carried out using the statistical program Statistica 14.

According to Trnka (2016), calculating the minimum size of a research sample is the process of assessing the sufficient sample size in terms of the requirements and objectives of a given study. The process involves determining the optimal sample size needed to achieve relevant results. A simple calculation is used to determine the sample size:

(1)

$$n = \frac{z^2 \times p \times (1-p)}{e^2}$$

where:
z – value, substituted from statistical tables (confidence level 95%, z = 1.96),
p – proportion of the sign, with unknown total values p = 0.5,
e – permissible margin of error (value 2–10%), research sets a value of 5%.

In connection with the main goal of the presented scientific study, the following hypotheses were formulated, which resulted from the current knowledge of the issue being addressed:

- H_1 It is assumed that businesses focus most on reducing water and energy consumption among selected activities within the framework of environmental sustainability.

Efficient water and energy management are among the most frequently implemented environmental measures in companies, as they are resources with high strategic value and limited availability (Blackburn, 2012). Reducing their consumption also brings a rapid return on investment and visible operational savings (Feroz *et al.*, 2021). Companies are thus responding to growing pressure from stakeholders and legislation, and these measures are often the first step towards a broader sustainability transformation (Ekins, Zenghelis, 2021). Research confirms that small and medium-sized enterprises in particular prefer simple and low-cost interventions that combine environmental and economic benefits (Abubakar *et al.*, 2022). In addition, digitalization in this sector allows for more accurate monitoring of consumption and identification of savings. These activities also support the achievement of sustainable development goals, especially in the areas of climate action and resource efficiency (Feroz *et al.*, 2021).

- H_2 It is assumed that implementing sustainable activities most often brings benefits to businesses in the form of lower operating costs.

Implementing sustainable measures, such as reducing energy consumption or more efficient waste management, often leads to significant cost savings (Ekins, Zenghelis, 2021). Several studies confirm that economic benefits are the main motivator for companies to implement environmental strategies (Ahmadi-Gh, Bello-Pintado, 2022). Effective sustainable practices can also improve production outputs and competitiveness of companies. In addition, companies with a high level of transparency achieve more favorable financing conditions, which further reduces their cost burden (Raimo *et al.*, 2021). Perceived savings and stakeholder pressure motivate companies to systematically improve environmental performance. As a result, it is expected that companies primarily perceive cost reduction as the main advantage of sustainable activities (Ahmadi-Gh, Bello-Pintado, 2022).

There are many practical situations where it is necessary to estimate the proportion, probability, or rate of successful observations π in a population. A two-sided confidence interval is used to test the hypotheses of a scientific study. A two-sided confidence interval is a statistical term that indicates the range of values within which a population parameter lies with a certain degree of confidence based on sample data. A two-sided confidence interval has the form (Pacáková *et al.*, 2009):

(2)

$$P\left(p - z_{1-\frac{\alpha}{2}}\sqrt{\frac{p(1-p)}{n}} < \pi < p + z_{1-\frac{\alpha}{2}}\sqrt{\frac{p(1-p)}{n}}\right) = 1 - \alpha$$

where:
π – proportion in the population,
p – percentage of marks in the questionnaire,
n – total range of values.

The final part of the study is based on the methods of analogy, synthesis, deduction and summarization, where the summary of conclusions is subsequently strategically supplemented by the use of a systems approach, which allows for the formulation of the future direction of the presented research.

3 RESULTS

The calculation of the minimum scope of the research shows that the size of the sample of enterprises in the questionnaire survey, which ensures sufficient representation and statistical significance, is at least 384 enterprises operating in Slovakia. The number of respondents was determined based on standard formula criteria, which include the required level of accuracy and reliability of the achieved results (Trnka, 2016). A total of 6,781 enterprises were contacted by us through direct communication via e-mail addresses. Of the total group of respondents contacted, 402 enterprises completed the questionnaire, which represents a relatively low return rate of 5.93%. The statistical level of the minimum scope of the research sample, i.e. 384 responses from the questionnaire survey, was exceeded, since 402 responses were recorded. It follows from the above that the achieved results can be generalized to the entire basic set.

The first question of the questionnaire served as an important element in the conducted survey, as it is generally expected that sustainability is more widely used in larger enterprises. The results of the questionnaire survey showed that medium-sized enterprises were the most represented, which amounted to 49.25% (198 enterprises). This was followed by small enterprises, which participated by 46.52% (187 enterprises) of the total number of enterprises, and the smallest representation was large enterprises, which responded by only 4.23% (17 enterprises).

From the data obtained, it is clear that the majority of companies in Slovakia (85.32%; 343 companies) responded that they carry out sustainable activities. Although only 28.86% (116 companies) indicated that they carry out sustainable activities regularly, it is noticeable that companies are increasingly dealing with sustainability issues, which is also confirmed by the fact that up to 50.75% (204 companies) responded that they carry out sustainable activities sporadically. A very positive finding is that only 2.24% (9 companies) indicated that they do not carry out any sustainable activities in their business.

Based on the nature of the data obtained, a two-sided 95% confidence interval was used to test the hypotheses. The data obtained for the first hypothesis H1 are presented in Table 2.

Tab. 2 Environmental sustainability activities

95% interval estimate	p	n	lower limit	upper limit
Recycling and waste minimization	48.01%	402	39%	57%
Protecting biodiversity	25.22%	402	17%	33%
Reducing carbon footprint (reducing greenhouse gas emissions)	33.91%	402	25%	43%
Green logistics (storing and delivering goods in a sustainable way)	31.30%	402	23%	40%
Reducing water and energy consumption	46.27%	402	37%	55%
Reducing greenhouse gas emissions	20.87%	402	13%	28%
Investing in renewable resources	26.96%	402	19%	35%
Producing green products	13.04%	402	7%	19%
No activities at all	5.22%	402	1%	9%

Source: Own research

It was found that 48.01% (193 companies) of the surveyed companies are engaged in recycling and waste minimization. Based on the confidence interval, it can be estimated that in the entire population of companies of a given type, from 39% to 57% of companies are engaged in recycling and waste minimization. The working hypothesis assumed that companies focus most on reducing water and energy consumption among the selected activities. Out of 402 respondents, 46.27% (186 companies) indicated that they are engaged in reducing water and energy consumption, but based on the two-sided 95% confidence interval, it can be said that in the entire population of companies of a given type, from 37% to 55% of companies are engaged in reducing water and energy consumption. This means that the working **hypothesis H1 was not confirmed**, because companies focus most on recycling and waste minimization. Reducing water and energy consumption was in second place. These two activities are followed by reducing the carbon footprint, which is addressed by 25% to 43% of the entire population of businesses of this type. The least of the selected activities is focused on the production of green products (from 7% to 19%).

Furthermore, companies were given the opportunity to express what benefits sustainable initiatives bring them. A two-sided 95% confidence interval is also used for the question regarding the benefits of implementing sustainable activities (Table3). The second working hypothesis H2 is linked to the question: It is assumed that implementing sustainable activities most often brings companies a benefit in the form of lower operating costs.

Tab. 3 Benefits of implementing sustainability in a business

95% interval estimate	p	n	lower limit	upper limit
Competitive advantage	20.00%	402	13%	27%
Lower operating costs	53.23%	402	44%	62%
Access to new markets and opportunities	42.61%	402	34%	52%
Attracting new investors and customers	29.57%	402	21%	38%
Growing company image	37.56%	402	29%	46%
Better stakeholder relations	32.17%	402	24%	41%
Does not bring us benefits	5.22%	402	1%	9%
No activities at all	4.35%	402	1%	8%

Source: Own research

In the second case (Table 3), the working **hypothesis H2 was confirmed** and established correctly, as up to 53.23% (214 companies) perceive that implementing sustainable activities brings them an advantage in the form of lower operating costs. Based on the confidence interval, it can be estimated that in the entire population of companies of a given type, this advantage is perceived by 44% to 62% of companies. High percentages also achieved advantages such as access to new markets and opportunities. The advantage in the form of access to new markets and opportunities is perceived by 34% to 52% of companies in the entire population of companies of the given type under study. The advantage in the form of a growing company image was indicated in the survey

by 37.56% (151 companies), which means that companies largely improve in the eyes of stakeholders if they implement sustainable activities. It can be estimated that in the entire population of businesses of a given type, from 1% to 9% of businesses do not perceive that implementing sustainable activities would bring them benefits.

4 DISCUSSION AND CONCLUSIONS

The research results show that companies in Slovakia carry out a wide range of sustainable activities, with the greatest emphasis on recycling and waste minimization (48.01% of companies) and reducing water and energy consumption (46.27% of companies). These findings directly answer the first research question regarding the most frequently implemented environmental activities, and are also in line with studies by authors around Laureti (2024), who emphasize the importance of environmentally responsible measures for the long-term competitiveness of companies. Similarly, Cavagnoro and Curiel (2022) confirm that environmental sustainability is a key pillar of corporate strategy, contributing to the improvement of both economic and social outcomes. A comparison with the research of Laureti *et al.* (2024) shows that Slovak companies follow similar trends to companies in other parts of Europe, especially when it comes to integrating environmental initiatives into their processes. Interestingly, however, Slovak companies still show a low level of implementation of advanced sustainable strategies, such as the production of green products (only 13.04% of companies), which is in contrast to the findings of Gazzola *et al.* (2024), who point to the growing popularity of this activity in Western European countries. The results also indicate that sustainable activities bring significant benefits to companies, in particular reduced operating costs (53.23%) and improved image (37.56%). In this way, the second research question focused on the perceived benefits of sustainable measures is also confirmed. These findings are in line with the claims of Monir and Gebremeskel (2024), who point to the synergistic effect between environmental responsibility and financial benefits. Despite the fact that up to 85.32% of companies reported that they carry out at least sporadic sustainable activities, differences in the intensity of their application point to shortcomings in a systematic approach.

The results of the analysis confirm that sustainability is an increasingly important aspect of business in the Slovak Republic. The survey showed that the majority of companies implement sustainable activities, with the greatest emphasis on recycling and waste minimization, as well as on reducing water and energy consumption. These initiatives not only contribute to environmental protection, but also strengthen the competitiveness of companies and bring financial benefits, including reducing operating costs. The findings indicate that the implementation of sustainable strategies brings companies wider development opportunities, such as access to new markets or building a positive image in the eyes of stakeholders and the public. Despite the fact that sustainable activities are not evenly spread across all sectors and sizes of companies, the overall trend indicates a growing awareness of their importance. To achieve long-term sustainability, it is crucial for companies to regularly evaluate their practices, identify shortcomings and develop innovations in accordance with environmental, economic and social requirements. At the same time, employee support and engagement are essential, playing a crucial role in the successful implementation of these activities.

From a practical perspective, the results can serve as a guideline for policymakers to support in particular activities with high economic benefits and low implementation costs – such as recycling or energy saving. For small and medium-sized enterprises, these measures represent an entry point into sustainability, bringing them measurable savings. Gradually, these basic activities should be complemented by more advanced forms, such as green product development or circular innovation. The key is a combination of research support, practical examples and education, which will show businesses that eco-innovation can also

be economically beneficial. This creates a framework for a systematic and realistic transition to strategic sustainability.

The research conducted also has certain limitations, which are mainly the accuracy of the data and information obtained, sampling error (few actively involved respondents in the questionnaire survey, insufficient representation of enterprises despite meeting the minimum research sample size). In addition, sector specificities and the size category of the enterprise should also be taken into account when implementing sustainable strategies. For example, larger enterprises may have greater capacities to implement advanced solutions, while small and medium-sized enterprises prefer measures with an immediate financial effect. Similarly, the sector sector (e.g. manufacturing vs. services) may determine which sustainable activities are practically feasible.

