VOLUME 12 NUMBER (1) 2026

ISSN (Online) 2466-2860

In Serbian:
Inženjerski menadžment

ENGINEERING MANAGEMENT

The International Student Journal for Theory and Practice of Management Science

Editor-in-Chief:
Sanela Arsić

Published by:
Technical Faculty in Bor

www.menadzment.tfbor.bg.ac.rs/english/student-journal/

Engineering management 12 (1) (2026)
The International Student Journal for Theory and Practice of Management Science

Engineering management

EDITORIAL BOARD

Editor - in - Chief

Sanela Arsić, assistant professor
University of Belgrade
Technical faculty in Bor, Serbia

Co-editor

Aleksandra Radić, PhD student
University of Belgrade,
Technical Faculty in Bor, Serbia

Lidija Krstić, PhD student
University of Belgrade,
Technical Faculty in Bor, Serbia

Technical editor

Milena Jevtić, associate professor
University of Belgrade
Technical faculty in Bor, Serbia

Editorial board

Anđelka Stojanović, assistant professor
University of Belgrade
Technical faculty in Bor, Serbia

Milena Gajić, associate professor
University of Belgrade
Technical faculty in Bor, Serbia

Ivica Nikolić, assistant professor
University of Belgrade
Technical faculty in Bor, Serbia

Adrijana Jevtić, PhD student
University of Belgrade,
Technical Faculty in Bor, Serbia

Mukil Kumar Yogesh, postgraduate student
National Institute of Technology,
Puducherry, India

Iva Savić, MSc student
University of Belgrade,
Faculty of Mechanical Engineering, Serbia

Violeta Yankolova-Ali, MSc student
University of Ruse "Angel Kanchev",
Faculty of Business and Management,
Bulgaria

Teodora Radivojević, MSc student
University of Belgrade,
Faculty of Mechanical Engineering, Serbia

Milica Zlatković, MSc student
University of Belgrade
Technical faculty in Bor, Serbia

Diana Lukela Wataka, MSc student
Obuda University,
Keleti Károly Faculty of Business, Hungary

Mihailo Džoković, MSc student
University of Belgrade
Faculty of Mechanical Engineering, Serbia

Ivana Pomorišac, MSc student
University of Belgrade
Technical faculty in Bor, Serbia

ISSN (Online)	2466-2860

Department of Engineering Management of Technical faculty in Bor, University of Belgrade started to publish a journal "Engineering management – The International Student Journal for Theory and Practice of Management Science", during 2015. The journal has international character and publishes student articles in the field of theory and practice of management.

The main goal of the journal is to develop research and writing skills for writing article in which students at all levels of study can present the results of their research.

Engineering management 12 (1) (2026) 1-11

Engineering management

SYSTEMIC RESOURCE CONSTRAINTS IN SMALL MANUFACTURING ENTERPRISES: TOWARD A CONCEPTUAL MODEL OF STRUCTURAL INTERDEPENDENCIES*

Violeta Yankolova-Ali
University of Ruse "Angel Kanchev", Faculty of Business and Management, Bulgaria

Abstract

This study investigates the nature and strategic significance of resource constraints encountered by small manufacturing enterprises. Drawing on the Resource-Based View (RBV) of the firm, five categories of constraints: financial, human, technological, managerial, and logistical are identified and analyzed as structurally interrelated factors that collectively shape the strategic capacity of the enterprise. The study argues that these constraints do not function as independent variables but constitute a self-reinforcing configuration that impedes the development of valuable and inimitable organizational capabilities. This configuration is theorized as a structural „resource trap" that generates path dependence and constrains the formation of sustained competitive advantage. The theoretical contribution of the study lies in reframing resource constraints as a systemic strategic phenomenon rather than isolated operational challenges, offering a conceptual foundation for empirical inquiry and evidence-based managerial intervention.

Keywords: *small enterprises, manufacturing sector, Resource-Based View, structural constraints, competitive advantage, strategic capability, path dependence*

1. INTRODUCTION

Small manufacturing enterprises occupy a significant position within the structure of national economies, contributing to employment, regional development, and industrial diversification. Nevertheless, they operate in an environment characterized by intensified competition, accelerated digitalization, and limited access to strategic resources. International studies and institutional reports consistently emphasize that resource constraints represent a key obstacle to the growth and competitiveness of small and medium-sized enterprises (European Commission, 2022; OECD, 2023).

The relevance of the study stems from the need to consider resource constraints not merely as operational difficulties, but as factors of strategic significance that determine the long-term development prospects of small manufacturing enterprises.

* *Paper presented at the XXII Student Symposium on Strategic Management*

The research problem lies in the fact that the existing literature predominantly examines individual resource deficits in isolation, without analyzing their mutual interaction and cumulative effect on the strategic position of enterprises.

The aim of the article is to systematize the main groups of resource constraints in small manufacturing enterprises and to interpret them as an interconnected system with strategic implications.

To achieve this aim, the following objectives are set: to analyze the Resource-Based View as a theoretical framework; to identify the main groups of resource constraints; to clarify the interrelationships among them; and to conceptually integrate these constraints into a systemic framework.

The main thesis of the study is that resource constraints in small manufacturing enterprises do not operate independently, but form a mutually reinforcing configuration that limits the accumulation of strategic resources and capabilities and thereby defines the boundaries of their competitive development.

The research methodology is based on a conceptual analysis, including a review of seminal works in the field of strategic management and resource theory, as well as an examination of international institutional reports and empirical studies. No primary empirical research is conducted; instead, the study provides an analytical synthesis and theoretical interpretation of existing academic sources.

The contribution of the article lies in expanding the theoretical understanding of resource constraints as a systemic strategic phenomenon and in establishing a conceptual foundation for future empirical research and managerial decisions aimed at overcoming the structural constraints faced by small manufacturing enterprises.

2. LITERATURE REVIEW

2.1. Theoretical framework: the resource-based view of the firm

The Resource-Based View (RBV) conceptualizes the firm as a bundle of resources and capabilities that determine its competitiveness and sustainability. According to this theory, long-term competitive advantage arises when a firm possesses resources that are valuable, rare, inimitable, and organizationally embedded the so-called VRIO logic (Barney, 1991).

Within this framework, a distinction is made between resources and capabilities. Resources refer to the assets and factors available to the firm, whereas capabilities reflect the organization’s ability to combine and coordinate these resources into stable managerial and production routines. Teece, Pisano, and Shuen (1997) argue that dynamic capabilities the capacity to adapt and reconfigure the resource base are critical for long-term competitiveness in a changing environment.

From this perspective, resource constraints in small manufacturing enterprises extend beyond a mere quantitative shortage of assets; they lead to limitations in organizational capabilities and reduced strategic adaptability. When a firm lacks a sufficient resource base, it cannot develop sustainable VRIO combinations, thereby establishing a structural boundary to the formation of competitive advantage.

Within this approach, resources may be categorized as tangible (financial capital, equipment, infrastructure), human (skills, knowledge, managerial competencies), and organizational (procedures, systems, corporate culture). Constraints in any of these resource components diminish the firm's capacity to build sustained competitive advantage.

For small manufacturing enterprises, resource constraints do not represent a temporary deviation but rather a structural characteristic stemming from the scale of operations, limited capitalization, and dependence on the external environment. In this sense, the analysis of resource deficits should be treated as a strategic issue rather than merely an operational problem.

2.2. Financial constraints

Within the RBV framework, financial capital constitutes a fundamental strategic resource that determines a firm's ability to invest, modernize, and build competitive advantages. According to Barney (1991), resources that generate sustained competitive advantage must be valuable and difficult to imitate, and financial capacity plays a key role in ensuring access to other strategic resources—technologies, human capital, and organizational capabilities.

In small manufacturing enterprises, financial constraints manifest in several main directions: limited access to external financing, restricted internal funds, and a relatively higher cost of capital. International studies indicate that small and medium-sized enterprises more frequently face credit rejections and are subject to stricter collateral requirements compared to large firms (Beck & Demirgüç-Kunt, 2006; OECD, 2023b).

Insufficient capitalization limits opportunities for investment in modern production assets, the implementation of quality management systems, and process digitalization. According to the Survey on the Access to Finance of Enterprises (SAFE), small enterprises significantly more often identify the cost of financing as a major barrier to their investment activity (European Central Bank, 2023).

From a strategic perspective, financial constraints cannot be reduced solely to liquidity problems; rather, they represent a structural limitation on development. The absence of stable financial resources reduces the firm's capacity to assume risk, implement innovations, and engage in long-term planning. This results in an orientation toward short-term survival, which contradicts the logic of sustained competitive advantage formulated within the RBV framework.

Under conditions of restricted access to formal financing, small enterprises frequently rely on informal mechanisms for resource mobilization. As noted by Pavlov et al. (2017) and Bakracheva et al. (2020), kinship networks and close social ties play a significant role in securing start-up and working capital in family and small firms. However, such dependence does not compensate for the systemic financial deficit; rather, it confirms its structural nature.

In this sense, financial deficit acts as a "primary constraint" that reinforces other resource deficiencies, as access to human, technological, and organizational resources is directly dependent on the availability of capital.

2.3. Human resource constraints

Within the RBV framework, human capital is regarded as a key strategic resource encompassing knowledge, skills, managerial competencies, and organizational experience. Barney (1991) emphasizes that intangible resources including human competencies more frequently meet the criteria for sustained competitive advantage, as they are difficult to imitate and replicate.

In small manufacturing enterprises, human resource constraints manifest both quantitatively and qualitatively. In several European countries, including Bulgaria, demographic processes and external migration have led to a persistent labor shortage, particularly outside major economic centers (European Commission, 2023). This shortage is especially acute in the manufacturing sector, where specific technical skills and technological discipline are required. As established by Poór, Slavić, Nikolić, and Berber (2021), "one of the main business problems in Central and Eastern Europe is labor shortage driven by emigration and unfavorable demographic trends."

Beyond quantitative deficits, small enterprises also encounter difficulties in attracting and retaining qualified specialists. Limited financial capacity reduces their ability to offer competitive remuneration, while the absence of formalized career structures constrains opportunities for professional development. According to OECD (2023a), small and medium-sized enterprises invest significantly less in systematic employee training compared to large firms, resulting in a long-term competence deficit.