The findings represent a significant contribution to the discussion on sustainable entrepreneurship in Slovakia and provide a basis for future research aimed at identifying specific tools and strategies that can enhance the positive impact of entrepreneurship on society and the environment. Although some findings (e.g., emphasis on cost reduction) confirm known trends, the paper provides a new perspective by analyzing the level of implementation of sustainable activities in the Slovak business environment on a large sample. The unique contribution of the study is the identification of a discrepancy between the declared importance of sustainability and the real implementation of advanced measures, as well as pointing out the need to move from reactive to strategic approaches. These findings provide a basis for improving policy instruments and practical strategies in the conditions of the Central European region. It is also appropriate to include moderating variables such as company size, industry affiliation, or market orientation in future research, which may influence the extent and form of sustainability implementation.

REFERENCES

ABUBAKAR, I. R., MANIRUZZAMAN, K. M., DANO, U. L., ALSHIHRI, F. S., ALSHAMMARI, M. S., AHMED, S. M. S., AL-GEHLANI, W. A. G., ALRAWAF, T. I. 2022. Environmental sustainability impacts of solid waste management practices in the Global South. *International Journal of Environmental Research and Public Health*. 19(19), 12717. https://doi.org/10.3390/ijerph191912717

AHMADI-GH, Z., BELLO-PINTADO, A. 2022. Why is manufacturing not more sustainable? The effects of different sustainability practices on sustainability outcomes and competitive advantage. *Journal of Cleaner Production*. 337, 130392. https://doi.org/10.1016/j.jclepro.2022.130392

BLACKBURN, R. W. 2012. *The Sustainability Handbook. The Complete Management Guide to Achieving Social, Economic, and Environmental Responsibility*. London: Earthscan. 777 p. ISBN-13:978-1-84407-495-2

CAVAGNERO, E., CURIEL, G. H. 2022. *The three levels of sustainability*. Routledge.

DANCIU, V. 2013. The sustainable company: new challenges and strategies for more sustainability. *Theoretical and Applied Economics*. 20(9), 7-26.

EKINS, P., ZENGHELIS, D. 2021. The costs and benefits of environmental sustainability. *Sustainability Science*. 16, 949–965. https://doi.org/10.1007/s11625-021-00910-5

FEROZ, A. K., ZO, H., CHIRAVURI, A. 2021. Digital transformation and environmental sustainability: A review and research agenda. *Sustainability*. 13(3), 1530. https://doi.org/10.3390/su13031530

GAZZOLA, P., DRAGO, C., PAVIONE, E., PIGNONI, N. 2024. Sustainable business models: An empirical analysis of environmental sustainability in leading manufacturing companies. *Sustainability*. 16(19), 8282. https://doi.org/10.3390/su16198282

CHAVALITTUMRONG, P., SPEECE, M. 2022. Three-Pillar sustainability and brand image: A qualitative investigation in Thailand's household durables industry. *Sustainability*. 14 (18), 11699.

KAJANOVÁ, J., MATÚŠOVÁ, S., NOVÁČEK, P. 2022. Sustainable business in the european economic area. *Juridical Tribune Journal = Tribuna Juridica*. 12(4), 495–508. https://doi.org/10.24818/TBJ/2022/12/4.04

KUNZ, V. 2012. *Společenská odpovědnost firem*. 1. vydanie. Praha: Grada Publishing, a.s., 208 s. ISBN 978-80-247-3983-0

LAURETI, L., COSTANTIELLO, A., ANOBILE, F., LEOGRANDEL, A., MAGAZZINO, C. 2024. Waste Management and Innovation: Insights from Europe. *Recycling*. 9(5), 82–96.

LITVAJ, I., DBRBÚL, M., BŮŽEK, M. 2023. Sustainability in small and medium enterprises, sustainable development in the Slovak Republic, and sustainability and quality management in small and medium enterprises. *Sustainability*. 15(3), 2039.

MORAIS, D. O., SILVESTRE, B. S. 2018. Advancing social sustainability in supply chain management: Lessons from multiple case studies in an emerging economy. *Journal of cleaner production*. 199, 222–235.

MUSOVÁ, Z., DRUGDOVÁ, J. 2021. Udržateľné odievanie ako nový trend v kontexte princípov kruhovej ekonomiky. *Studia Commercialia Bratislavensia*. 14(47), 82–93.

CARAGNANO, A., ZITO, M., VITOLLA, F., MARIANI, M. 2021. Extending the benefits of ESG disclosure: The effect on the cost of debt financing. *Corporate Social Responsibility and Environmental Management.* 28(4), 1412–1421. https://doi.org/10.1002/csr.2134

NOSRATABADI, S., MOSAVI, A., SHAMSHIRBAND, S., ZAVADSKAS, E. K., RAKOTONIRAINY, A., CHAU, K. W. 2019. Sustainable business models: A review. *Sustainability*. 11(6), 1663.

RAIMO, N., CARAGNANO, A., ZITO, M., VITOLLA, F., MARIANI, M. 2021. Extending the benefits of ESG disclosure: The effect on the cost of debt financing. *Corporate Social Responsibility and Environmental Management*. 28(4), 1412–1421. https://doi.org/10.1002/csr.2134

SCHALTEGGER, S., WAGNER, M. 2011. Sustainable entrepreneurship and sustainability innovation: categories and interactions. *Business strategy and the environment*. 20(4), 222–237.

TRNKA, A. 2016. *Základné štatistické metódy marketingového výskumu.* 1. vydanie. Trnava: Univerzita sv. Cyrila a Metoda v Trnave. 116 s. ISBN 978-80-8105-768-7

VRABCOVÁ, P. 2021. *Udržitelné podnikání v praxi*. 1. vydanie. Praha: Grada Publishing, a.s. 192 s. ISBN 978-80-271-3303-1

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EVOLUTION OF USAGE PATTERNS FOR ONLINE TOOLS IN THE CONTEXT OF DIGITAL TRANSFORMATION

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ABSTRACT

The paper focuses on analysis of data available from various sources regarding the usage of internet services. The paper goal is to put the data about internet usage in the context of digital transformation (DT) of the society. Both social and human-resource aspects of the DT were emphasized in the presented research oriented primarily to the investigation of share of population accessing the internet in various countries, its relation to various parameters reflecting public services (e.g. government efficiency). For selected relations, correlation and/or regression analyses were performed as well. The main conclusion is that a relation between internet user ratio and government efficiency seem to exist but it is weak.. Also, the study argues that the minority not adopting the digital transformation tools is large enough and should not be neglected in making decisions, e.g. by eliminating non-IT ways to use public services.

Keywords: Internet usage, Government efficiency, Digital transformation, Statistics, Pearson correlation

JEL Code: L86, C21, C88, O31

1 INTRODUCTION

Only slightly more than fifty years have passed since the ARPAnet (an Internet immediate predecessor) origin, and thirty-four years since Tim Bernes-Lee at CERN proposed first version of web communication (see HTTP/0.9 protocol at w3c.org n.d.) that started real dissemination of internet usage among ordinary users. During such a (historically short) period, almost everything around us has changed significantly. Such a change is usually considered as a part of the digital transformation. According to Vial (2021), the digital transformation is

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usually described as a profound change of multiple aspects in both the industry and society harnessing various facets of digital technologies in order to achieve higher efficiency of business and social life. Nevertheless, Vial (2021) focus lies in digital transformational changes to businesses. On the opposite, Hilbert (2020) emphasizes societal changes being part of the digital transformation including increasing number of people having access to the internet.

As a part of digital transformation, most people adopted to use various online services and tools, ranging from browsing web pages, communicating over e-mail or instant messengers, up to social networks of various types. Moreover, such a change is no more limited to people with an IT or related qualification or people with higher economic status. As numerous reports say (e.g. Ofcom 2024a, Statista.com 2023), even around three quarters of population from lower socio-economic groups in western countries use internet regularly. On the other hand, the remaining portion is still far from being negligible so their needs and attitudes should be considered as well in making decisions related to e.g. non-digital availability of inevitable services like public administration, banking etc. Even the non-digital population aspect of the digital transformation deserves consideration and will be the object of research in this paper, too.

In 2024, the total number of internet user worldwide exceeded 5.5 billion (making 67.5% of the world population – according to Datareportal 2024). This confirms the data from World bank and ITU (International Telecommunication Union, 2025) saying that 67% of the world population had access to the internet in 2023. Therefore, an obvious conclusion could be made that most of the worldwide population use internet services as a common tool in their daily life.

Among the changes invoked by the digital transformation, a significant simplification in searching and accessing information play an important role as documented e.g. by the study Xu and Reed (2021) documenting the increase of research results number with the increase of internet availability. On the other hand, the fact that so much information is easily accessible, poses other challenges, among which the most significant is how to select the most relevant and proper information resources and avoid those incorrect, misleading and similar (e.g. Saracevic 2022).

Obviously, there is another closely related question whether using internet makes their lives easier and more comfortable, but this is not addressed directly in the paper.

Because of the reasons mentioned above, the main emphasize of the paper lies in the research how the internet usage evolves in recent years. To achieve the goal, the paper explores selected sources of data about usage of various internet-enabled services first. In section 2, selected interesting observation about internet usage are cited. In section 3, certain new relations were investigated and in section 4, some conclusions were formulated.

2 RELEVANT EXISTING RESEARCH OF ONLINE TOOLS USAGE

From the very beginning of the era of internet usage by wide public (started in early 1990's by the emergence of www), various attempts focusing on user behavior in the internet has appeared, primarily because of anonymous nature of www service (later partly eliminated by cookies). There is a nice overview of data resources in Nadhom and Loskot (2018) where 40 resources containing measurements of internet usage are described.

Among those that are extremely useful, an overview about internet usage through the period from 2000 till 2015 is given by Perrin and Duggan (2015) for the US market excels. The main conclusions include the gradual increase of people with internet access (from 52% US adults in 2000 to 84% in 2015) with significant differences among age groups (only 58% seniors 65+ vs. 81–96% in younger age groups in 2015), a bit smaller among groups according to the highest education (from 90–95% for university through 76% for secondary till 66%

for lower), and income level (highest above 95%, medium 85% and low only 74%). This is complemented by newer data from OECD (2025) reporting 77.8% share of internet users in the US population in 2023.

A rather historical view from an econometric perspective is brought by an older study Bauer *et al.* (2002) where US and EU market were investigated via a multivariate panel regression model. The main conclusion hereof is that structural factors including regulator policy, economic conditions of country and the communication infrastructure play an important role in explaining cross-national differences in Internet access. This conclusion is based on data from 1999 and earlier, but it is true in most cases even in 2025.

The (cyber)security aspect of internet access has also been addressed in some research papers recently. Among them, Lysenko *et al.* (2024) and Pour *et al.* (2023) were chosen as the most relevant to this paper. While the latter thoroughly summarizes the existing measurements with regards to various security aspects of internet communication ranging from routing, through DNS attacks, up to phishing, including newer vector like IoT devices, (Pour *et al.* 2023), Lysenko *et al.* (2024) focuses on specific attacks using phones (in fact a variant of phishing where the vector for the initial message is a phone call instead of common mail message) and analyzes possibilities to detect and avoid such attacks

As the research results mentioned above demonstrates, there are still some niches that were not addressed sufficiently. Overall, lots of available statistics exist but their differences in methodology, data collection period, variables etc. avoid being comparable. The authors consider just the analysis of internet usage patterns in the context of actual changes in the society as one of such niches and therefore the following sections address just this topic.

3 INTERNET USAGE RESEARCH

3.1 Internet usage pattern investigation

As mentioned in the previous sections, one of the acutest issues at present stage of internet usage is inequal share of internet users in population both according to age and to the economic status. The “age digital gap” meaning the fact that older generations tend to use digital technologies less and have fewer digital skills seems to be a serious issue as illustrated e.g. by Fig. 1 containing share of internet users in population from OECD countries. While Norway and Iceland of the left reach almost 100% share of internet users and the difference between qualification group seems negligible, the situation is much worse in other countries including the ones considered “rich” like UK (92.3% share seems good but only 64.3% among people with low education looks as a warning), or USA (here, even the total share 80.4% is much lower that the average number for the whole population that was 84 % even 9 years earlier, and just 57.1% share among people with low education seems not to correspond the overall economic status of the country. And in poorer OECD countries, the situation is even worse (30.6% share among people with low education in Poland, 29% in Lithuania, 25.2% in Chile).

The more detailed view on this issue in UK has been recently offered by OFCOM Adults’ Media Use and Attitudes (Ofcom, 2024a) and Online Nation (Ofcom, 2024b) reports. In the latter, reasons why people do not have internet access from home were summarized and costs were reported as the most significant reason form medium age group (51% for age 16–64), and primarily for 28% of respondents from lowest socio-economic groups. This seems a motivation point for digital transform promoters because these data demonstrate that a non-negligible minority in the society is not likely to adopt using digital tools (e.g. being part of the digital transform) just because it is not affordable enough for them.

There is another aspect of the digital transform in societies as well. As a recent survey by EUs Eurobarometer Digital decade reported (European Union 2024), 23% of respondents claim that digitalization of daily public and private services is making their life more difficult

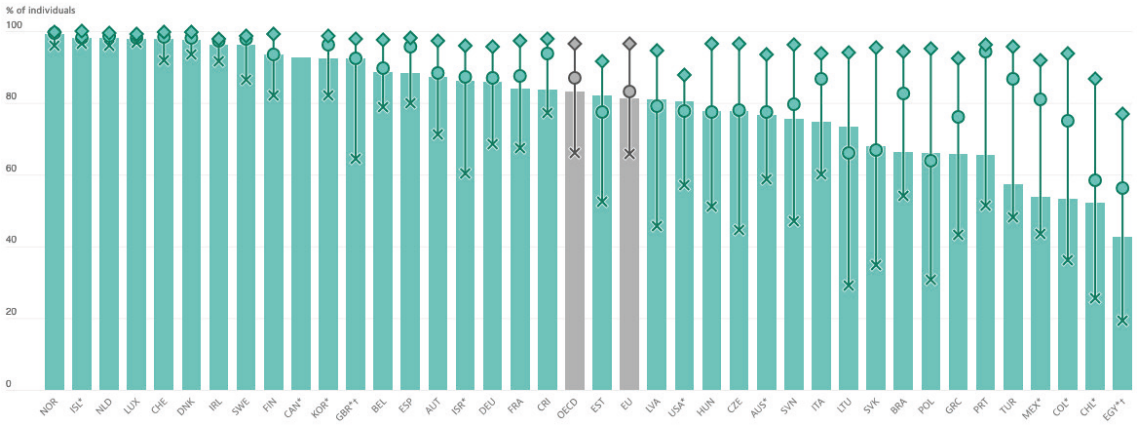

Fig. 1: Share of individuals aged 55-74 years using the Internet as of 2023 (* and + indicate a difference in data collection time) in different countries (plus OECD and EU averages – grey). Diamond, circle and cross indicate high, medium and low education, respectively.
Source: OECD 2025.

(of course, 73% claim the opposite that the digitalization make their life easier (or even much easier). This is still a significant share of population whose opinion should not be suppressed. Therefore, at least public (and preferably also critical private) services should remain available in a non-digital (like paper-based) form even after the service is digitized. Such a view is significantly critical for private sector services like banking. On one hand, submitting e.g. paper-based payment order is still acceptable for most banks but, on the other hand, some banks require quite expensive fee for this (e.g. about 6 Eur for one big Czech bank being part of a large European banking group). One should counter that this fee is not applied to people above 65. Nevertheless, it should be noted that even among younger generation, there are people not able and/or willing to participate the digital transform (at least for now), and such an approach looks adversary for them.

Anyway, the above observations demonstrate that a minority, but still significant part of rich society population still do not use IT tools so they do not participate in the digital transformation either much or at all. Sch minority should be taken into account when making decisions about the digital transformation progress, primarily bearing in mind that traditional ways of interaction with public services (as well as vital services provided by private bodies, like banking) should be kept for the above mentioned minority.

3.2 Relation between internet usage and government services

Another question to investigate was the dependence of government efficiency on the internet penetration. For this investigation, data from World bank (2025), and ITU (International Telecommunication Union 2025) were used as primary sources. The comparison for all countries seems to reveal certain tendency to correlate as shown in Fig. 2 but the correlation in not very strong (Pearson's correlation coefficient 0.67).

Even when only selected developed countries were selected (EU, UK, USA, Japan), the dependence is not much stronger as Fig. 3 demonstrates. On the other hand, a simple regression model using OLS was created with coefficient of determination 0.52 (for EU only, it had increased up to 0.62). Even though the level of dependence in not strong, still certain level of dependence has been proven.

Another important aspect of the digital transform in societies is gradual shift of public services into a digital form. As mentioned above, this shift seems to be welcome by a majority of population usually, but the unwilling and/or refusing minority is far from having negligible size. There is a frequently cited example of shifting public services into digital form, namely

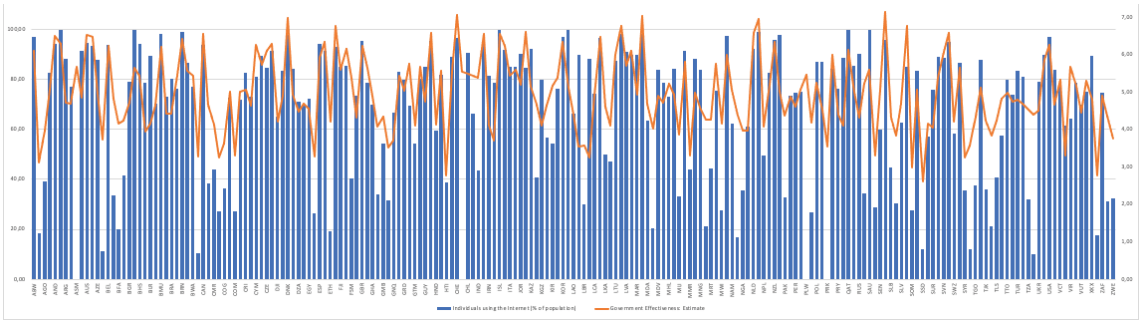

Fig. 2: Graph of countries comparing ratio of internet users in overall population (blue columns, left axis), and the World Bank government efficiency indicator (orange line, right axis)
Source: World Bank, ITU, authors' pro-cessing.

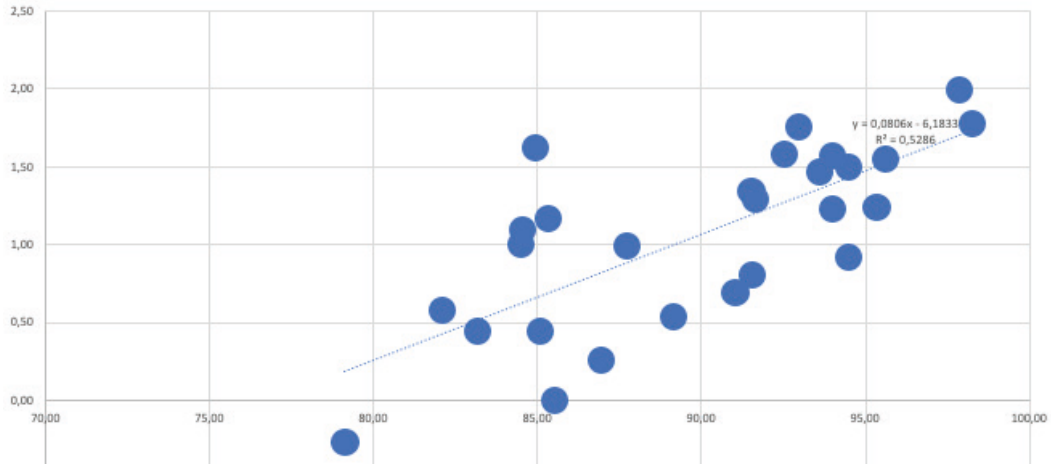

Fig. 3: Graphical demonstration of the dependence of WB government efficiency (vertical axis) on the share of inter-net users in population for EU, UK, USA, Japan
Source: WB, ITU, authors' processing.

elections in Estonia. According to a recent survey about their digitization (Ehin *et al.* 2022), the share of voters having used the digital voting (from all voters) has increased from 1.9% in 2005 (first digital elections in Estonia) up to 17.6% in 2019 (46.7% of participating voters). On the other hand, the introduction of digital voting process (despite optional for voters) did not affect either the voter turnout, or voter trust level. Also, the majority of paper-based voters recruit from older age groups, but the average age between the paper-based voters and i-voters seems to tend getting closer.

This example was mentioned here as another confirmation of the conclusion that the availability of public services in digital form is considered as a positive step forward by most people, but non-negligible portion of population do not tend to adopt to such changes. It further confirms observations about "non-digital" minority mentioned in section 3.1.

4 CONCLUSIONS

As the previous sections demonstrated, there are still numerous facets of internet usage that remain partly hidden in such a big amount of data being produced and published in this field. The presented study demonstrated that looking at the internet usage statistics from a closer view, it is apparent that the speed of adoption of changes being part of the digital transform is not so quick as expected earlier. Therefore, the society should avoid the transformatory

changes from being too quick and/or not taking into account the minor but still significant portion of population that is unable or unwilling to adopt their habits and attitudes so that to becoming users of digital services. Therefore, it is necessary to keep traditional way of interaction with public and private services in place despite (slowly) decreasing share of population using them.

In addition, a relation between the share of internet users in population and the quality (or efficiency) of the government was observed. Despite the relation seems to be weak, it can work an important role in many countries in the near future.

REFERENCES

BAUER, J. M., BERNE, M., MAITLAND, C. F. 2002. Internet access in the European Union and in the United States. *Telematics and Informatics*. 19(2), 117–137. https://doi.org/10.1016/S0736-5853(01)00009-0

DATAREPORTAL 2024. Digital Around the World. *Datareportal.com*. [Accessed: 2025-01-06] https://datareportal.com/global-digital-overview

EHIN, P., SOLVAK, M., WILLEMSON, J., VINKEL, P. 2022. Internet voting in Estonia 2005–2019: Evidence from eleven elections. *Government Information Quarterly*. 39(4), 101718.

EUROPEAN UNION. 2024. Eurobarometer. The digital decade. *Europa.eu*. [Accessed: 2025-01-06] https://europa.eu/eurobarometer/surveys/detail/3174.

HILBERT, M. 2020. Digital technology and social change: the digital transformation of society from a historical perspective. *Dialogues in clinical neuroscience*. 22(2), 189–194. https://doi.org/10.31887/DCNS.2020.22.2/mhilbert

INTERNATIONAL TELECOMMUNICATION UNION. 2025. Statistics. *ITU*. [Accessed: 2025-01-12] https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

LYSENKO, S., BOKHONKO, O., VOROBIYOV, V., GAJ, P. 2024. Method for identifying cyberattacks based on the use of social engineering over the phone. In: *IntelITSIS*. pp. 318–329. [Accessed: 2025-01-11] https://ceur-ws.org/Vol-3675/paper23.pdf

NADHOM, M., LOSKOT, P. 2018. Survey of public data sources on the Internet usage and other Internet statistics. *Data in brief*. 18, 914–1929. https://doi.org/10.1016/j.dib.2018.04.107

OECD. 2025. Share of individuals aged 55-74 years using the Internet. *OECD Going digital Toolkit*. [Accessed: 2025-01-10] https://goingdigital.oecd.org/indicator/50

OFCOM. 2024a. Media Nations 2024. *Ofcom.org.uk*. [Accessed: 2025-01-12] https://www.ofcom.org.uk/media-use-and-attitudes/media-habits-adults/media-nations-2024/

OFCOM. 2024b. Online Nation 2024. *Ofcom.org.uk*. [Accessed: 2025-01-12] https://www.ofcom.org.uk/media-use-and-attitudes/online-habits/online-nation/

PERRIN, A., DUGGAN, M. 2015. Americans' internet access: 2000-2015. *Pewresearch.org*. [Accessed: 2025-01-10] https://www.pewresearch.org/internet/2015/06/26/americans-internet-access-2000-2015/

POUR, M.S., NADER, C., FRIDAY, K., BOU-HARB, E. 2023. A comprehensive survey of recent internet measurement techniques for cyber security. *Computers & Security*. 128, 103123. https://doi.org/10.1016/j.cose.2023.103123

SARACEVIC, T. 2022. *The Notion of Relevance in Information Science: Everybody knows what relevance is. But, what is it really?* Springer Nature.