A characteristic feature of small manufacturing enterprises is the high degree of workforce multifunctionality. The limited scale of operations often requires a single employee to perform production, control, and administrative functions simultaneously. Although this model provides flexibility, it increases the risk of overload, errors, and merely formal compliance with procedures. Strategically, this reduces organizational resilience and makes the enterprise more dependent on specific individuals.

From the RBV perspective, constraints in human capital constitute a limitation on the strategic capabilities of the enterprise. The lack of specialized knowledge and managerial competencies hampers the implementation of new technologies, quality standards, and innovations. Thus, the personnel deficit becomes not merely an operational issue but a factor limiting strategic flexibility and long-term development potential.

2.4. Technological constraints

Within the Resource-Based View framework, technological resources constitute a substantial component of the firm's tangible asset base and a prerequisite for the development of organizational capabilities. Production equipment, the level of automation, and the degree of digitalization directly influence productivity, quality, and the potential for scaling operations.

In small manufacturing enterprises, technological constraints often manifest through the use of depreciated equipment, low levels of automation, and limited integration of digital systems. According to OECD (2023), there is a clearly pronounced gap between small and large enterprises in terms of digital technology adoption, with SMEs significantly lagging behind in the use of integrated management systems.

Insufficient digitalization complicates production planning, inventory management, and process control. Eurostat data indicate that the use of ERP systems is considerably more widespread among large enterprises than among small ones, creating a structural disparity in organizational capacity (Eurostat, 2023).

From a strategic perspective, technological constraints limit the firm's ability to build effective organizational routines and ensure process repeatability. Teece, Pisano, and Shuen (1997) argue that competitive advantage is based not only on the resources possessed but also on the firm's capacity to combine and adapt them through dynamic capabilities. The absence of modern technological infrastructure restricts precisely this adaptability.

Therefore, technological deficit should not be viewed solely as a production-related issue but as a structural limitation on the organizational capabilities and innovation potential of small manufacturing enterprises.

2.5. Informational and managerial constraints

Beyond tangible and human resources, the Resource-Based View emphasizes the importance of organizational capabilities structured processes, managerial practices, and control systems through which the firm coordinates and utilizes its available resources (Barney, 1991; Teece et al., 1997). These capabilities represent an intangible yet strategically critical resource.

In small manufacturing enterprises, informational and managerial constraints often manifest through a low degree of process formalization, limited strategic planning, and dependence on the personal experience of the owner (Banabakova and Georgiev, 2018). International research indicates that managerial practices in SMEs are less structured compared to those in large enterprises, lacking systematic mechanisms for performance monitoring and evaluation (OECD, 2023).

Management "by intuition," without the use of integrated information systems and clearly defined procedures, increases the risk of operational inconsistencies, planning inaccuracies, and coordination difficulties. In a production environment, this may result in quality instability, challenges in cost control, and limited process traceability. According to Kunev et al. (2024), "the integration of stakeholder representatives in defining problems and developing solutions is essential for enhancing organizational effectiveness."

From the RBV perspective, organizational capabilities are decisive in transforming resources into competitive advantage. Even when a firm possesses tangible assets and qualified personnel, the absence of managerial structure may hinder their effective utilization. In this sense, informational and managerial constraints act as a secondary but strategically significant limitation on development.

2.6. Logistical constraints

Logistical resources, transportation, warehousing infrastructure, supply control, and coordination of material flows constitute an essential element of the tangible and organizational base of manufacturing enterprises. Within the RBV framework, they may be considered part of physical resources and as a foundation for building operational capabilities.

In small manufacturing enterprises, logistical constraints often manifest through the lack of proprietary transportation, limited storage capacity, and dependence on external logistics operators. This model increases the relative cost per unit of output and reduces flexibility in delivery planning. According to OECD (2023), small enterprises face greater difficulties in supply chain optimization due to limited scale and the absence of specialized logistics units.

In manufacturing sectors, the management of storage and transportation conditions is of particular importance, requiring adequate infrastructure and coordination. The European Commission emphasizes that small enterprises more frequently encounter difficulties in complying with technical and hygiene requirements along the supply chain due to limited resource capacity (European Commission, 2022).

From a strategic perspective, logistical constraints limit the firm's ability to ensure regularity, predictability, and operational stability. Within the RBV framework, this implies that limited material infrastructure reduces the capacity to develop reliable operational capabilities. Logistical deficit may increase operational risk, reduce flexibility in responding to market changes, and heighten dependence on external partners. Additionally, Deneva et al. (2022) highlight the importance of the geographical location of suppliers and customers, which implies the need for the development of specific logistical systems.

Therefore, logistical constraints should be considered not merely as technical or infrastructural issues, but as structural factors influencing the strategic stability of small manufacturing enterprises.

3. DATA AND METHODOLOGY

The present study has a theoretical-analytical character and is based on a systematic review and conceptual interpretation of academic literature and institutional sources related to the resource constraints of small manufacturing enterprises. The analysis is grounded in the Resource-Based View (RBV) of the firm, which serves as the theoretical framework for interpreting the identified constraints.

The methodological approach includes:

1) a review of seminal works in the field of strategic management and resource theory (Barney, 1991; Wernerfelt, 1984; Teece et al., 1997);
2) an analysis of international institutional reports and studies concerning access to finance, digitalization, managerial practices, and supply chains in small and medium-sized enterprises (OECD, European Commission, ECB);
3) the systematization and conceptual grouping of resource constraints into five main categories: financial, human, technological, informational-managerial, and logistical.

The study does not involve primary empirical data collection but aims at an analytical synthesis and theoretical interpretation of existing academic and institutional sources. The principal method applied is conceptual analysis, focused on clarifying the interrelationships among the different resource constraints and their strategic significance for the sustainability of small manufacturing enterprises.

4. RESULTS AND DISCUSSION

4.1. Systemic nature of resource constraints

The analysis of the five groups of resource constraints demonstrates that they do not represent separate, independent problem areas, but rather form an interconnected structure of deficits. Financial constraints limit opportunities for technological upgrading and investment in human capital. Technological deficits, in turn, reduce productivity and increase costs, thereby generating additional financial pressure. Human resource constraints hinder the implementation of managerial and digital systems, reducing the efficiency of organizational processes.

This interdependence indicates that resource constraints possess a systemic character. They form a configuration of mutually dependent elements in which weakness in one area generates tension in others. As a result, the enterprise operates in a mode of continuous adaptation to constraints rather than in a mode of strategic development.

4.2. Mechanism of mutual reinforcement and the “Resource trap”

Beyond systemic interdependence, the analysis reveals a mechanism of mutual reinforcement among the individual constraints. Limited financial resources reduce investments in modern equipment and qualification. Low productivity and higher costs restrict the generation of internal capital, thereby reproducing the initial financial deficit. A cycle of resource limitation is thus formed.

Simultaneously, personnel shortages hinder the effective utilization of technological resources and the introduction of formalized managerial practices. The absence of a managerial structure increases the risk of inefficiency, further diminishing financial performance. This process can be interpreted as a “resource trap,” in which a limited resource base obstructs the accumulation of strategic capabilities.

Within the RBV framework, such a trap implies the inability to accumulate valuable and difficult-to-imitate resources. The enterprise remains in a state of operational functioning without the capacity to build sustained competitive advantage.

4.3. Strategic implications

The systemic nature and mutual reinforcement of resource constraints have a clear strategic dimension. First, they limit strategic flexibility the firm’s ability to respond to changes in the external environment. Second, they reduce opportunities for scaling and diversification, as any new investment requires a resource base that is often insufficient.

Moreover, resource constraints direct managerial attention toward short-term decisions aimed at stabilizing current operations rather than toward strategic planning and innovation. This creates a development trajectory characterized by low investment capacity and limited ability to build sustainable organizational capabilities.

Therefore, resource constraints should be regarded as a structural strategic factor defining the boundaries of growth and competitiveness of small manufacturing enterprises.

Based on the conducted analysis, a conceptual model of mutually reinforcing resource constraints can be formulated, in which financial, human, technological, managerial, and logistical deficits form a system of interdependencies. This system constitutes a “resource trap” that restricts the ability of small manufacturing enterprises to accumulate strategic resources and build sustained competitive advantage.

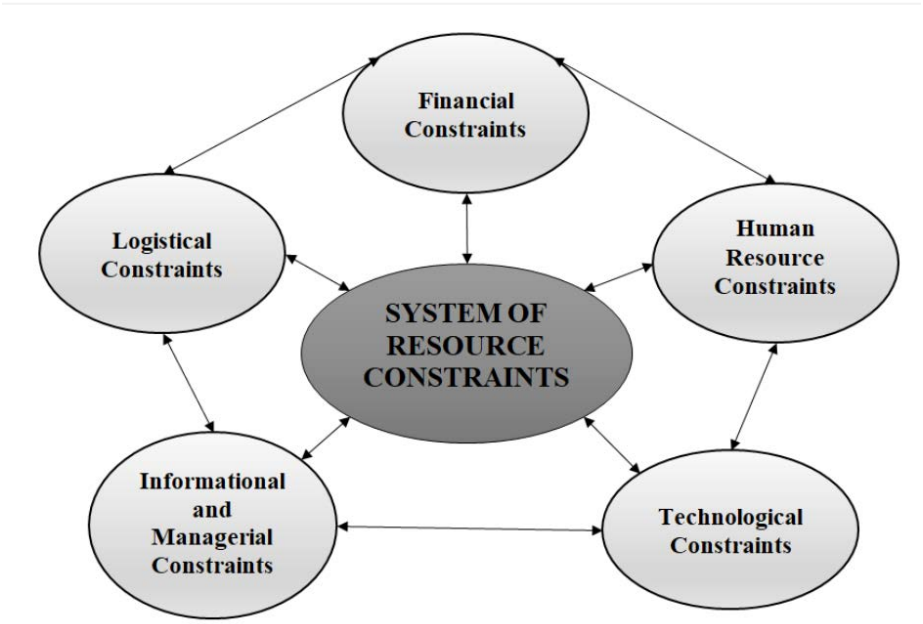


Figure 1. Conceptual framework of mutually reinforcing resource constrains

The arrows in Figure 1 denote the bidirectional interrelationships among the identified resource constraints. Financial constraints affect opportunities for technological investment and human capital development, while technological and managerial deficits reduce productivity and financial performance. Human resource shortages limit the effective implementation of digital and organizational systems, further reinforcing operational inefficiencies. The model illustrates how these interdependencies create a self-reinforcing structural mechanism, interpreted as a “resource trap,” that constrains the accumulation of strategic capabilities.