STATISTA. 2023. Internet usage via any device in any location in the United Kingdom (UK) from 2014 to 2016, by socio-economic group. *Statista*. [Accessed: 2025-01-06] https://www.statista.com/statistics/546570/internet-usage-in-the-uk-by-socio-economic-group/

VIAL, G. 2021. Understanding digital transformation: A review and a research agenda. In: *Managing digital transformation*. 1st Edition. Routledge, pp.13-66.

W3C.ORG. (n.d.). The Original HTTP as defined in 1991. *W3C.ORG*. https://www.w3.org/Protocols/HTTP/AsImplemented.html [Accessed: 2025-01-06].

WORLD BANK. 2025. *Data Catalog* [Online Datasets]. [Accessed: 2025-01-06] https://datacatalog.worldbank.org/home

XU, X., REED, M. 2021. The impact of internet access on research output-a cross-country study. *Information Economics and Policy*. 56, 100914. https://doi.org/10.1016/j.infoecopol.2021.100914

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FACILITATION OF EMPLOYMENT OF PERSONS WITH DISABILITIES: LEGAL ASPECTS

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ABSTRACT

This article explores the legal obligations of states and businesses in facilitating the employment of persons with disabilities, emphasizing the intersection between sustainable business practices and human rights. It examines key international legal frameworks, including the Convention on the Rights of Persons with Disabilities, the UN Guiding Principles on Business and Human Rights, the OECD Guidelines for Multinational Enterprises, and the International Labour Organization's Tripartite Declaration of Principles. The study highlights the role of corporate sustainability due diligence, particularly in light of the EU Directive 2024/1760, in ensuring equal employment opportunities. It focuses on measures to facilitate employment, including affirmative action, support for career development, vocational training, self-employment opportunities, and public sector initiatives aimed at fostering an inclusive labour market.

Keywords: Employment of persons with disabilities, Human rights obligations, Sustainable business

JEL Code: K31, J14, M14

1 INTRODUCTION

The right to work is fundamental, integral to human dignity, and crucial for realizing other human rights. It supports individual and family survival and, when freely chosen or accepted, fosters personal growth and social recognition (CRPD, 2022, para. 2).

Disability is part of being human. An estimated 1.3 billion people – about 16% of the global population – currently experience significant disability. (WHO). Persons with disabilities face significant barriers to equal employment, including high unemployment, lower wages, job instability, poor hiring conditions, and inaccessible workplaces. They are less likely to hold managerial roles and more often work in vulnerable or informal employment. These challenges are even greater for women with disabilities. (CRPD, 2022, para. 4).

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The study published by the International Labour Organization stresses that people with disability are consistenly less likely to participate in the labour market. On average across countries, having disabilities decreases the likelihood of labour market participation by 29 percentage points for men, and by 20 percentage points for women" (Ananian, Dellaferrera, 2024, p. 14). Persons with disabilities face higher unemployment rates and are more often in self-employment or precarious work than those without disabilities . When employed, they also tend to earn lower wages on average. It is important to note, that such disparity is not fully explained by differences in education, experience, or occupation, but rather by factors like insufficient workplace accommodations, limited job flexibility options, and outright discrimination (Ananian, Dellaferrera, 2024).

This article aims to reveal the content of the obligation of states and businesses to facilitate the employment of persons with disabilities. It will demonstrate the link between sustainable business and assurance of human rights; the links between the notion of sustainability and disability as well as will cover specific obligations of states set out in the norms of international law regarding facilitation of employment of persons with disabilities. This paper seeks to answer the following questions: (1) How do selected international legal instruments influence national efforts to employ persons with disabilities? (2) What role does corporate sustainability due diligence play in enforcing these obligations in practice? The research uses a doctrinal legal method and limited comparative analysis.

2 DISABILITY AND SUSTAINABLE DEVELOPMENT

The Sustainable Development Goals (hereinafter – SDGs), developed under the auspices of the United Nations include the aspect of disability in their content. Disability is referenced in various parts of the SDGs and specifically in parts related to education, growth and employment, inequality, accessibility of human settlements, as well as data collection and monitoring of the SDGs (UN DESA). "The 2030 Agenda pledges to leave no one behind, including persons with disabilities and other disadvantaged groups, and recognizes disability as a cross-cutting issue to be considered in the implementation of all of its goals. The Agenda also includes seven targets and 11 indicators explicitly referencing persons with disabilities, covering access to education and employment, availability of schools that are sensitive to students with disabilities, inclusion and empowerment of persons with disabilities, accessible transport, accessible public and green spaces, and building the capacity of countries to disaggregate data by disability" (UN DESA-a).

Specifically, regarding employment, Goal 8 states the aim to "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all". The UN analysis showed that people with disabilities are 1/3 to 1/2 less employed than person without disability (UN DESA-a).

To bridge employment gaps and achieve SDG Goal 8 for persons with disabilities, States should take the following actions:

- Enact and enforce national legislation that prohibits discrimination against persons with disabilities in all aspects of employment.
- Promote the hiring of persons with disabilities in the public sector.
- Implement public procurement policies that incentivize the employment of persons with disabilities.
- Ensure public employment services are inclusive and accessible to persons with disabilities.
- Adapt mainstream vocational education to accommodate persons with disabilities.
- Include persons with disabilities in mainstream entrepreneurship training and microfinance systems.
- Establish policies to support job retention and return-to-work options for individuals who acquire a disability, including those with mental health conditions.

- Provide support for individuals in sheltered employment to transition into the mainstream labour market.
- Design social protection systems that ensure income security and address disability-related needs.
- Develop evaluation frameworks to monitor and improve employment initiatives for persons with disabilities.
- Create and maintain a database with comprehensive, disaggregated data on disability and employment (UN DESA-a).

3 SUSTAINABLE BUSINESS AND HUMAN RIGHTS

Corporate sustainability is a notion where businesses commit to value system and principles-based approach in conducting business (UNGC-a). The notion of responsible business, or socially responsible business has been developed on the level of the United Nations (hereinafter – UN) by forming the UN Global Compact, which is a corporate sustainability initiative[1]. Its first principle states that "Businesses should support and respect the protection of internationally proclaimed human rights" (UNGC). The UN Global Compact is a voluntary initiative, but it adds to the implementation of human rights.

Companies should determine their responsibility to respect human rights by assessing three key factors. First, they should evaluate the country and local context for human rights challenges, especially in regions with weak laws or enforcement, using resources like NGO reports, trade union data, and risk assessments. Second, they must examine whether their own activities, such as production, employment practices, or political actions, cause or contribute to adverse human rights impacts and adjust policies to prevent infringements. Finally, companies should analyse relationships with governments, partners, and suppliers to identify risks of being implicated in human rights abuses, including complicity in violations caused by others (UNGC).

This notion is further stressed by the UN "Guiding Principles on Business and Human Rights: Implementing the United Nations 'Protect, Respect and Remedy' Framework" which were endorsed by the UN Human Rights Council in 2011 (OHCHR, 2011). Despite being formally a recommendation, it is an authoritative source for states seeking to uphold their human rights obligations. Principles state that "in meeting their duty to protect, States should:

a) Enforce laws that are aimed at, or have the effect of, requiring business enterprises to respect human rights, and periodically to assess the adequacy of such laws and address any gaps.
b) Ensure that other laws and policies governing the creation and ongoing operation of business enterprises, such as corporate law, do not constrain but enable business respect for human rights.
c) Provide effective guidance to business enterprises on how to respect human rights throughout their operations.
d) Encourage, and where appropriate require, business enterprises to communicate how they address their human rights impacts" (OHCHR, 2011, p. 4).

The discussed concept of human rights due diligence was also addressed by the Organisation of Economic Cooperation and Development in its Guidelines for Multinational Enterprises on Responsible Business Conduct (OECD, 2023). They emphasize the positive contribution that enterprises can make to economic, environmental and social progress, including contribution to ensuring human rights.

[1] With more than 15,000 companies and 3,800 non-business signatories based in over 160 countries, and 69 Local Networks, the UN Global Compact is the world's largest corporate sustainability initiative.

The concept of due diligence is also integral to the recommendations outlined in the International Labour Organization's Tripartite Declaration of Principles on Multinational Enterprises and Social Policy. "The principles laid down in the Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy (MNE Declaration) offer guidelines to multinational enterprises, governments, and employers' and workers' organizations in such areas as employment, training, conditions of work and life, and industrial relations" (ILO, 2022).

Corporate sustainability due diligence notion as a legal obligation is currently being developed in the European Union. EU Directive 2024/1760, adopted on 25 July 2024, aims to foster sustainable and responsible corporate behaviour in companies' operations and across their global value chains (European Parliament and Council, 2024). "The new rules will ensure that companies in scope identify and address adverse human rights and environmental impacts of their actions inside and outside Europe." (European Commission).

This Directive establishes a corporate due diligence obligation, requiring companies to identify and address actual or potential adverse impacts on human rights and the environment within their operations, subsidiaries, and value chains, including those of their business partners. The Directive applies primarily to large EU limited liability companies and partnerships with over 1,000 employees and a net global turnover exceeding EUR 450 million, encompassing approximately 6,000 entities. It also covers around 900 large non-EU companies with a net turnover of more than EUR 450 million within the EU (European Commission).

However, the research by Stein and Bantekas (2021) illustrates that despite this progress in business and human rights issue, "persons with disabilities and disability rights are absent from both the key instruments and practice of business and human rights." This gap is in place even though the United Nations (UN) Convention on the Rights of Persons with Disabilities (hereinafter – CRPD) is almost universally ratified. Furthermore, persons with disability constitute over 15 per cent of the global population and the operations of multinational corporations impact persons with disability greatly and disproportionately. Therefore, the future lies in "the development and self-enforcement of disability-specific human rights due diligence (HRDD) processes, and creating a general culture of diversity, equity and inclusion that encompasses disability." (Stein, Bantekas, 2021).

4 HUMAN RIGHTS OBLIGATIONS REGARDING EMPLOYMENT OF PERSONS WITH DISABILITY

"The right to work has occupied a central place in the human rights discourse. It is increasingly being acknowledged as inextricably linked with human dignity, life, identity and privacy among a host of other fundamental rights" (Bhattacharjee, 2013, p. 42). It is recognized by major international human rights treaties. The Universal Declaration of Human Rights (UN, 1948) enlists it as one of the universally applicable human rights. As a legal obligation it is established in Article 6(1) of the International Covenant on Economic, Social and Cultural Rights (hereinafter – ICESCR), which states that "the States Parties to the present Covenant recognize the right to work, which includes the right of everyone to the opportunity to gain his living by work which he freely chooses or accepts, and will take appropriate steps to safeguard this right" (UN, 1966). The right to work is also covered in International Covenant on Civil and Political Rights, International Convention on the International Convention on the Elimination of All Forms of Racial Discrimination, the Convention on the Elimination of All Forms of Discrimination against Women, the Convention on the Rights of the Child, and other universal and regional international treaties.