In this sense, the resource trap should be considered a structural limiter of strategic development that obstructs the accumulation of sustained competitive advantages. Overcoming such a configuration of mutually reinforcing deficits requires an integrated managerial approach aimed at simultaneously addressing key resource constraints.

Furthermore, the resource trap can also be interpreted through the lens of development trajectories, in which accumulated constraints predetermine the future strategic opportunities of the enterprise. When a small manufacturing enterprise operates over a prolonged period under conditions of resource limitation, managerial decisions become oriented toward short-term survival rather than the development of strategic capabilities. This creates a self-sustaining trajectory in which limited investment, low technological modernization, and insufficient organizational formalization become stable characteristics of development.

As a result, the enterprise's strategic flexibility is reduced, and opportunities for transformation and scaling become constrained. In this way, the resource trap not only hinders the accumulation of VRIO resources but also generates path dependence on an established mode of functioning that is difficult to overcome without structural change or an external impulse.

5. CONCLUSION

The present study examines the resource constraints of small manufacturing enterprises through the lens of the Resource-Based View of the firm. The analysis demonstrates that financial, human, technological, managerial, and logistical deficits do not constitute isolated problems, but rather form an interconnected system of constraints with a cumulative effect. Their simultaneous manifestation creates a structural configuration that limits the accumulation of strategic resources and capabilities.

Within the proposed conceptual interpretation, resource constraints can be regarded as a "resource trap," in which mutually reinforcing deficits hinder the development of sustained competitive advantage. In this way, resource limitation becomes a structural strategic factor that defines the boundaries of growth, flexibility, and long-term development of small manufacturing enterprises.

The scientific contribution of the article lies in the systematization of the main groups of resource constraints and their conceptual integration into a framework of mutually reinforcing interdependencies. Such an interpretation expands the understanding of constraints faced by small enterprises by positioning them not merely as operational difficulties, but as a systemic strategic phenomenon requiring an integrated managerial approach. The proposed conceptual framework provides a foundation for future empirical research and for the development of managerial mechanisms aimed at overcoming systemic resource limitations.

ACKNOWLEDGMENT

This research was conducted within the framework of: Project 2026-BM-01 „Intelligent leadership and digital transformation", supported by the Scientific Research Fund of the University of Ruse "Angel Kanchev."

SISTEMSKA OGRANIČENJA RESURSA U MALIM PROIZVODNIM PREDUZEĆIMA: KA KONCEPTUALNOM MODELU STRUKTURNIH MEĐUZAVISNOSTI

Violeta Yankolova-Ali
Univerzitet u Ruseu „Angel Kančev“, Fakultet za biznis i menadžment, Bugarska

Izvod

Ova studija istražuje prirodu i strateški značaj ograničenja resursa sa kojima se suočavaju mala proizvodna preduzeća. Polazeći od teorije resursno zasnovanog pristupa preduzeću (Resource-Based View - RBV), identifikovano je i analizirano pet kategorija ograničenja: finansijska, ljudska, tehnološka, menadžerska i logistička, kao strukturno međusobno povezani faktori koji zajedno oblikuju strateški kapacitet preduzeća. U radu se tvrdi da ova ograničenja ne funkcionišu kao nezavisne varijable, već čine samoodrživu konfiguraciju koja otežava razvoj vrednih i teško imitabilnih organizacionih sposobnosti. Ova konfiguracija teorijski je predstavljena kao strukturna „zamka resursa“, koja stvara zavisnost od prethodno izabranog razvojnog puta (path dependence) i ograničava formiranje održive konkurentske prednosti. Teorijski doprinos studije ogleda se u redefinisanju ograničenja resursa kao sistemskog strateškog fenomena, a ne kao izolovanih operativnih izazova, čime se pruža konceptualna osnova za empirijska istraživanja i menadžerske intervencije zasnovane na dokazima..

Ključne reči: *mala preduzeća, proizvodni sektor, resursno zasnovani pristup (RBV), strukturna ograničenja, konkurentska prednost, strateški kapacitet, zavisnost od razvojnog puta*

LITERATURA / REFERENCES

Bakracheva, M., Pavlov, D., Gudkov, A., Diaconescu, A., Kostov, A., Deneva, A., Kume, A., Wójcik-Karpacz, A., Zagorcheva, D., Zhelezova-Mindizova, D., Dedkova, E., Haska, E., Stanimirov, E., Strauti, G., Taucean, I., Jovanović, I., Karpacz, J., Ciurea, J., Rudawska, J., Ivascu, L., Milos, L., Venera, M., Sheresheva, M., Tamasila, M., Veličković, M., Damyanova, S., Demyen, S., Kume, V., Blazheva, V. (2020) THE INTERGENERATIONAL FAMILY BUSINESSES AS A STRESS MANAGEMENT INSTRUMENT FOR ENTREPRENEURS (Volume 1). Ruse (Bulgaria), Academic Publisher University of Ruse “Angel Kanchev”, 126, ISBN 978-954-712-794-4. http://intergen-theory.eu/INTERGEN-BOOK-1.pdf

Banabakova, V., Georgiev, M. (2018). The Role of the Balanced Scorecard as a Tool of Strategic Management and Control. Conference: 5th International conference of Education and Social Sciences (INTCESS) Istanbul, Turkey, Feb 05-07 2018, 468-483, ISBN: 978-605-82433-2-3.

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99-120. https://doi.org/10.1177/014920639101700108

Beck, T., & Demirgüç-Kunt, A. (2006). Small and medium-size enterprises: Access to finance as a growth constraint. Journal of Banking & Finance, 30(11), 2931-2943. https://doi.org/10.1016/j.jbankfin.2006.05.009

Deneva, A., Hristova, V., Pavlov, D., Blazheva, V., Kostov, I., Angelova, D., & Petrova, M. (2022). The Geographical Location as a Limitation for Starting Entrepreneurial Initiatives and Career Development. European Journal of Sustainable Development, 11(3), 124. https://doi.org/10.14207/ejsd.2022.v11n3p124

European Central Bank. (2023). Survey on the Access to Finance of Enterprises (SAFE). https://www.ecb.europa.eu/stats/ecb_surveys/safe/html/index.en.html

European Commission. (2022). Annual Single Market Report 2022. Publications Office of the European Union. https://single-market-economy.ec.europa.eu

European Commission. (2023). Employment and Social Developments in Europe 2023. Publications Office of the European Union. https://ec.europa.eu/social/

Eurostat. (2023). ICT usage in enterprises - ERP systems. https://ec.europa.eu/eurostat

Kunev, S., Antonova, D., & Ruskova, S. (2024). An approach stimulating the competitiveness and sustainable development of academic institutions: Implementation and results. In Industrial Growth Conference 2024 Proceedings, 346-356. https://doi.org/10.53656/igc-2024.30

OECD. (2023a). Financing SMEs and entrepreneurs 2023: An OECD scoreboard. OECD Publishing. https://doi.org/10.1787/061fe03d-en

OECD. (2023b). SME and entrepreneurship outlook 2023. OECD Publishing. https://doi.org/10.1787/34907e9c-en

Pavlov, D., Sheresheva, M., & Perello, M. (2017). The Intergenerational Small Family Enterprises as Strategic Entities for the Future of the European Civilization - A Point of View. Journal of Entrepreneurship & Innovation, (9), 121-133, URL: https://jei.uni-ruse.bg/Issue-2017/10.%20Pavlov_Sheresheva_Perello.pdf

Poór, J., Slavić, A., Nikolić, M., & Berber, N. (2021). The managerial implications of the labor market and workplace shortage in Central Eastern Europe. Strategic Management, 26(2), 31-41. https://doi.org/10.5937/StraMan2102031P

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. Strategic Management Journal, 18(7), 509-533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7

Wernerfelt, B. (1984). A resource-based view of the firm. Strategic Management Journal, 5(2), 171-180. https://doi.org/10.1002/smj.4250050207

Engineering management 12 (1) (2026) 12-22

Engineering management

MACHINE LEARNING-BASED PREDICTION OF CAMPUS PLACEMENTS USING ACADEMIC PERFORMANCE AND EMPLOYABILITY SKILLS*

Mukil Kumar Yogesh
National Institute of Technology, Puducherry, India

Abstract

Securing employment after graduation is a primary objective for students pursuing higher education. The increasing competition in the job market has encouraged educational institutions to strengthen their placement strategies by providing students with academic support and employability-focused training. This study aims to predict students' placement outcomes by considering both academic performance and selected psychological characteristics. The factors examined include academic achievement, self-esteem, confidence, emotional intelligence, and anxiety levels, as these attributes play a significant role in employability and can be enhanced through appropriate training interventions.

Keywords: *academic performance, campus placement, employability skills, graduates, predictive analytics*

1. INTRODUCTION

Placement is defined as getting a job through the educational institution during or at the end of the course duration. It is an important milestone in a student's academic journey. Students enroll for higher studies in colleges majorly aim to get a job so that they can apply their knowledge and skills and start earning for their livelihood. Educational institutions train and equip their students to get the best possible job with a high salary package in reputed organizations. Development of employability skills is essential for the career growth of the students. Hence, placement training is taken with utmost care and caution by the academic institutions. Placement training develops students with the required skills and capabilities that are sought after by companies.

College campus placements are platforms where industry's human resource needs and demands meet with the hopeful aspirations of many promising students. In general, it might be observed that even candidates having similar academic credentials and skills do not get placed for the same company offering the same value propositions in terms of both monetary and non-monetary benefits. This implies that in placing the students in reputed organizations besides the academic credentials many other factors play important role. These factors are considered as psychological factors that could be trained and improved through a structured training process.

The reputation of the educational institute, especially the higher education institutes is a deciding factor for the choice of the students to aspire for it. The reputation is built on

* *Paper presented at the XXII Student Symposium on Strategic Management*

many factors like curriculum, teachers' profile and their skills and knowledge, teaching methodology, infrastructure, programs offered, and mainly the placement records. Students look for these factors before enrolling and they give importance to the placement records of the institute as getting an employment is a major priority for the students. Educational institutes also place a major concern in enhancing the employability opportunities of the students. In doing so, they try to enhance the skills and capabilities of the students which could attract better employment opportunities. With numerous skills and capabilities playing a role in determining the employability, the placement training is unclear on what skills do play a role in determining the employability. With the advent of machine learning, the prediction of employability is made easy.

This is the era of artificial intelligence (AI) in general and machine learning (ML) in particular. Hence, the prediction models based on the machine learning algorithms: Naïve Bayes, support vector machine, random forest, decision tree and logistic regression have been used in this study. The prediction models developed in this work help the educational institutions to take appropriate initiatives to increase the percentage of students placed in reputed organizations. Over a period of time the educational institutions have observed that it is not sufficient to train the students in terms of cumulative grade point average (CGPA) or percentage of marks alone. The placement history indicates that some students with very good CGPA are not able to make it during the placement and some students who seem to be mediocre in terms of academic performance perform well during the placement. The proposed work analyses the role of CGPA and the non-academic attributes like confidence, anxiety, self-esteem, calmness, self-control, self-efficacy, happiness and emotional intelligence, to predict the probability with which students will get the placement.

The collected data from the students are applied to the developed prediction models (that are based on machine learning) and the role of each non-academic attribute in placement is analysed. This analysis enables the educational institutions to identify the strength and weakness of students in various non-academic attributes. Besides analysing the role of each non-academic attribute, the suitability of the machine learning algorithms is also analysed. Once an institution identifies the strength and weakness of the students in terms of non-academic attributes with the help of the developed machine learning algorithms it can plan for counselling, soft skill development and other strategies that will equip the students to get placed in the organizations with better packages that match their knowledge, skill set, intelligent quotient (IQ) and academic performance. In other word this study helps the educational institutions to make their students to overcome the handicaps they have in the non-academic attributes.

2. LITERATURE REVIEW

Majority of the available literature has taken academic performance as a success factor for students and have attempted using machine learning algorithms in the prediction process. Studies have used academic achievement either on the program or on a particular subject as the target variable and models were analyzed using ML algorithms (Rastrollo-Guerrero et al., 2020). Zabriskie, Yang, DeVore and Stewart (2019) have used Naïve Bayesian classifier to classify the students in to a dichotomous group of 'risky students' and 'successful student'. In their study the classification is based on the student behavior-based attributes like student interaction in the class, class login, and task accomplishment.

Use of many Machine Learning Algorithm in the prediction of student performance, in terms of academic performance is reported in few studies. Algorithms like Decision Tree,

Support Vector Machines, Naïve Bayesian Classifier, Random Forest are used in predicting student performance (Imran et al., 2019; Sekeroglu et al., 2019). Recently, studies have used artificial neural networks (ANN) to predict student performance (Rodríguez-Hernández et al., 2021). Student's performance is assessed using skills acquired, knowledge acquired, change in behavior and expertise in making decisions. Usage of only one or two algorithms (Sandra et al., 2021) in student performance prediction was common earlier and, in the usage, and comparison of multiple Machine Learning algorithms has been noted recently (Batool et al., 2023; Chango et al., 2021; Tomasevic et al., 2020).

Studies attempting student placement has widely used the available data in the educational institute to predict the employment probabilities of students (Joy & Raj, 2019). Surya et al. (2022) have used past placement percentage of a university to predict the next year's placement. Few supervised machine learning classifiers were used to predict the placement of a student in the IT industry based on their academic performance in class Tenth, Twelve, Graduation, and Backlog till date in Graduation have been proposed by Maurya et al. (2021). The classification algorithms like Support Vector Machine, Gaussian Naive Bayes, K-Nearest Neighbor, Random Forest, Decision Tree, Stochastic Gradient Descent, Logistic Regression, and Neural Network are used to develop the classifiers. They have used accuracy scores, heat map and classification reports to test the accuracy of the various tested algorithms. They reported SVM and logistic regression to show high accuracy when compared to other algorithms. Cakit and Dagdeviren (2022) had attempted a similar study but with input parameters of educational institutes' facilities, location and reputation and found that of the various algorithms used extreme gradient boosting (EGB) algorithm resulted in better accuracy. This study is done with Turkish universities.

It has been observed from our survey that performance and other student related achievements are analyzed only in terms of academic attributes. Many of them consider only academic attributes and only very few non- academic attributes or no non-academic attribute at all. Hence, an attempt has been made to estimate the probability of a student getting placed in terms of a set of relevant academic and non-academic attributes. It is proven that non-academic and psychological attributes play a significant role in the success of a students and especially the placement (Norida et al., 2014; Belle et al., 2022; Ristiani & Lusianingrum, 2022; Karvendan & Jayakumar, 2025). Hence, this study has taken psychological factors namely confidence, anxiety, self-esteem, calmness, self-control, self-efficacy, happiness and emotional intelligence as predictors of student placement.

3. DATA AND METHODOLOGY

3.1. Data collection

For the CGPA and non-academic attributes, data was collected from final year students of engineering colleges and universities using a structured questionnaire. All the attributes were measured using standard questionnaire. For example, Self-esteem was measured using 10 item Rosenberg scale (1965), emotional intelligence (EI) was measured by brief emotional intelligence questionnaire (BEIS-10) (Davies et al., 2010). The questionnaire was distributed through Google forms to various educational institutions and gathered the data across educational institutions. After reminders and request for forwards, the data was collected for a period of 3 months. The data set has 830 data points. The data set includes the following attributes: CGPA, confidence, anxiety, self-esteem, calmness, self-control, self-efficacy, happiness, emotional intelligence and placement. Placement is the target variable, taken as dichotomous variable 'placed' and 'not placed'. Once the data is

collected, they are cleaned and pre-processed. The data set has 830 data points. As a thumb rule, we have used 70% of the collected data for training and 30% for testing.

3.2. ML based Prediction models

Since the data set has so many attributes apart from CGPA it is very difficult to analyze the probability of a student getting placed by making an exhaustive analysis or a brute force method. Machine learning (ML) algorithms which have been formulated based on Artificial Intelligence (AI) comes to our help to do this challenging task. In this study Naïve Bayes, support vector machine, random forest, and logistic regression machine learning algorithms are used.

3.3. Proposed Models

All machine learning algorithms build a prediction model and a Model is an explicit description of patterns within the data. Models based on machine learning algorithms have three associated parameters namely task, experience and performance measure. All the machine learning algorithms used in this study come under the category of supervised learning since they expect the data points to be labelled. The data set is a labelled data set with dichotomous labelling of ‘placed’ and ‘not placed’.

Naive Bayes is based on Baye’s Theorem, an approach to calculate conditional probability based on prior knowledge, and the naive assumption that each feature is independent to each other. The biggest advantage of Naive Bayes is that, while most machine learning algorithms rely on large amount of training data, it performs relatively well even when the training data size is small.

Support vector machine (SVM) finds the best way to classify the data based on the position in relation to a border between positive class and negative class. This border is known as the hyperplane which maximize the distance between data points from different classes. Similar to decision tree and random forest, support vector machine can be used in both classification and regression, support vector classifier (SVC) is for classification problem.

Random forest is a collection of decision trees. It is a common type of ensemble methods which aggregate results from multiple predictors. Random forest additionally utilizes bagging technique that allows each tree trained on a random sampling of original dataset and takes the majority vote from trees. Compared to decision tree, it has better generalization but less interpretable, because of more layers added to the model.

Logistics regression uses sigmoid function above to return the probability of a label. It is widely used when the classification problem is binary, true or false, win or lose, positive or negative. In our study, it is whether a student has got placed or not. Dependent Variable is binary. The sigmoid function generates a probability output. By comparing the probability with a pre-defined threshold, the object is assigned to a label accordingly.

In this study, these four machine learning based prediction models that predict the probability with which the students will secure a job are proposed and implemented. The prediction models have been implemented in Python programming language. Python is a popular and versatile programming language. The proposed models have been evaluated in terms of a set of prediction evaluation metrics.

3.4. Prediction evaluation metrics

All the four prediction models need to be evaluated to decide the suitability of these models for the chosen problem. Besides deciding their suitability, it is also necessary to suggest which one among the four is more suitable. To evaluate the proposed models a set of prediction evaluation metrics is required. This section explains the various performance evaluation metrics used in this study.

3.4.1. Confusion Matrix

Confusion Matrix is a matrix that describes the complete performance of the model. When performing classification predictions, there are four types of outcomes that could occur.True positives are when you predict an observation belongs to a class and it actually does belong to that class. True negatives are when you predict an observation does not belong to a class and it actually does not belong to that class. False positives occur when you predict an observation belongs to a class when in reality it does not. False negatives occur when you predict an observation does not belong to a class when in fact it does.

3.4.2. Accuracy

Accuracy is the fraction of predictions our model got right. Accuracy is the proportion of number of correct predictions to the total number of predictions. It works well only if there are equal number of samples belonging to each class.

3.4.3. Precision

It is the number of correct positive results divided by the number of positive results predicted by the classifier.

3.4.4. Recall

It is the number of correct positive results divided by the number of *all* relevant samples (all samples that should have been identified as positive).

3.4.5. F score

The range for F score is [0, 1]. It tells how precise the classifier is (how many instances it classifies correctly), as well as how robust it is (it does not miss a significant number of instances). The greater the F1 Score, the better is the performance of the model.

3.4.6. Receiver Operating Characteristics (ROC)

Receiver operating characteristics is the area under curve, which is one of the most widely used metrics for evaluation. It is used for binary classification problem. ROC of a classifier is equal to the probability that the classifier will rank a randomly chosen positive example higher than a randomly chosen negative example. ROC is the area under the curve of plot *False Positive Rate vs True Positive Rate* at different points in [0, 1]**.** ROC has a range of [0, 1]. The greater the value, the better is the performance of the model.

4. RESULTS AND DISCUSSION

The test for normal distribution of the collected dataset is check for its suitability in applying it to the various prediction models. Except the predictor variable, placement, all other attributes are checked for normal distribution of datasets. Shapiro- Wilk test was applied and it was observed that all the attributes have the significance $p>0.05$, indicating that all the attributes are normally distributed and hence, we can apply the chosen ML algorithms.

The prediction models based on Naïve Bayes algorithm, support vector machine, random forest and logistic regression have been implemented using Python programming language. The performance measure of the Naïve Bayes algorithm is given in Figures 1 and 2.