The Convention on the Rights of Persons with Disabilities (hereinafter – Convention or CRPD) and its Optional Protocol was adopted on 13 December 2006 and came into force on 3rd May 2008 (UN, 2006). "The Convention adopts a broad categorization of persons with disabilities

and reaffirms that all persons with all types of disabilities must enjoy all human rights and fundamental freedoms. It clarifies and qualifies how all categories of rights apply to persons with disabilities and identifies areas where adaptation has to be made for persons with disabilities to effectively exercise their rights and areas where their rights have been violated, and where protection of rights must be reinforced" (Vasiliauskienė, Pranevičienė, p. 83; CRPD-a).

Article 27 of the Convention highlights the right of persons with disabilities to work on an equal basis with others, emphasizing the importance of an inclusive, accessible, and open labour market. It acknowledges the right of individuals with disabilities to freely choose or accept employment and earn a living under favourable conditions. To achieve this, the article outlines specific measures that States Parties must take to promote and safeguard this right. These measures include prohibiting discrimination in all aspects of employment, ensuring equal pay for work of equal value, and providing safe and healthy working conditions, free from harassment.

The article also focuses on empowering persons with disabilities to participate fully in the labour market. It mandates the promotion of technical and vocational training, access to career advancement opportunities, and the facilitation of self-employment and entrepreneurship. Additionally, it calls for the inclusion of persons with disabilities in both the public and private sectors through policies such as affirmative action and reasonable accommodation. Rehabilitation, job retention, and return-to-work programs are also emphasized to ensure continued participation in the workforce, even for those who acquire disabilities during their careers.

Lastly, Article 27 unequivocally condemns slavery, servitude, and forced labour, ensuring persons with disabilities are protected from such practices. By implementing these comprehensive measures, the article seeks to foster a labour environment where persons with disabilities can achieve economic independence, dignity, and equality, while contributing meaningfully to society.

Article 27 of the Convention provides guidance to States Parties on ensuring the right to work for persons with disabilities by establishing key principles:

1. Non-discrimination: Persons with disabilities must have the right to work on an equal basis with others;
2. Accessibility: The right to work includes the opportunity for persons with disabilities to earn a living in an accessible work environment, which requires identifying and removing barriers that impede their ability to work equally with others;
3. Reasonable Accommodation: States must facilitate equal access to work by ensuring that reasonable accommodations are provided to persons with disabilities upon request. Denial of such accommodations should be recognized as a form of discrimination, and effective measures, including legislative actions, should be taken to address this;
4. Positive Measures: Beyond imposing obligations on private-sector employers, States are encouraged to adopt proactive measures to promote employment opportunities for persons with disabilities (Della Fina, Cera, 2015, p. 147).

One of the actions that include facilitation of the employment of persons with disabilities, listed in Article 27, is to "promote employment opportunities and career advancement for persons with disabilities in the labour market, as well as assistance in finding, obtaining, maintaining and returning to employment" (UN, 2006, Article 27(1)(e)). The Committee on the Rights of Persons with Disabilities, established according to the provisions of the Convention under the auspices of the UN (hereinafter – the Committee), elaborates that "States parties should ensure that persons with disabilities have meaningful opportunities to develop their careers, whatever the form of their employment. Opportunities for development include reskilling and upskilling, training, lifelong learning and mentorship programmes" (CRPD, 2022, para. 36). It stresses the need to ensure fair, merit-based and transparent processes for promotion in the field of employment. Furthermore, it outlines the importance of analysis of

barriers which directly or indirectly hinder career advancement of persons with disabilities, including training necessary for advancement of their career (CRPD, 2022, para 37).

Further, another provision regarding facilitation of employment of persons with disabilities encourages states to "Promote opportunities for self-employment, entrepreneurship, the development of cooperatives and starting one's own business" (Article 27(1)(f)). The Committee underscores that "States parties should take targeted measures to protect and support persons with disabilities in the informal economy, to promote and accelerate their transition to the formal economy, and to prevent work in the formal economy from becoming informal." (Commentary, para. 38.) The persons with disabilities should be able to get information about entrepreneurship, micro, small and medium-sized enterprises, and other forms of business models and economic units, such as cooperatives. The integrated policy framework should be inclusive for persons with disabilities, ensuring effective coordination among various levels of government and fostering collaboration between relevant entities and authorities, including tax agencies and social security institutions. (CRPD, 2022, para 39)

Other obligation of states is to "employ persons with disabilities in the public sector" (Convention). The Committee stresses that States Parties should establish objective criteria for hiring and promoting persons with disabilities based on merit while actively working to increase their representation in the workforce. Where necessary, targeted measures should be implemented to raise awareness within the public sector, attract and recruit persons with disabilities, and provide support for employees with disabilities. These efforts should aim to reflect the diversity of society and leverage the valuable lived experiences of persons with disabilities. The Committee urges States Parties to boost employment of persons with disabilities through affirmative action, such as targeted funding and vocational programs in public and private sectors. Additional measures include quotas or targets, with mandatory annual compliance reporting by public authorities (CRPD, 2022, para. 40–41).

Lastly, Article 27 also requires states to "promote the employment of persons with disabilities in the private sector through appropriate policies and measures, which may include affirmative action programmes, incentives and other measures". The Committee outlines that "Specific affirmative action measures may be required, such as quotas to increase the employment of persons with disabilities in the private sector. At the same time, quotas alone are insufficient to promote the employment of persons with disabilities and may be resisted by persons with disabilities if the system focuses on impairment rather than ability." (CRPD, 2022, para. 42). Affirmative action measures include public procurement preferences for businesses owned by or employing persons with disabilities, along with targeted funding for workplace modifications, wage support, tax deductions, and subsidies. However, policies supporting segregated employment do not align with the Convention. (CRPD, 2022, para. 42–43).

5 CASE STUDY: IMPLEMENTATION OF CRPD ARTICLE 27 IN LITHUANIA

In 2023, Lithuania reported that 42.7% of persons with disabilities were at risk of poverty or social exclusion, significantly higher than the EU average of 28.8%. Furthermore, the at-risk-of-poverty rate among persons with disabilities in Lithuania stood at 36.6%, compared to 14.1% for those without disabilities . These figures highlight the socioeconomic disparities experienced by individuals with disabilities.(European Commission, 2024). In 2021, expenditure on disability benefits in Lithuania amounted to EUR 795.4 million, representing 7.8% of total social protection benefits. This marked a 17% increase compared to 2020, indicating a growing investment in supporting persons with disabilities (Lithuanian Department of Statistics).

Lithuania has undertaken significant steps to align its national employment policies with international human rights standards, particularly the CRPD. The country's Law on Employment (Lietuvos Respublikos Seimas, 2016) and complementary legislation set forth

a legal foundation that prohibits discrimination based on disability and mandates equal treatment in all aspects of employment. These commitments are reinforced by the "Neįgalumo reforma" (Disability Reform), which aims to modernize the support system and promote independent living and labour market participation for persons with disabilities (Ministry of Social Security and Labour).

The Law on Employment (Lietuvos Respublikos Seimas, 2016) recognizes persons with disabilities as a distinct group entitled to additional support in the labour market. Article 25 of the Law on Employment classifies certain persons seeking employment as "additionally supported," including those with various levels of reduced working capacity and individuals formerly employed in social enterprises. To facilitate their integration, the Law introduces subsidized employment measures under Article 41. Employers hiring such individuals may receive wage subsidies ranging from 50% to 75%, depending on the degree of disability and employment status of the worker. These subsidies serve as financial incentives for employers to overcome reluctance and accommodate workers with disabilities. Additional support includes coverage of job assistant costs and sustained support during times of economic disruption, such as national emergencies.

Further measures to ensure inclusiveness are embedded in public sector employment policy. As of January 2024, public institutions and state-owned enterprises in Lithuania must meet a 5% quota for employees with disabilities, provided qualified candidates are available (Lietuvos Respublikos Seimas, 1991, Art. 10). This affirmative action requirement, overseen by the Ministry of Social Security and Labour, is designed to ensure that public sector bodies serve as role models in advancing inclusive employment. Where candidates with disabilities are not available, institutions are expected to coordinate with the Employment Service to facilitate appropriate training or upskilling measures.

Lithuania's evolving legal and institutional framework reflects a rights-based approach to disability and employment. Through its combined use of quotas, financial incentives, individualized support services, and monitoring mechanisms, the country demonstrates a comprehensive commitment to integrating persons with disabilities into the open labour market. However, the success of these measures depends on effective implementation, including adequate funding, employer awareness, and systemic cooperation between institutions. As a case study, Lithuania offers a valuable example of how national legislation can concretely operationalize CRPD obligations and promote economic participation for persons with disabilities.

6 DISCUSSION AND CONCLUSIONS

Achieving sustainable development requires the full inclusion of persons with disabilities in the labour market, as emphasized by the Sustainable Development Goals (SDGs). Despite commitments to economic growth and decent work for all under SDG Goal 8, persons with disabilities remain significantly underrepresented in employment. To bridge this gap, states must take concrete actions, including enacting anti-discrimination laws, promoting public sector hiring, adapting vocational education, and ensuring inclusive public employment services. Additional measures, such as supporting entrepreneurship, facilitating transitions from sheltered to mainstream employment, and establishing social protection systems, are essential for fostering economic security. Developing evaluation frameworks and maintaining disaggregated employment data will further enhance policy effectiveness. By implementing these strategies, states can create more equitable and inclusive labour markets, ensuring that persons with disabilities are not left behind in sustainable economic growth efforts.

Corporate sustainability and human rights protection are essential components of responsible business conduct, requiring enterprises to integrate ethical principles into their operations. Frameworks such as the UN Global Compact, the UN Guiding Principles on

Business and Human Rights, the OECD Guidelines for Multinational Enterprises, and the ILO's Tripartite Declaration of Principles emphasize corporate responsibility in assessing and mitigating human rights risks. The increasing formalization of human rights due diligence, as seen in EU Directive 2024/1760, reflects a shift from voluntary commitments to legal obligations, ensuring greater accountability in business practices. To achieve meaningful progress, businesses must actively implement due diligence processes, foster transparency, and collaborate with stakeholders to uphold human rights and sustainability standards within their operations and supply chains.

The right to work is a fundamental human right recognized in major international treaties, including the Universal Declaration of Human Rights, the International Covenant on Economic, Social and Cultural Rights, and the Convention on the Rights of Persons with Disabilities (CRPD). Article 27 of the CRPD provides a framework for ensuring that persons with disabilities have equal access to employment, emphasizing non-discrimination, accessibility, and the promotion of inclusive labour markets. States are required to implement legal and policy measures to remove employment barriers, such as prohibiting discrimination in hiring and workplace conditions, ensuring equal pay for equal work, and facilitating safe and healthy work environments. Additionally, promoting technical and vocational training, as well as career advancement opportunities, is crucial in enabling persons with disabilities to participate fully in the labour market.

Facilitating employment also includes support for self-employment and entrepreneurship, ensuring access to business development resources and financial mechanisms. The CRPD Committee highlights the importance of integrating persons with disabilities into mainstream employment through affirmative action, hiring quotas, and targeted public sector initiatives. States are encouraged to implement public procurement measures that prioritize businesses owned by or employing persons with disabilities and to establish compliance monitoring frameworks. Furthermore, cross-sector collaboration between government agencies, tax authorities, and social security institutions is essential in developing a coordinated approach to inclusive employment policies. By enforcing these measures, states can foster an equitable labour environment where persons with disabilities can achieve economic independence, career development, and social inclusion.

REFERENCES

ANANIAN, S., DELLAFERRERA, G. 2024. *A study on the employment and wage outcomes of people with disabilities*. ILO Working Paper No. 124. Geneva: International Labour Organization. [Accessed: 29 May 2025] https://www.ilo.org/publications/study-employment-and-wage-outcomes-people-disabilities

BHATTACHARJEE, S. 2013. Situating the right to work in international human rights law: an agenda for the protection of refugees and asylum-seekers. *NUJS Law Review*. 6(1), 41–62.