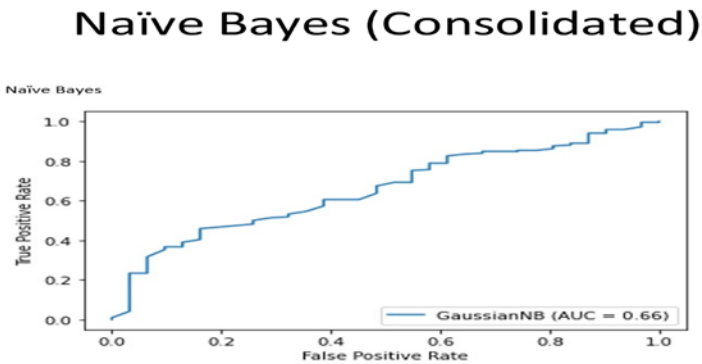


Figure 1. Naïve Bayes - True positive & False positive

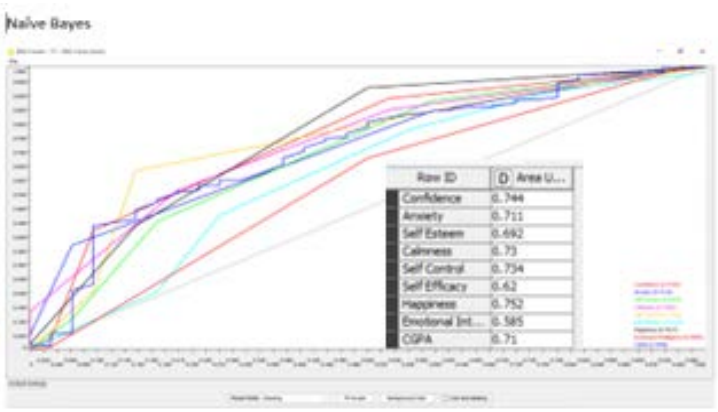


Figure 2. Naïve Bayes - ROC & area under curve

Table 1 presents a comparative overview of the accuracy statistics obtained in the analysis, enabling a clear evaluation of model performance across different approaches.

Table 1. Comparative Results - accuracy statistics

Algorithm	Accuracy	Recall	Precision	F-Score	Specificity	Sensitivity
SVM	0.992	0.991	0.926	0.962	0.991	0.991
Logistic regression	0.855	0.972	0.875	0.921	0.91	0.972
Naïve Bayes	0.996	0.995	0.969	0.998	0.995	0.995
Random Forest	0.859	0.973	0.881	0.924	0.973	0.973

Similar performance measures were taken for all algorithms and the consolidated results are given in table. From Table 1, it is inferred that Naïve Bayes algorithm gives better results when compared to the other algorithms, Random Forest, SVM and Logistics Regression. The consolidated results of the area under the curve of the attributes considered are given in Table 2.

Table 2. Comparative results - Area under curve

Attributes					
Algorithm	Self -control	Self -Efficacy	Happiness	EI	CGPA
SVM	0.59	0.56	0.6	0.626	0.6
Logistic regression	0.718	0.696	0.7	0.644	0.7
Random Forest	0.698	0.618	0.6	0.564	0.6
Naïve Bayes	0.734	0.62	0.8	0.585	0.7

From Table 2 it could be inferred that the area occupied by the various attributes considered is more for naïve Bayes algorithm, when compared to the other ML algorithms. It could also be inferred that the non- academic attributes play a vital role in predicting the placement of the students. Attributes like happiness, self-control, confidence, self-esteem plays a predominant role in predicting the placement of students when compared to CGPA.

From this study it is found that Naïve Bayes is a better algorithm in predicting the student placement when compared to the other algorithms like SVM, Random Forest and Logistic Regression. Naive Bayes algorithm performs well for working with text classification. As the placement is taken as a text “placed” and “not placed”, Naïve Bayes has been effective. Moreover, Naïve Bayes algorithm works well for a small data set with limited number of attributes. The data set used for this study is also small in number with few attributes, it might result in Naïve Bayes being a better prediction algorithm

The present study concludes that psychological factors, self-control, self-efficacy, psychological well-being, and emotional intelligence exert a stronger influence on employability than academic performance measured through CGPA. This finding highlights the importance of non-cognitive competencies as critical determinants of getting a job, a measure of career success. While CGPA reflects academic knowledge and cognitive ability, it does not fully capture the interpersonal, emotional, and behavioral competencies required for successful job attainment and performance.

Previous research has also established that self-efficacy mediates the relationship between emotional intelligence and employability, suggesting that individuals who are emotionally intelligent are more confident in their abilities, which in turn improves their employment prospects (Dacre et al., 2013). Individuals with higher levels of psychological well-being, which is measured through the attribute happiness, are better equipped to manage stress, maintain focus, and exhibit a positive attitude during the recruitment and selection process. Higher education institutions traditionally emphasize academic achievement, often measured through CGPA. However, the labor market demands a broader set of competencies, including emotional intelligence, adaptability, and resilience. The present study supports the argument that educational institutions should integrate psychological skill development into their curricula to better prepare students for employment. This finding will help the trainers, teachers and the students in developing the psychological abilities of the students to fetch employment.

5. CONCLUSION

Education is considered a vital need for motivating self-assurance as well as providing the things that are needed to partake in today's World. Technologies like Artificial Intelligence had a surprising evolution in many fields especially in educational teaching and learning processes. Prediction of student’s performance in terms of fetching a job can be used as a basis for early intervention on the potential failure of students to achieve the goal and to make changes in the strategies of the institutions to facilitate the student achievement.

The major conclusion of this paper is that the psychological variables play a vital role in predicting placement when compared to CGPA. This finding helps educational institutions to realize the need for imparting soft skills to the students apart from the curriculum. From the output of various prediction models, it is found that Naïve Bayes is a better algorithm than other algorithms. It is observed that Naive Bayes algorithm performs well for working with text classification and for the data sets with limited number of attributes.

PREDVIĐANJE ZAPOŠLJAVANJA STUDENATA PRIMENOM MAŠINSKOG UČENJA NA OSNOVU AKADEMSKOG USPEHA I VEŠTINA ZAPOŠLJIVOSTI

Mukil Kumar Yogesh
Nacionalni institut za tehnologiju, Pudučeri, Indija

Izvod

Obezbeđivanje zaposlenja nakon diplomiranja predstavlja jedan od primarnih ciljeva studenata koji pohađaju visoko obrazovanje. Sve veća konkurencija na tržištu rada podstakla je obrazovne institucije da unaprede svoje strategije zapošljavanja studenata pružanjem akademske podrške i obuka usmerenih na razvoj veština zapošljivosti. Cilj ove studije je predviđanje ishoda zapošljavanja studenata uzimajući u obzir kako akademski uspeh, tako i odabrane psihološke karakteristike. Analizirani faktori obuhvataju akademska postignuća, samopoštovanje, samopouzdanje, emocionalnu inteligenciju i nivo anksioznosti, budući da ove karakteristike imaju značajnu ulogu u zapošljivosti i mogu se unaprediti odgovarajućim programima obuke i razvoja.

Ključne reči: *akademski uspeh, zapošljavanje studenata, veštine zapošljivosti, diplomci, prediktivna analitika*

LITERATURA / REFERENCES

Batool, S., Rashid, J., Nisar, M. W., Kim, J., Kwon, H. Y., & Hussain, A. (2023). Educational data mining to predict students' academic performance: A survey study. Education and Information Technologies, 28(1), 905-971.

Belle, M. A., Antwi, C. O., Ntim, S. Y., Affum-Osei, E., & Ren, J. (2022). Am I gonna get a job? Graduating students' psychological capital, coping styles, and employment anxiety. Journal of Career Development, 49(5), 1122-1136.

Çakıt, E., & Dağdeviren, M. (2022). Predicting the percentage of student placement: A comparative study of machine learning algorithms. Education and Information Technologies, 27(1), 997-1022.

Chango, W., Cerezo, R., & Romero, C. (2021). Multi-source and multimodal data fusion for predicting academic performance in blended learning university courses. Computers & Electrical Engineering, 89, 106908.

Dacre Pool, L., & Qualter, P. (2013). Emotional self-efficacy, graduate employability, and career satisfaction: Testing the associations. Australian Journal of Psychology, 65(4), 214-223.

Davies, K. A., Lane, A. M., Devonport, T. J., & Scott, J. A. (2010). Validity and reliability of a brief emotional intelligence scale (BEIS-10). Journal of Individual Differences, 31(4).

Imran, M., Latif, S., Mehmood, D., & Shah, M. S. (2019). Student academic performance prediction using supervised learning techniques. International Journal of Emerging Technologies in Learning, 14(14), 92-104.

Joy, L. C., & Raj, A. (2019, March). A review on student placement chance prediction. In 2019 5th International conference on advanced computing & communication systems (ICACCS), 542-545. IEEE.

Karvendhan, A., & Jayakumar, K. N. (2025). Can Emotional Intelligence, Self-Regulation and Cognitive Styles of College Students Predict Job Placement?. Psychological Thought, 18(1), 173-193.

Maurya, L. S., Hussain, M. S., & Singh, S. (2021). Developing classifiers through machine learning algorithms for student placement prediction based on academic performance. Applied Artificial Intelligence, 35(6), 403-420.

Norida, A., Tajudin, N. M., Kalthom, H., Jano, Z., Sharif, M., & Shahrulanuar, M. (2014, July). Model of self-esteem, job-search intensity and career decision-making self-efficacy for undergraduate students. In Proceedings of the International Conference on Science, Technology and Social Sciences (ICSTSS) 2012, 257-265. Singapore: Springer Singapore.

Rastrollo-Guerrero, J. L., Gómez-Pulido, J. A., & Durán-Domínguez, A. (2020). Analyzing and predicting students' performance by means of machine learning: A review. Applied sciences, 10(3), 1042.

Ristiani, R., & Lusianingrum, F. P. W. (2022). The effect of self-confidence on job readiness. Journal of Applied Business, Taxation and Economics Research, 1(5), 450-461.

Rodríguez-Hernández, C. F., Musso, M., Kyndt, E., & Cascallar, E. (2021). Artificial neural networks in academic performance prediction: Systematic implementation and predictor evaluation. Computers and Education: Artificial Intelligence, 2, 100018 (1-14).

Rosenberg, M. (1965). Rosenberg self-esteem scale. Journal of Religion and Health.

Sandra, L., & Lumbangaol, F. (2021). Machine Learning Algorithm to Predict Student's Performance: A Systematic Literature Review. TEM Journal, 10(4), 1919-1927.

Sekeroglu, B., Dimililer, K., & Tuncal, K. (2019, March). Student performance prediction and classification using machine learning algorithms. In Proceedings of the 2019 8th international conference on educational and information technology, 7-11.

Surya, M. S., Kumar, M. S., & Gandhimathi, D. (2022, April). Student placement prediction using supervised machine learning. In 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), 1352-1355. IEEE.

Tomasevic, N., Gvozdenovic, N., & Vranes, S. (2020). An overview and comparison of supervised data mining techniques for student exam performance prediction. Computers & education, 143, 103676.

Zabriskie, C., Yang, J., DeVore, S., & Stewart, J. (2019). Using machine learning to predict physics course outcomes. Physical Review Physics Education Research, 15(2), 020120(1-18).

Engineering management 12 (1) (2026) 23-32

Engineering management

A FORECAST INTEGRATED AHP FRAMEWORK FOR INTERNATIONAL MARKET EVALUATION*

Selen Nihan Taşçı, Buse Hoşgören, Elif Günenç
Istanbul Technical University, Faculty of Management, Türkiye

Abstract

Identifying attractive foreign markets is an important challenge for firms wanting to grow internationally. Selecting a suitable market requires considering not only current conditions but also future opportunities and many strategic factors. This study proposes a decision-support framework that combines sales forecasting with the Analytic Hierarchy Process (AHP) to improve market evaluation. Forecasted demand values, which are generated using macroeconomic indicators, are included in the AHP model as a decision criterion, allowing future market expectations to be taken into account along with other important factors. The framework is applied to the European bus market, where France, Germany, and Spain are evaluated based on criteria related to market attractiveness, sustainability, geographical centrality, existing dealership networks, and competitor density. By integrating forecasting results into a multi-criteria decision analysis, the study provides a more comprehensive and forward-looking approach to market selection. The findings offer practical insights for organizations looking to support international expansion decisions through data-driven decision-making methods.

Keywords: *multi-criteria decision analysis, demand forecasting, Analytic Hierarchy Process, international market selection*

1. INTRODUCTION

In today's global business environment, companies looking to expand internationally face increasing difficulty in selecting the right markets. Market selection is no longer something that can be based on intuition or a single factor. Instead, it needs a more structured approach that considers a range of economic, operational, and strategic factors. This challenge is especially visible in industries such as automotive, where demand is closely linked to macroeconomic conditions, regulatory changes, and ongoing technological developments. Recent studies show that firms increasingly rely on data-based frameworks to improve the quality of international market selection decisions (López-Cadavid et al., 2023; Paul & Benito, 2018).

As a result, data-driven decision-making has become an important part of strategic planning. Forecasting models are commonly used to predict future demand and identify potential growth opportunities across different markets. By using macroeconomic indicators such as GDP, inflation, and employment levels, these models can provide useful information on how markets may perform. However, relying only on forecasting has its limitations. While it offers

* *Paper presented at the XXII Student Symposium on Strategic Management*

quantitative projections, it does not fully capture qualitative aspects, nor does it provide a structured way to compare multiple options at the same time.

To address these limitations, multi-criteria decision-making (MCDM) methods are frequently used in strategic contexts. Among these methods, the Analytic Hierarchy Process (AHP) is one of the most widely applied tools for handling complex decision problems. AHP allows decision-makers to break down a problem into smaller components and evaluate alternatives based on multiple factors. It combines both numerical data and expert judgments within a consistent framework. Still, in many applications related to market selection, the input data used in AHP tends to focus on present or past conditions, which may not fully show how markets will change in the future. Recent studies review how international market selection models increasingly combine qualitative and quantitative approaches, especially in bigger sized companies (Deaza et al., 2020).

This study addresses this gap by using a hybrid approach that integrates forecasting results into the AHP framework for market selection. Instead of looking at forecasting and decision-making as separate steps, this method connects them in a single structure. Forecasted demand factors are used as direct inputs in the evaluation process, allowing future expectations to play a role in how alternatives are reviewed and prioritized.

The practical part of the study focuses on selected European countries within the bus market. Based on forecasted sales data based on macroeconomic indicators, the countries are evaluated using several criteria, including market potential, sustainability, and business needs. By combining these elements, the study aims to provide a more comprehensive and forward-looking framework for decision-making.

The contribution of the paper can be summarized in two main points. First, it presents a hybrid methodology that connects forecasting results with AHP, adding on to current research on data-driven strategic decisions. Second, it demonstrates how this approach can be applied in a practical context, offering insights for companies looking to improve their market expansion strategies.

The rest of the paper is structured as follows. The next section reviews the relevant literature on market selection and multi-criteria decision-making methods. This is followed by the methodology section, where the suggested approach is explained. The results and discussion section presents the outcome of the analysis, and the final section concludes with key takeaways and suggestions for future research.

2. LITERATURE REVIEW

Market selection is widely recognized as a vital part of a company's international expansion plans. Companies entering new markets need to look at a variety of economic, demographic, and competitive factors to identify the best opportunities. Given the wide variation across countries in terms of their economies, infrastructure, culture, and market characteristics, evaluating international market opportunities becomes a difficult and complex task (Cavusgil et al., 2004). As a result, systematic screening and comparison of countries are needed to reduce the number of alternatives and find the most promising markets for further analysis (Cavusgil et al., 2004). In this context, market attractiveness is formed not only by economic conditions but also by broader institutional and strategic factors that affect international investment decisions (Dunning, 1988).

To address the multi-dimensional nature of these decisions, MCDM methods have become more popular both in academic research and practical applications. These methods allow decision-makers to evaluate alternatives by looking at multiple criteria that often clash, in a systematic way (Greco et al., 2016). Among MCDM techniques, the AHP, developed by Thomas L. Saaty, is a method that structures complex decision problems using pairwise comparisons and allows both quantitative data and subjective judgments to be incorporated into the analysis (Saaty, 1987). In practice, decision-making problems often include both quantitative and qualitative factors, making them a good fit for decision-making tools like AHP (Büyüközkan & Çifçi, 2012). This shows the importance of using decision-making methods when assessing a problem with multiple criteria.

Recent studies have also applied AHP in evaluating business opportunities under economic and strategic considerations. For example, Al Shamsi and Shannaq (2023) developed an AHP-based model to check the profitability of various business areas by incorporating expert opinions and comparing multiple criteria. The study demonstrates how AHP can be used to structure complex decision problems and generate a prioritized ranking of alternatives based on qualitative judgments.

In another study, Ekici et al. (2026) used a combines AHP and TOPSIS method to evaluate logistics center locations by considering criteria such as cargo traffic, population, and economic development. Their results point out both established logistics hubs and previously overlooked regions with high potential, providing useful ideas for better infrastructure planning. This shows the suitability of AHP for complex decision-making problems that involve multiple economic and strategic criteria.

At the same time, forecasting models also play a crucial role in projecting future market demand and finding growth opportunities. Forecasting is widely used in both business and government planning contexts, as many decisions heavily depend on expectations about uncertain future outcomes. As Armstrong (2001) explains, forecasting helps organizations plan investments, evaluate different scenarios, and make more informed decisions in uncertain environments. This makes forecasting a key tool in strategic decision-making processes, especially in dynamic and competitive markets.

Recent research highlights the increasing importance of data-driven approaches in economic forecasting. For example, Lin & Wei (2024) show that the use of big data has greatly improved how economic forecasts are generated by incorporating large and varied datasets into prediction models. This leads to a more detailed understanding of economic patterns and improves the ability to capture complex relationships that traditional models may miss. As a result, forecasting methods have become more flexible and better at analyzing fast-changing market environments.

Even though both forecasting and MCDM methods are useful on their own, they are usually used separately in the literature. Because of this, decision-making processes may not fully take future expectations into consideration when comparing different alternatives. To deal with this issue, this study proposes a hybrid approach that combines forecasting results with the AHP method. By bringing these two approaches together, the goal is to create a more practical and comprehensive way to support market selection decisions.

3. DATA AND METHODOLOGY

3.1. Data description

The dataset used in the forecasting part of the study consists of historical bus sales data, and macroeconomic indicators for selected European countries. The dataset combines historical sales figures from the European Automobile Manufacturers' Association (ACEA) with supplementary internal market data provided by an industry manufacturer. To keep the study accurate while protecting the company's privacy, this private data was anonymized and cross-referenced against public records for consistency. This allowed for a more detailed analysis of market changes that publicly available datasets alone could not provide.

Macroeconomic variables considered in the study include indicators such as Gross Domestic Product (GDP), inflation, population, employment levels, and other relevant economic factors that are commonly associated with transportation demand. These variables were chosen based on their relevance to market trends and their impact on vehicle sales.

To support a forward-looking analysis, forecasted values of bus sales were generated using a data-based approach based on past patterns between sales and macroeconomic indicators. The forecasting results serve as key inputs for the next step.

For the purpose of this study, three European countries were selected as alternative markets, which are France, Spain and Germany. These countries were picked based on their strategic relevance and availability of reliable data, enabling a comparative evaluation within the suggested framework.

For the data used in the AHP analysis, both quantitative and qualitative inputs were included. Quantitative data for the criteria were obtained from publicly available sources and used directly in the evaluation. However, for certain criteria that could not be measured with clear numerical data, qualitative assessments were needed.

These qualitative evaluations were based on expert opinions, where the relative importance of criteria was compared using a rating scale. This process allowed both measurable data and expert judgment to be considered together within the AHP framework.

3.2. Methodological framework

This study proposes a hybrid decision-making framework that puts forecasting results into the AHP to support strategic market selection. The methodology consists of two main stages: (i) forecasting of market potential and (ii) multi-criteria evaluation of alternative countries.

In the first step, forecasted sales numbers are generated using a data-driven approach based on past connections between bus sales and macroeconomic indicators. These indicators include variables such as GDP, inflation, and population, which are commonly linked to transportation demand. The forecasting process captures underlying trends and relationships in the data, making the estimation of future market potential for each country possible.

Instead of focusing on methodological complexity, the forecasting step aims to provide a reliable and quantitative foundation for comparing alternative markets based on their future potential. This allows the decision-making process to move beyond fixed past data and include expectations about future performance.