COMMITTEE ON THE RIGHTS OF PERSONS WITH DISABILITIES (CRPD). 2025. Background to the Convention. [Accessed: 29 January 2025] https://www.ohchr.org/en/treaty-bodies/crpd/background-convention

COMMITTEE ON THE RIGHTS OF PERSONS WITH DISABILITIES (CRPD). 2022. *General comment No. 8 on the right of persons with disabilities to work and employment*. United Nations. [Accessed: 29 January 2025] https://documents.un.org/doc/undoc/gen/g22/518/57/pdf/g2251857.pdf

DELLA FINA, V., CERA, R. (eds.). 2015. *Protecting the Rights of People with Autism in the Fields of Education and Employment: International, European and National Perspectives*. Cham: Springer. https://doi.org/10.1007/978-3-319-13791-9

EUROPEAN COMMISSION. 2025. Corporate sustainability due diligence. *European Commission*. [Accessed: 29 May 2025] https://commission.europa.eu/business-economy-euro/doing-business-eu/sustainability-due-diligence-responsible-business/corporate-sustainability-due-diligence_en

EUROPEAN COMMISSION. 2024. Disability statistics – poverty and income inequalities. Eurostat Statistics Explained. *European Commission*. [Accessed: 29 May 2025] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Disability_statistics_-_poverty_and_income_inequalities

EUROPEAN PARLIAMENT AND COUNCIL. 2024. Directive (EU) 2024/1760 of the European Parliament and of the Council of 13 June 2024 on corporate sustainability due diligence and amending Directive (EU) 2019/1937. *Official Journal of the European Union*. L 176, 25 July. [Accessed: 29 January 2025] https://eur-lex.europa.eu/eli/dir/2024/1760/oj

INTERNATIONAL LABOUR ORGANIZATION (ILO). 2022. *Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy*. 6th Edition. Geneva: ILO. [Accessed: 29 January 2025] https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_094386.pdf

LIETUVOS RESPUBLIKOS SEIMAS. 1991. *Lietuvos Respublikos asmens su negalia teisių apsaugos pagrindų įstatymas Nr. I-2044*. [Accessed: 29 May 2025] https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.2319/rELFBlvgfe

LIETUVOS RESPUBLIKOS SEIMAS. 2016. *Lietuvos Respublikos užimtumo įstatymas. TAR, 2016-07-05, Nr. 18825*. [Accessed: 29 May 2025] https://www.e-tar.lt/portal/lt/legalAct/5d66c4e047a311e6ae2bfd8f3ce4854a/asr

LITHUANIAN DEPARTMENT OF STATISTICS. 2023. Lithuania in figures (edition 2023): Social protection. *Official Statistics Portal*. [Accessed: 29 May 2025] https://osp.stat.gov.lt/en/socialine-apsauga1

MINISTRY OF SOCIAL SECURITY AND LABOUR OF THE REPUBLIC OF LITHUANIA. 2025. Inclusion of persons with disabilities. *Ministry of Social Security and Labour of the Republic of Lithuania.* [Accessed: 29 May 2025] https://socmin.lrv.lt/lt/veiklos-sritys/socialine-integracija/negalios-reforma-ir-asmenu-su-negalia-itrauktis/

OFFICE OF THE HIGH COMMISSIONER FOR HUMAN RIGHTS (OHCHR). 2011. *Guiding Principles on Business and Human Rights: Implementing the United Nations "Protect, Respect and Remedy" Framework*. [Accessed: 29 January 2025] https://www.ohchr.org/sites/default/files/Documents/Publications/GuidingPrinciplesBusinessHR_EN.pdf

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD). 2023. OECD *Guidelines for Multinational Enterprises on Responsible Business Conduct*. OECD Publishing, Paris. https://doi.org/10.1787/81f92357-en

STEIN, M. A., BANTEKAS, I. 2021. Including disability in business and human rights discourse and corporate practice. *Business and Human Rights Journal*. 6(3), 444–471.

UNITED NATIONS (UN). 1948. The Universal Declaration of Human Rights. *United Nations.* [Accessed: 29 January 2025] https://www.un.org/en/about-us/universal-declaration-of-human-rights

UNITED NATIONS (UN). 1966. International Covenant on Economic, Social and Cultural Rights. *United Nations.* [Accessed: 29 January 2025] https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-economic-social-and-cultural-rights

UNITED NATIONS (UN). 2006. Convention on the Rights of Persons with Disabilities. *United Nations.* [Accessed: 29 January 2025] https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html

UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS (UN DESA). 2025a. Sustainable Development Goals (SDGs) and disability. *United Nations Department of Economic and Social Affairs*. [Accessed: 29 January 2025] https://social.desa.un.org/issues/disability/sustainable-development-goals-sdgs-and-disability

UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS (UN DESA). 2025b. Employment of persons with disabilities: promoting rights in the labour market. *United Nations Department of Economic and Social Affairs*. [Accessed: 29 January 2025] https://social.desa.un.org/sites/default/files/migrated/15/2020/08/Employment_Brief.pdf

UNITED NATIONS GLOBAL COMPACT (UNGC). 2025a. Principle 1: Businesses should support and respect the protection of internationally proclaimed human rights. *United Nations Global Compact*. [Accessed: 29 January 2025] https://unglobalcompact.org/what-is-gc/mission/principles/principle-1

UNITED NATIONS GLOBAL COMPACT (UNGC). 2025b. The Ten Principles of the UN Global Compact. *United Nations Global Compact*. [Accessed: 29 January 2025] https://unglobalcompact.org/what-is-gc/mission/principles

VASILIAUSKIENĖ, V., PRANEVIČIENĖ, B. 2024. International and domestic protection from violence of persons with disabilities in care institutions. *Czech Yearbook of Public & Private International Law*. Vol. 15, pp.41-62. [Accessed: 29 January 2025] https://www.cyil.eu/contents-cyil-2024/

WORLD HEALTH ORGANIZATION (WHO). 2025. Disability. *World Health Organization*. [Accessed: 29 January 2025] https://www.who.int/health-topics/disability#tab=tab_1

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ISSUING MICRO-CREDENTIALS WITH BLOXBERG BLOCKCHAIN

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ABSTRACT

The increasing demand for flexible, modular learning credentials has positioned micro-credentials as an attractive alternative to traditional educational qualifications. However, effectively verifying and securing micro-credentials remains a significant challenge. This paper investigates the utilization of the Bloxberg blockchain—a platform specifically tailored for academic and research use cases—to issue and manage micro-credentials. Our approach builds on previous work by proposing a proof-of-concept application that integrates Bloxberg's Proof of Authority consensus mechanism with three key API end-points: registering credential issuers, issuing new certificates, and verifying existing certificates. By separating on-chain credential identifiers from off-chain storage of sensitive personal data, our design addresses both GDPR requirements and the practical need for privacy. We develop a REST API with Swagger documentation and a React-based frontend to facilitate integration into existing institutional infrastructures or to function as a standalone solution. The paper details the technical architecture, including the generation of decentralized identifiers (DIDs) for issuers and certificates, and presents an initial evaluation of the system's capabilities for handling revocation and validation. Our findings suggest that blockchain-based micro-credentialing offers improved security, reduces reliance on centralized authorities, and can improve trust among stakeholders. This study not only demonstrates the technical feasibility but also proposes a methodological framework for assessing the effectiveness of such blockchain-based systems, addressing key issues such as centralization, cost, and accessibility that are inherent in traditional credentialing systems. The framework includes verifiable metrics for evaluating improvements in security, trust, and efficiency.

Keywords: blockchain, digitalization, micro-credentials

JEL Code: L8, O3

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1 INTRODUCTION

In recent years, the proliferation of digital technologies has significantly transformed the landscape of education and professional development. Among these advancements, micro--credentials have emerged as a flexible and efficient means of recognizing and validating specific skills and competencies acquired through various learning experiences (Hogan *et al.*, 2019). Micro-credentials have gained significant traction over the past decade and offer a modular approach, allowing learners to accumulate certifications that reflect their evolving expertise in targeted areas (Jones & Silver, 2020).

However, the issuance and management of micro-credentials pose challenges related to verification, security, and interoperability, which are critical for ensuring their credibility and widespread acceptance (Williams & Smith, 2021). Early studies by Lemoine and Richardson (2020) examined various micro-credentialing frameworks used in higher education, identifying substantial inconsistencies in issuance protocols and verification mechanisms across institutions. Their research highlighted the need for standardized approaches to ensure the reliability and portability of these credentials. Building on this foundation, Chen ***et al.*** (2022) conducted a comprehensive analysis of 42 micro-credential platforms, revealing that 78% suffered from verification challenges, with employers experiencing difficulty in authenticating credential validity and provenance.

Blockchain technology presents a promising solution to these challenges by providing a decentralized, immutable, and transparent ledger system that can enhance the trustworthiness and accessibility of micro-credentialing processes (Zheng ***et al.***, 2018). Specifically, blockchain's inherent features—such as decentralization, cryptographic security, and smart contract functionality—enable secure issuance, storage, and verification of digital credentials without the need for intermediaries (Shah & Gupta, 2020).

While several researchers have explored blockchain applications in educational credentialing, existing approaches have significant limitations. Gräther ***et al.*** (2018) pioneered one of the first implementations of blockchain-based credentialing systems using Ethereum, demonstrating feasibility but encountering substantial scalability issues and high transaction costs that limited practical deployment. Similarly, Ocheja ***et al.*** (2019) proposed a blockchain framework for educational records but focused primarily on theoretical models without addressing the technical implementation challenges. More recent research by Mikroyannidis *et al.* (2022) examined various blockchain platforms for educational credentials, including Ethereum, Hyperledger Fabric, and Bloxberg. Their comparative analysis suggested that specialized academic blockchains like Bloxberg offer distinct advantages for educational applications, though their study stopped short of providing detailed implementation protocols or user experience considerations. Additionally, Jirgensons and Kapenieks (2023) identified significant gaps in existing blockchain credential solutions, particularly noting the absence of standardized approaches for credential revocation, practical guidelines for institutional implementation, and empirical evidence regarding user adoption.

Among the various blockchain platforms, Bloxberg has been recognized for its focus on academic and research applications, offering a robust infrastructure tailored to the needs of educational institutions and learners (Bayer ***et al.***, 2020).

The integration of micro-credentials with the Bloxberg blockchain offers several advantages. Firstly, it ensures tamper-proof issuance and storage of credentials, thereby enhancing their legitimacy and preventing fraudulent claims (Mougayar, 2016). Secondly, the use of smart contracts facilitates automated and efficient credential verification processes, reducing administrative overhead and enabling seamless interoperability across different systems and institutions (Tapscott & Tapscott, 2017). Additionally, the transparency provided by blockchain allows learners to have greater control over their credential data, fostering a more personalized and user-centric approach to lifelong learning (Alfian ***et al.***, 2021).

Despite these potential benefits, existing implementations have not adequately addressed several critical aspects. While Lamantia and Berger (2024) successfully deployed a blockchain-based credential system across three European universities, their solution required significant technical expertise and failed to provide scalable frameworks applicable to institutions with limited resources. Additionally, Wang ***et al.*** (2023) identified substantial barriers to blockchain credential adoption, including technical complexity, institutional inertia, and user experience challenges—issues that remain largely unaddressed in current literature. Current centralized systems also often face issues such as high costs, lack of transparency, and reliance on intermediaries, which can lead to inefficiencies and potential vulnerabilities (Kshetri, 2021). Gono ***et al.*** (2024) demonstrated that blockchain technology can enhance security and trust in decentralized systems, which provides additional evidence of the applicability of blockchain for the management of micro-credentials.