In the second stage, the AHP method is applied to evaluate and prioritize alternative countries based on multiple criteria. AHP enables the decomposition of the decision problem into an organized structure consisting of the main goal, evaluation criteria, and alternative options.

3.3. Application of AHP

The AHP model is structured in three levels. At the top is the main goal, which is to select the optimal country for growing the business into new markets. The next level consists of key decision factors, which are future sales (market potential), sustainability, geographical centrality, existing dealership networks, and competitor density. Finally, the bottom level includes options, which are France, Germany and Spain.

Pairwise comparison matrices are built to determine the relative importance of each criterion. A standard rating scale (the Saaty scale) is used to assign comparison values, and normalized weights are calculated accordingly. Consistency ratios are also evaluated to ensure the reliability of judgments.

A key contribution of this study lies in the combination of forecasting results into the AHP framework. Specifically, forecasted sales values are added directly as a quantitative input under the market potential criterion. This allows expectations about the demand in the future to directly affect the weighting and final ranking of alternatives.

3.4. Evaluation process

After calculating the criteria weights and alternative scores, a final ranking of the selected countries is obtained. The results reflect both quantitative forecasts and qualitative evaluations, providing a thorough foundation for strategic decision-making.

By combining forecasting results with a structured multi-criteria method, the proposed methodology makes the market selection stronger and reduces the limitations of using only one way to analyze data.

4. RESULTS AND DISCUSSION

The suggested hybrid framework was used to evaluate three European countries (Germany, France, and Spain) as potential markets for growth in the bus industry. The analysis combines forecasted sales values with several strategic criteria within the AHP structure, allowing a pairwise comparison of future market potential.

In the first stage, forecast results showed clear differences in expected market performance between the selected countries. Germany showed the highest predicted demand over the analysis period, reflecting its strong economic indicators and stable market conditions. France followed with moderate expectations, while Spain demonstrated relatively lower but still positive demand. These forecast values were added to the AHP model under the market potential criterion.

Table 1. Forecasted Total Sales of the Next Five Years

Country	Sales volume
Germany	32 681
France	21 390
Spain	23 523

In the second stage, pairwise comparisons were performed to determine the relative importance of each evaluation criteria. The results indicated that market potential was assigned the highest weight, followed by sustainability, geographical centrality, existing dealership networks, and competitor density. This weighting shows a focus on future demand while still including strategic and operational factors.

Table 2. Final Criteria Weights

Criteria	Weight
Market Potential (Forecasted Sales)	0.44
Sustainability	0.23
Geographical Centrality	0.14
Existing Dealership Networks	0.11
Competitor Density	0.07

Based on the calculated criteria weights and alternative scores, an overall ranking of the countries is created. The results show that France ranks as the most suitable market for expansion, despite not leading the forecasted sales values. Germany is positioned as the second-best option, offering a balanced combination of each criterion. Spain ranks third, mainly due to comparatively lower projected demand and less advantageous economic indicators.

Table 3. Final Scores and Rankings

Country	Score	Ranking
France	0.38	1
Germany	0.35	2
Spain	0.26	3

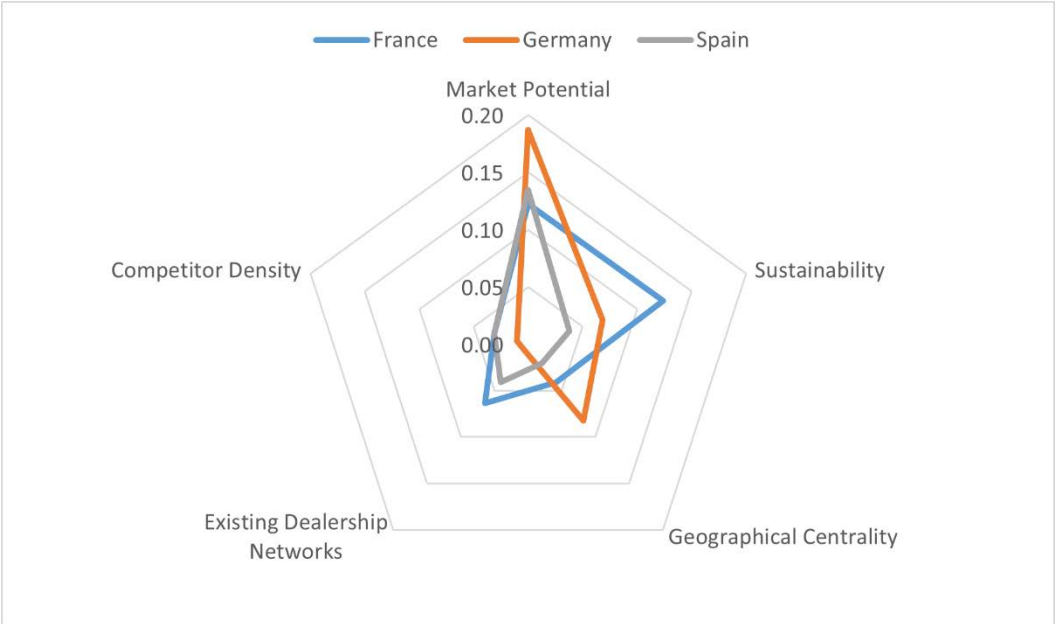


Figure 1. Country performance across evaluation criteria

Figure 1 provides a radar chart of the selected countries across evaluation criteria. Germany demonstrates strong performance in market potential and geographical factors, while France shows balanced results across multiple criteria. Spain exhibits lower values overall.

The results show how important it is to combine future-focused data with organized decision-making systems. While the prediction model found that Germany would have the highest expected sales, the AHP analysis concluded that France is actually the best choice for opening new dealerships. This difference shows that how good a market is doesn't depend on sales numbers alone. This approach allows decision-makers to still incorporate forecasted data to their decision-making systems while not relying solely on forecasts.

Overall, the results show that the integration of forecasting outputs into the AHP framework provides a more comprehensive and stronger foundation for market selection. The hybrid method not only improves the consistency of the evaluation process but also makes it more useful for real-world strategic decisions.

5. CONCLUSION

This study looked at the problem of choosing a market for international expansion by using a hybrid approach that combines forecasting results with the AHP. The aim was to go beyond fixed evaluations and support making more organized decisions.

The results show that integrating forecasted demand into the AHP framework provides a more realistic basis for comparing alternative markets. Instead of relying only on forecasted demand, the approach allows future expectations to directly influence the evaluation process while taking other important factors into consideration. In the application, the selected countries were assessed not only in terms of their current conditions but also their projected market potential, leading to a more dynamic ranking.

In practice, the results suggest that companies can benefit from data-based predictions with organized decision tools when making strategic expansion plans. This is especially relevant

in industries where demand is closely linked to macroeconomic conditions and long-term trends.

At the same time, the study has some limitations. The analysis is based on a limited number of countries and partially relies on internal company data, which might limit how well the results apply to other situations. In addition, the weighting process in AHP includes a level of personal judgement, even though consistency checks were applied.

Future research could expand the model by including a larger set of countries, adding extra criteria, or comparing different decision-making methods. Despite these limitations, the proposed method offers a simple but useful framework for supporting strategic market selection in a data-driven way.

OKVIR INTEGRISANOG PROGNOZIRANJA I AHP METODE ZA EVALUACIJU MEĐUNARODNIH TRŽIŠTA

Selen Nihan Taşçı, Buse Hoşgören, Elif Günenç
Istanbulski tehnički univerzitet, Fakultet za menadžment, Turska

Izvod

Identifikovanje atraktivnih inostranih tržišta predstavlja značajan izazov za kompanije koje žele međunarodno da se šire. Izbor odgovarajućeg tržišta zahteva razmatranje ne samo trenutnih uslova, već i budućih prilika i brojnih strateških faktora. Ova studija predlaže okvir za podršku odlučivanju koji kombinuje prognoziranje prodaje sa Analitičkim hijerarhijskim procesom (AHP) radi unapređenja evaluacije tržišta. Prognozirane vrednosti tražnje, generisane na osnovu makroekonomskih indikatora, uključene su u AHP model kao kriterijum odlučivanja, čime se omogućava da se buduća očekivanja u vezi sa tržištem uzmu u obzir zajedno sa drugim važnim faktorima. Predloženi okvir primenjen je na evropsko tržište autobusa, gde su Francuska, Nemačka i Španija ocenjene na osnovu kriterijuma koji se odnose na atraktivnost tržišta, održivost, geografsku centralnost, postojeće distributerske mreže i gustinu konkurencije. Integrisanjem rezultata prognoziranja u višekriterijumsku analizu odlučivanja, studija pruža sveobuhvatniji i dugoročnije orijentisan pristup izboru tržišta. Rezultati istraživanja nude praktične uvide organizacijama koje žele da podrže odluke o međunarodnoj ekspanziji primenom metoda donošenja odluka zasnovanih na podacima.

Ključne reči: *višekriterijumska analiza odlučivanja, prognoziranje tražnje, Analitički hijerarhijski proces (AHP), izbor međunarodnog tržišta.*

LITERATURA / REFERENCES

Al Shamsi, I., & Shannaq, B. (2023). Assessing profitability and sustainability: An analytic hierarchy process (AHP) model for future Middle East businesses. International Journal of Management and Applied Science, 9(8), 62-69.

Armstrong, J. S. (Ed.). (2001). Principles of forecasting: A handbook for researchers and practitioners. Springer. https://doi.org/10.1007/978-0-306-47630-3

Büyüközkan, G., & Çifçi, G. (2012). A combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry. Expert Systems with Applications, 39(3), 2341-2354. https://doi.org/10.1016/j.eswa.2011.08.061

Cavusgil, S. T., Kiyak, T., & Yeniyurt, S. (2004). Complementary approaches to preliminary foreign market opportunity assessment: Country clustering and country ranking. Industrial Marketing Management, 33(7), 607-617. https://doi.org/10.1016/j.indmarman.2003.10.005

Deaza, Jose & Díaz, Néstor & Castiblanco Moreno, Suelen & Barbosa-Camargo, María. (2020). International market selection models: a literature review. Tendencias. 21. 191-217. 10.22267/rtend.202102.147.