Our research specifically builds upon and extends these previous studies by addressing three key limitations. First, unlike the theoretical framework proposed by Ocheja *et al.* (2019), we present a practical implementation blueprint specifically optimized for the Bloxberg platform. Second, we address the scalability and cost challenges identified in Gräther ***et al.*** (2018) Ethereum-based approach by using Bloxberg's academic-focused consensus mechanism. Third, we extend Mikroyannidis ***et al.*** (2022) comparative analysis by providing empirical evidence on performance metrics and user experience considerations, filling a gap in the literature on blockchain-based credential systems.

Specifically, we aim to develop a verifiable and measurable methodology that can be used to assess the improvements achieved by implementing a blockchain-based microcredentialing system compared to traditional approaches.

2 METHODOLOGY AND DATA

This paper builds on Masaryk University's application for issuing micro-certificates and extends our previous work (Zaklasnik, 2024), which proposed using blockchain to verify the micro-credentials and protect them against tampering and falsification. We present a proof of concept that extends the original application by integrating Bloxberg blockchain. We are proposing an application that offers three API endpoints: one for registering the micro-credential issuers, another for issuing new certificates, and a third for retrieving information about required micro-certificates. These functionalities utilize Bloxberg to securely store data without complicating the user experience. Bloxberg was chosen for testing due to its use of Proof of Authority consensus mechanism and its focus on academic applications. Additionally, the Bloxberg appeared to be a suitable blockchain for proof of concept, as Mendel university is a member of the Bloxberg community and operates a Bloxberg node.

To explore the potential of our proposed blockchain-based micro-credentialing system, we adopted a primarily qualitative and descriptive approach, with limited quantitative assessment. Due to the early stage of implementation and resource constraints, we focused on system prototyping and initial validation rather than full-scale deployment or performance benchmarking. Specifically, we measured basic operational metrics such as processing time and transaction success rate on the Bloxberg network, primarily to confirm functional feasibility.

3 RESULTS

Our proposed platform is designed specifically to address the needs of universities and educational institutions implementing micro-credential systems.

Platform solution consists of a front-end interface, API infrastructure and backend services. From the perspective of educational institutions, the primary requirement for implementing a micro-credential system is integration with existing institutional infrastructure and IT systems.

API and backend

To ease integration, we developed a REST API with Swagger documentation, so any institution can integrate it. The API supports standard authentication methods and provides these endpoints:

POST /api/issuers/register
- Registers a new issuer‘s DID on the blockchain
- Returns registration status

POST /api/certificates/issue
- Issues a new certificate DID
- Links it to the issuer‘s DID
- Returns registration confirmation

GET /api/certificates/verify/:certificateDID
- Verifies certificate status on blockchain
- Checks issuer verification status
- Returns verification result

The first endpoint handles onboarding of new authorized certificate issuers. The certificate issuance endpoint processes new certificate by generating appropriate DID and recording them on the Bloxberg blockchain. The verification endpoint allows third parties to verify credential authenticity by cross-referencing the blockchain registry.

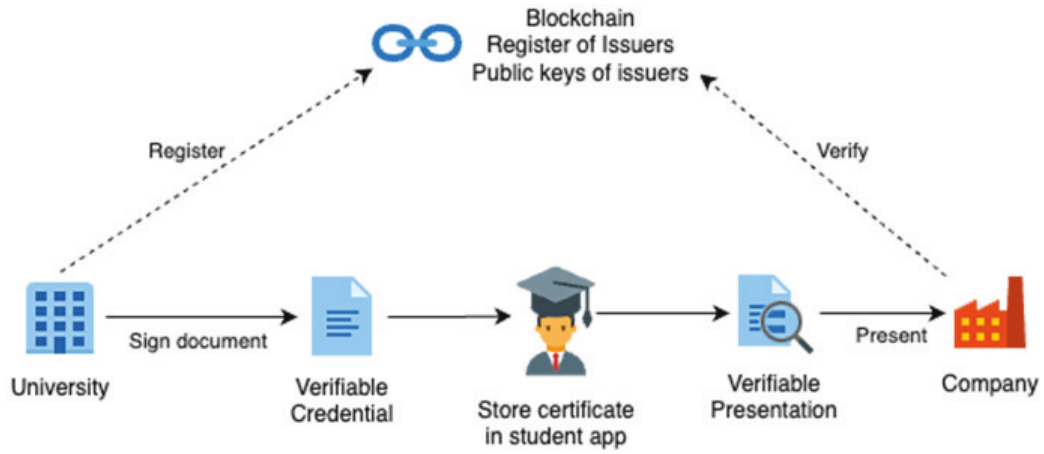

Fig. 1: Diagram of the process of issuing, storing and verifying a micro-credential

As you can see from the endpoints, we don't store any certificates on the blockchain. The primary consideration is data privacy, as certificates contain sensitive personal information about students including names, dates of birth and academic achievements that should not be publicly accessible on an immutable blockchain, which would be in violation of GDPR regulations. Another reason is expenses and transactions fees, which can be quite high, when storing large volumes of certificates on the blockchain.

The diagram below shows the process of issuing, storing, and verifying a micro-credential using blockchain. The API and backend part that has been described is shown as "University" and "Blockchain" in the diagram.

In the script below, we demonstrate how to establish a connection to smart contract deployed on Bloxberg using the Ethers.js library. The mock smart contract contains a method getStatus(string DID), which retrieves the status of micro-certificate with a specific DID. This method is invoked in the sample script below.

The smart contract was written using the Remix Ethereum IDE. After the compilation, Remix also generated the ABI (application binary interface), which is required for interaction with the contract. The IDE also facilitates the deployment of contracts to a chosen blockchain, after which we are able to obtain the contract's transaction address.

To connect to Bloxberg, we created a provider instance using a JSON-RPC endpoint (https://core.bloxberg.org). Next, we created a wallet instance using a private key and connected it to the provider to enable transaction signing. Afterwards, we created the contract instance using three parameters:

1. The contract address
2. The ABI
3. The wallet

The contract, wallet, and provider were initialized by initializeContract() function. We set up a server with a sample endpoint, GET /api/certificates/verify/:certificateDID. The endpoint accepts a micro-certificate's DID as input, calls the contracts' getStatus() method, and returns the status of the corresponding micro-certificate:

```
const ethers = require(‚ethers‘);

let contract;

const initializeContract = async () => {
     const PRIVATE_KEY = process.env.PRIVATE_KEY;
     const provider =
            new ethers.providers.JsonRpcProvider(„https://core.bloxberg.org“)

     const wallet = new ethers.Wallet(PRIVATE_KEY, provider);

     contract = new ethers.Contract(contractAddress, abi, wallet);

     // Tests the getStatus() method of the contract and logs the result
     const DID = 3;
     const status = contract.getStatus(DID);
     status.then((result) =>
            console.log(result);
});
}

app.get(‚/api/certificates/verify/:certificateDID‘, (req, res) => {
     const certificateDID = req.params.certificateDID;
     const status = contract.getStatus(certificateDID);
});

initializeContract();
```

Frontend

If institutions don't need to integrate it into their system, we also have proposed a front-end. It's a web application built using React and TypeScript. Styling is handled with Shadcn components and Tailwind CSS. The app is available online in a web browser. The interface consists of dashboard, certificate issuance, verification, and certificate management pages. The dashboard displays an overview of key metrics and recent activities and buttons for quick operations like issuance and verification certificates. The credential issuance page is a multi-step wizard for creating new certificates. Wizard supports upload functionality in CSV and JSON formats. Part of the issuance page is also template management system for reusable credential structures and preview functionality showing how credentials will look like. The Verification page enables users to verify any certificate. Certificate must be in JSON-LD format. To verify certificate, the user just uploads a file and clicks on Verify certificate. Last but not least is the certificate management page, where each user can see their issued certificates and can do some operations on them.

Initial results from our implementation show a significant reduction in verification times compared to traditional methods. On average, verification through our blockchain-based system takes less than 2 seconds, compared to several days or weeks required for manual verification processes. Additionally, transaction costs on the Bloxberg network are negligible, making it a cost-effective solution for issuing and verifying micro-credentials at scale. Qualitative feedback from users indicates a high level of trust in the system, particularly due to the transparency and immutability provided by the blockchain. However, some users expressed concerns about the technical complexity of interacting with blockchain-based systems, highlighting the need for improved user interfaces and educational resources.

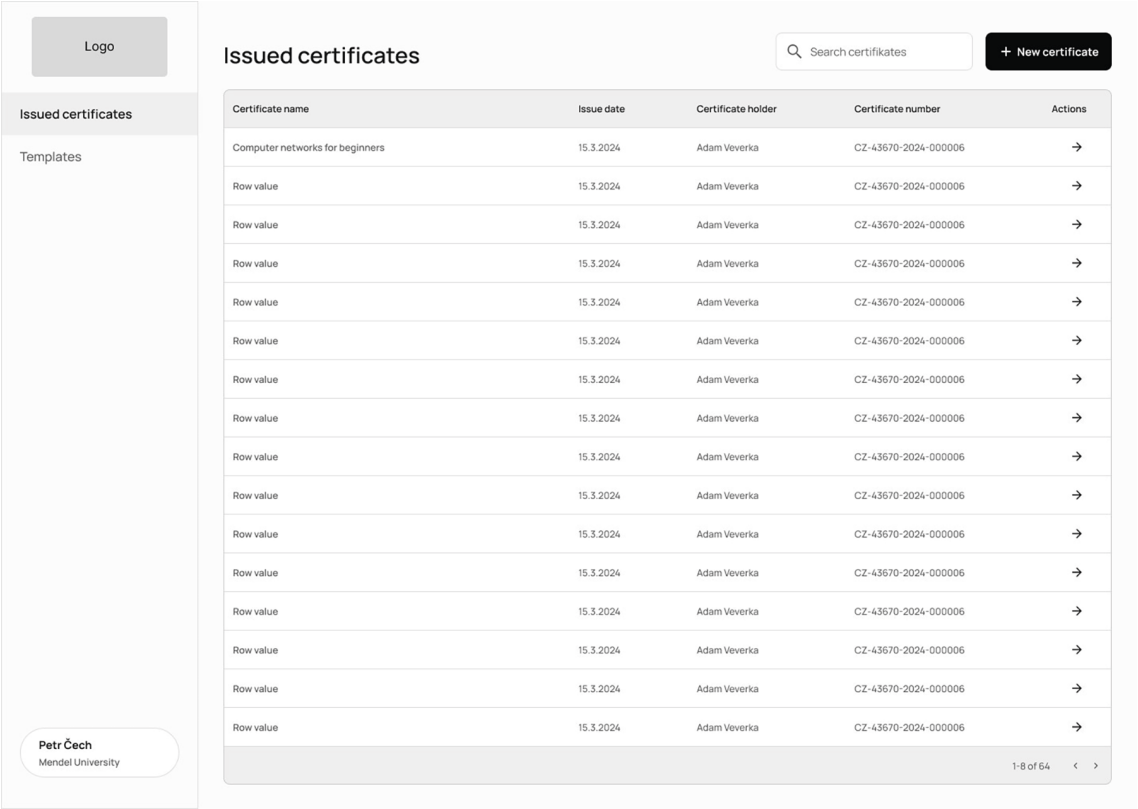

Fig. 2: Wireframe – overview of issued certificates

4 DISCUSSION

Several studies have explored the application of blockchain in educational credentialing, identifying key limitations in current methods.

San ***et al.*** (2020) emphasized the importance of incorporating both revision and revocation mechanisms within blockchain-based credentialing systems. They introduced local credential IDs for efficient storage, while Vidal ***et al.*** (2020) proposed methods to revoke digital diplomas without altering existing data. Our platform currently focuses on invalidation for revocation, akin to blacklisting or marking credentials as void. Although it does not explicitly support credential revision, the foundational structure—particularly its DID-based design—could be extended to accommodate revision features in the future.

Privacy-aware designs frequently incorporate off-chain components to reconcile blockchain's immutable nature with GDPR's requirements for data rectification and erasure (Molina *et al.*, 2020). San ***et al.*** (2019) developed a system allowing credential recipients to determine how much information to reveal during verification, mitigating unnecessary data exposure. While we do not currently implement anonymous verification protocols, our approach aligns with these recommendations by storing only credential identifiers and issuer references on-chain, while personal details remain off-chain. This design is also consistent with Al-Abdullah ***et al.*** (2020), who argue that integrating off-chain storage and privacy impact assessments is crucial for GDPR compliance.

Baldi ***et al.*** (2019) pinpointed impersonation risks in protocols lacking authenticated issuer profiles, advocating for DIDs as a mitigation strategy. Our platform incorporates DIDs for issuers and credentials, which strengthens authentication and mitigates the vulnerabilities highlighted by Baldi ***et al.*** (2019). Bu ***et al.*** (2024) and Garzon ***et al.*** (2024) illustrate advanced DID frameworks designed for IoT and D2D networks, as well as TLS

1.3 authentication, respectively. While our platform is tailored for educational credentialing rather than IoT or transport-layer security, the underlying principle of ledger-anchored identities remains relevant.

Future research should also focus on several other key areas to improve the functionality and adoption of blockchain-based micro-credentialing systems:

- Complex user testing at multiple institutions and stress-testing under high transaction loads. This will help identify potential bottlenecks and areas for optimization, ensuring the platform can support large-scale deployments.
- Implementing zero-knowledge proofs or cryptographic accumulators (Freitag, 2022). This could improve selective disclosure capabilities, enabling recipients to control precisely what information is shared during verification.
- Exploring bridges or standardized protocols could allow the platform to function across multiple blockchains, in line with the need for interoperable systems highlighted by Li *et al.* (2022) and Alsobhi ***et al.*** (2023).

5 CONCLUSIONS

In this paper, we designed a platform solution that includes a frontend, API, and backend for issuing and validating micro-credentials using the Bloxberg blockchain.

Within the front-end, we proposed technologies and specific pages that are needed to issue and manage micro-credentials. In the API and backend, we designed three basic endpoints for registering, issuing, and validating micro-credentials. We also designed a simple smart contract using Ethers.js to validate the micro-credential based on the DID. Overall, our proposed solution demonstrates the possibilities of issuing micro-credentials with W3C open standards such as Verifiable credentials and Decentralized ID and using the Bloxberg blockchain.

As stated by the authors Bochnia (2024) and Erbguth (2022) in their papers, the use of blockchain is a suitable choice for issuing micro-credentials with an important focus on longevity and verifiability even if educational institutions no longer exist in the future. The authors also conclude that Bloxberg is one of the suitable blockchain options for micro-credentials because of its scientific focus, neutrality, and worldwide distribution.

Further research should focus on performance testing, cryptography, and the possibility of extending to other blockchains.

REFERENCES

AL-ABDULLAH, M., ALSMADI, I., ALABDULLAH, R., FARKAS, B. 2020. Designing privacy-friendly data repositories: a framework for a blockchain that follows the GDPR. *Digital Policy, Regulation and Governance*. 22(5/6), 389-411. https://doi.org/10.1108/DPRG-04-2020-0050

AYE MI SAN, N., CHOTIKAKAMTHORN, N., SATHITWIRIYAWONG, C. 2020. Blockchain-based Learning Credential Revision and Revocation Method. In: *Proceedings of the 21st Annual Conference on Information Technology Education (SIGITE, 20)*. Association for Computing Machinery, New York, NY, USA, pp. 42–45. https://doi.org/10.1145/3368308.3415456

AZBEG, K., OUCHETTO, O., JAI ANDALOUSSI, S. LAILA, F. 2020. An Overview of Blockchain Consensus Algorithms: Comparison, Challenges and Future Directions. In: *Advances on Smart and Soft Computing*. *Advances in Intelligent Systems and Computing*. Vol 1188. Springer, Singapore. https://doi.org/10.1007/978-981-15-6048-4_31

BALDI, M., CHIARALUCE, F., KODRA, M. and SPALAZZI, L. (2019). Security Analysis of a Blockchain-based Protocol for the Certification of Academic Credentials. *ArXiv*, abs/1910.04622.

BAYER, R., BRANDENBURG, K., KLETKE, P. 2020. Bloxberg: A Blockchain Platform for Academic and Research Applications. *International Journal of Information Management*. 55, 102213.

BOCHNIA, R., ANKE, J. 2024. Long-Lived Verifiable Credentials: Ensuring Durability Beyond the Issuer's Lifetime. In? *Proceedings of the 19th International Conference on Availability, Reliability and Security (ARES, 24)*. Association for Computing Machinery, New York, NY, USA, Article 87. https://doi.org/10.1145/3664476.3669933

BU, G., FDIDA, S., POTOP-BUTUCARU, M. G., ZAGHDOUDI, B. (2024). Blockchain-based decentralized identity system: Design and security analysis. *IACR Cryptol. ePrint Arch.* 2024, 597.

CHEN, G., ZHANG, L., MARTINEZ, R. 2022. Verification challenges in digital microcredential ecosystems: A comprehensive analysis of 42 credentialing platforms. *International Journal of Educational Technology in Higher Education*. 19(1), 47. https://doi.org/10.1186/s41239-022-00352-8

GARZON, S. R., NATUSCH, D., PHILIPP, A., KÜPPER, A., EINSIEDLER, H. J., SCHNEIDER, D. 2024. DID Link: Authentication in TLS with Decentralized Identifiers and Verifiable Credentials. In: *21st Annual International Conference on Privacy, Security and Trust (PST)*. Sydney, Australia, pp. 1-11. https://doi.org/10.1109/PST62714.2024.10788053

GISH-LIEBERMAN, J.J., TAWFIK, A., GATEWOOD, J. 2021. Micro-Credentials and Badges in Education: a Historical Overview. *TechTrends.* 65, 5-7. https://doi.org/10.1007/s11528-020-00567-4

GONO, A., PISAŘOVIC, I., ZEJDA, M., LANDA, J., PROCHÁZKA, D. 2024. Improving IoT Management with Blockchain: Smart Home Access Control. *European Journal of Business Science and Technology*. 10(2), 225-241. https://doi.org/10.11118/ejobsat.2024.012

GRÄTHER, W., KOLVENBACH, S., RULAND, R., SCHÜTTE, J., TORRES, C., WENDLAND, F. 2018. Blockchain for education: Lifelong learning passport. In: *Proceedings of 1st ERCIM Blockchain Workshop 2018*. European Society for Socially Embedded Technologies.

Hada A. ALSOBHI, Rayed A. ALAKHTAR, Ayesha UBAID, Omar K. HUSSAIN, Farookh Khadeer HUSSAIN. 2023. Blockchain-based micro-credentialing system in higher education institutions: Systematic literature review. *Knowledge-Based Systems*. 265, 110238. https://doi.org/10.1016/j.knosys.2022.110238

HOGAN, M., CHEN, S., EDWARDS, A. 2019. Micro-Credentials in Higher Education: Benefits and Challenges. *Studies in Higher Education*. 44(7), 1234-1248. https://doi.org/10.xxxx/she.2019.4407.1234

JIRGENSONS, M., KAPENIEKS, J. 2023. Blockchain for educational credential management: A systematic literature review and future research agenda. *Journal of Computer Assisted Learning*. 39(2), 341-358.

JONES, L., SILVER, H. 2020. The Rise of Micro-Credentials: Implications for Higher Education Institutions. *Higher Education Research & Development*. 39(2), 290-303.

LAMANTIA, F., BERGER, S. 2024. Practical challenges in cross-institutional blockchain credential systems: Lessons from the European Credential Blockchain initiative. *Computers & Education*. 187, 104706.

LEMOINE, P. A., RICHARDSON, M. D. 2020. Micro-credentials, nano degrees, and digital badges: New credentials for global higher education. *International Journal of Technology and Educational Marketing*. 10(1), 36–49.

LIN, I. C., LIAO, T. C. 2017. Blockchain Technology: A Survey on the Security and Privacy Issues. *Future Generation Computer Systems*. 78, 544-546. https://doi.org/10.xxxx/fgcs.2017.780544

MIKROYANNIDIS, A., THIRD, A., DOMINGUE, J., BACHLER, M. and QUICK, K. 2022. Blockchain applications in education: A comparative analysis of platforms and approaches. *IEEE Access*. 10, 42325-42343.

MOLINA, F., BETARTE, G., LUNA, C. 2020. A Blockchain based and GDPR-compliant design of a system for digital education certificates. *arXiv*. 12980. https://doi.org/10.48550/arXiv.2010.12980

MOUGAYAR, W. 2016. *The Business Blockchain: Promise, Practice, and Application of the Next Internet Technology*. Harper Business. ISBN: 978-1119300311

OCHEJA, P., FLANAGAN, B., OGATA, H. 2019. Connecting decentralized learning records: A blockchain based learning analytics platform. In: *Proceedings of the 9th International Conference on Learning Analytics & Knowledge*. pp. 265-269.

SHAH, A., GUPTA, A. 2020. Smart Contracts and Their Application in Education Credentialing. IEEE Access, 8, 145678-145690.

TAPSCOTT, D., TAPSCOTT, A. 2016. *Blockchain Revolution: How the Technology Behind Bitcoin Is Changing Money, Business, and the World*. Penguin. ISBN: 9781101980132

VARSHINEE CH., GEEANESWARI N., ROOPESH S. 2021. The future of continuous learning–Digital badge and microcredential system using blockchain. *Global Transitions Proceedings*. 2(2), 355-361. https://doi.org/10.1016/j.gltp.2021.08.026

VIDAL, F. R., GOUVEIA, F., SOARES, C. 2020. Revocation Mechanisms for Academic Certificates Stored on a Blockchain. In: *15th Iberian Conference on Information Systems and Technologies (CISTI)*. Seville, Spain 2020, pp. 1-6. https://doi.org/10.23919/CISTI49556.2020.9141088

YANG, Z., SALMAN, T., JAIN, R., PIETRO, R. 2022. Decentralization Using Quantum Blockchain: A Theoretical Analysis. *IEEE Transactions on Quantum Engineering*. 3, 4100716. https://doi.org/10.1109/TQE.2022.3207111

WANG, H., KHAN, S. U. and ZHANG, Y. 2023. Barriers to blockchain adoption in educational credentials: A mixed-methods investigation. *Computers in Human Behavior*. 139, 107516.

WILLIAMS, H., SMITH, J. 2021. Ensuring Credential Integrity through Blockchain Technology. *Journal of Digital Learning*. 12(4), 210-225. https://doi.org/10.xxxx/jdl.2021.1204.0210

WOLFORD, B. 2023. Everything you need to know about the "Right to be forgotten" *GDPR.eu*. September 14, 2023. https://gdpr.eu/right-to-be-forgotten/

ZÁKLASNÍK, M., FARANA, R., SURMA, S. 2023. Digitization of University Diplomas in the European Union. In: *Software Engineering Research in System Science. CSOC 2023*. Lecture Notes in Networks and Systems, vol 722. Springer, Cham. https://doi.org/10.1007/978-3-031-35311-6_39

ZÁKLASNÍK, M., KONECNA, V., FALDIK, O., TRENZ, O., GONO, A. 2024. Enhancing Micro-credentials with Blockchain. In: *Economic Competitiveness and Sustainability 2024 Proceedings*. Mendelu University in Brno, pp. 201-210. https://doi.org/10.11118/978-80-7509-990-7-0201

ZHENG, Z., XIE, S., DAI, H., CHEN, X., WANG, H. 2018. An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In: *Proceedings of the IEEE International Congress on Big Data*. pp. 557-564. https://doi.org/10.xxxx/icbd.2018.0557

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27TH ANNUAL INTERNATIONAL CONFERENCE

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