Dunning, J. H. (1988). The eclectic paradigm of international production: A restatement and some possible extensions. Journal of International Business Studies, 19(1), 1-31. https://doi.org/10.1057/palgrave.jibs.8490372

Ekici, Ü., Akay, M. E., & Moslem, S. (2026). Determination of logistics center locations in Türkiye using AHP-based TOPSIS methods. Transportation Research Interdisciplinary Perspectives, 37, 101967. https://doi.org/10.1016/j.trip.2026.101967

Greco, S., Ehrgott, M., & Figueira, J. R. (Eds.). (2016). Multiple criteria decision analysis: State of the art surveys. Springer. https://doi.org/10.1007/978-1-4939-3094-4

Lin, W., & Wei, Y. (2024). Economic forecasting with big data: A literature review. Journal of Management Science and Engineering, 9(2), 254-270. https://doi.org/10.1016/j.jmse.2024.01.003

López-Cadavid, D. A., Vanegas-López, J. G., Restrepo-Morales, J. A., & Roldán-Sepúlveda, M. (2023). Systematic selection of international markets using a hybrid multi-criteria approach: A study in the paper and paperboard industry. Cogent Business & Management, 10(3). https://doi.org/10.1080/23311975.2023.2277555

Paul, J., & Benito, G. R. G. (2018). A review of research on outward foreign direct investment from emerging countries, including China: what do we know, how do we know and where should we be heading? Asia Pacific Business Review, 24(1), 90-115. https://doi.org/10.1080/13602381.2017.1357316

Saaty, R. W. (1987). The analytic hierarchy process - what it is and how it is used. Mathematical Modelling, 9(3-5), 161-176. https://doi.org/10.1016/0270-0255(87)90473-8

Engineering management 12 (1) (2026) 33-42

Engineering management

DYNAMIC PARAMETER CONFIGURATION AND INTEGRATED INVENTORY OPTIMIZATION: AN APPLICATION IN THE AUTOMOTIVE SECTOR*

Büşra Çil, İrem Çelik, Sevde Sözden
Gazi University, Faculty of Engineering, Department of Industrial Engineering, Türkiye

Abstract

Inventory management within the automotive industry is highly complex due to intense demand volatility and diverse product portfolios. This research presented a structured methodology centered on inventory optimization, stochastic demand modeling, simulation-based optimization, and data-driven framework design. Through a systematic literature review compliant with PRISMA guidelines, 63 core papers were selected and evaluated out of an initial pool of 1 598 publications. This analysis revealed that existing methodologies rarely provide dynamic parameter optimization for large-scale operations with over 20 000 SKUs. To address this research gap, an innovative architecture coupling SimPy-based stochastic simulation and Optuna-backed Bayesian optimization was developed. This integrated system was thoroughly tested through an empirical case study conducted at a global automotive firm. The empirical outcomes confirmed that the methodology successfully minimizes total inventory costs and enhances processing efficiency without compromising on prescribed service levels

Keywords: *inventory control, demand volatility, SimPy simulation, Bayesian optimization, PRISMA methodology*

1. INTRODUCTION

Managing inventory levels under stochastic demand and lead-time uncertainties remains a critical efficiency challenge in modern industrial operations (Azoury & Miyaoka, 2020). Traditional inventory models often lack the scalability required to encompass the dynamic interactions and real-time variability inherent in large-scale systems, particularly where lead-time and demand variability are critical factors (Braglia et al., 2019). Consequently, there is a growing necessity for integrated frameworks that combine robust statistical foundations with modern computational intelligence methods to navigate these uncertainties effectively.

The primary objective of this paper is to conduct a systematic literature review (SLR) following the PRISMA 2020 guidelines to identify and synthesize state-of-the-art stochastic inventory optimization strategies. By filtering 1,598 initial records down to 63 high-quality studies, this review explores the evolution of decision-making frameworks in the field. A significant contribution of this work is the proposal of an integrated perspective

* *Paper presented at the XXII Student Symposium on Strategic Management*

that evaluates advanced forecasting algorithms, simulation-supported decision systems, and intelligent optimization approaches within stochastic inventory management literature.

Within this scope, the reviewed studies emphasize that machine learning-based forecasting approaches improve inventory planning accuracy under uncertain demand conditions, while simulation-based models provide reliable evaluation environments for operational decision-making (Corlu et al., 2020). In addition, recent studies highlight that dynamic inventory policies and intelligent optimization techniques contribute significantly to minimizing operational costs and maintaining target service levels in stochastic systems (Bhuiya & Chakraborty, 2020; Darendeliler et al., 2023). Therefore, this review aims to identify current methodological trends, compare dominant optimization approaches, and reveal existing research gaps in stochastic inventory management literature.

2. LITERATURE REVIEW

The systematic synthesis of the 63 included studies identified through the PRISMA 2020 protocol reveals a clear methodological transition from static analytical models to dynamic, simulation-integrated frameworks. To provide a comprehensive understanding of the field, this review is guided by three fundamental Research Questions (RQs):

- RQ1. Which machine learning algorithms have been predominantly preferred for different types of inventory problems in the last decade, and how does the literature analyze their impact on inventory parameter optimization and forecasting performance?
- RQ2. What are the effects of Dynamic Inventory Management Models on operational costs and service levels in industrial applications?
- RQ3. What is the reliability level of discrete-event simulations, used as "digital twins" of inventory systems, in decision-making processes under operational constraints such as Minimum Order Quantity (MOQ) and Lead Time?
- RQ4. What are the comparative successes of “Grid Search” and “Bayesian Optimization” (Optuna) methods in minimizing total inventory costs when determining inventory parameters?

2.1. Analysis of machine learning algorithms and forecasting impact (RQ1)

Regarding RQ1, the selected studies show that recent inventory research increasingly relies on data-driven and learning-based methods to improve forecasting and parameter optimization. Abdi et al. (2025) emphasize the role of machine learning in multi-objective and multi-period supply chain optimization through demand forecasting, while Kourentzes et al. (2020) focus on optimizing forecasting models for inventory planning. In addition, Dehaybe et al. (2024), Stranieri et al. (2024), and Meisheri et al. (2022) highlight the growing use of deep reinforcement learning for dynamic replenishment and inventory optimization under uncertain demand. These studies indicate that learning-based algorithms are preferred because they can capture non-stationary demand patterns and support more adaptive inventory decisions.

2.2. Dynamic inventory models, operational costs, and service levels (RQ2)

The literature suggests that dynamic inventory models provide stronger operational performance than static policies, especially under stochastic demand and lead-time uncertainty. Bhuiya and Chakraborty (2020) analyze a continuous-review production-

inventory model with service-level constraints, showing the importance of balancing cost reduction with service performance. Similarly, Azoury and Miyaoka (2020), Braglia et al. (2019), and Rahdar et al. (2018) examine production-inventory and reorder-point models under uncertain demand and lead time. Overall, the selected studies indicate that dynamic inventory policies improve responsiveness, reduce total inventory-related costs, and help maintain service levels in industrial applications.

2.3. Reliability of discrete-event simulation as digital twins (RQ3)

The selected studies support the reliability of simulation-based approaches as decision-support tools for complex inventory systems. Corlu et al. (2020) review stochastic simulation under input uncertainty and show that simulation is useful when inventory systems include uncertainty that is difficult to solve analytically. Sbai and Berrado (2020) also emphasize the importance of simulation models in multi-echelon inventory management, while Maheshwari and Kamble (2022) discuss the use of supply chain digital twins for measuring optimal inventory policies. In addition, Liu et al. (2023) and Ziarnetzky et al. (2020) demonstrate that simulation-based performance assessment can support decision-making under constraints such as lead-time variability, safety stock requirements, and production uncertainty.

2.4. Comparative success of grid search vs. bayesian optimization (RQ4)

The selected studies indicate that intelligent optimization methods are increasingly preferred over exhaustive search methods such as Grid Search because they reduce computational effort and improve parameter tuning efficiency. Han and Ouyang (2022) propose a Bayesian approach for multi-objective stochastic simulation optimization, showing the potential of probabilistic optimization in complex systems. Horng and Lin (2017; 2025) also demonstrate the effectiveness of metaheuristic and skill-based optimization algorithms for constrained stochastic inventory problems. Additionally, Zabraoui et al. (2025) provide a comparative multi-algorithm perspective for inventory analytics, supporting the view that advanced optimization methods can achieve more efficient cost minimization than traditional parameter-search approaches.

Table 1. Methodological Synthesis of Key Selected Studies

Author(s) & Year	Methodology
Azoury & Miyaoka (2020)	Stochastic Modeling
Corlu et al. (2020)	Simulation-Optimization
Bhuiya & Chakraborty (2020)	Continuous Review
Berling & Sonntag (2023)	Cost Minimization
Bersani et al. (2019)	Distributed Flow Control
Braglia et al. (2019)	Lead-time Variability
Darendeliler et al. (2023)	Hybrid AI
Dbouk et al. (2023)	Economic Descriptors
Abad et al. (2020)	Benders Decomposition
Cunha et al. (2017)	Two-Stage Programming

The 10 studies listed in Table 1 were selected to represent a balanced cross-section of the literature relevant to the research questions. The selection prioritized papers that offer specific methodological insights into (r, Q) policies, Machine Learning applications, and simulation-based optimization. While academic impact was considered, emphasis was also placed on the relevance of the findings to large-scale industrial systems. This collection

provides a focused foundation for analyzing current trends and identifying research gaps in stochastic inventory management.

3. RESULTS AND DISCUSSION

The literature selection followed PRISMA 2020 guidelines to ensure transparency and reproducibility. A systematic search was conducted across Web of Science, ScienceDirect, and Google Scholar using keywords such as 'stochastic inventory control', 'machine learning', and 'discrete event simulation'. Initially, 1 598 records were identified, and after removing 4 duplicates, 1 594 unique records entered the screening phase. Following a title and abstract review, 1 337 studies were excluded for being out of scope. The remaining 257 reports underwent full-text assessment, where 131 were removed due to insufficient technical detail or lack of optimization focus. Ultimately, 126 studies were assessed for eligibility, resulting in a final set of 63 selected studies that provide a robust foundation for the proposed decision-support framework presented in Figure 1.

Table 2. Quantitative distribution of key findings in the reviewed studies

KPI	Number of Studies	Percentage
Cost Reduction Reported	41	65.1%
Service Level Improvement	29	46.0%
Simulation-Based Validation	35	55.6%
Machine Learning-Based Forecasting	41	65.1%
Bayesian / Intelligent Optimization	24	38.1%
Dynamic (r, Q) Inventory Policies	25	39.7%

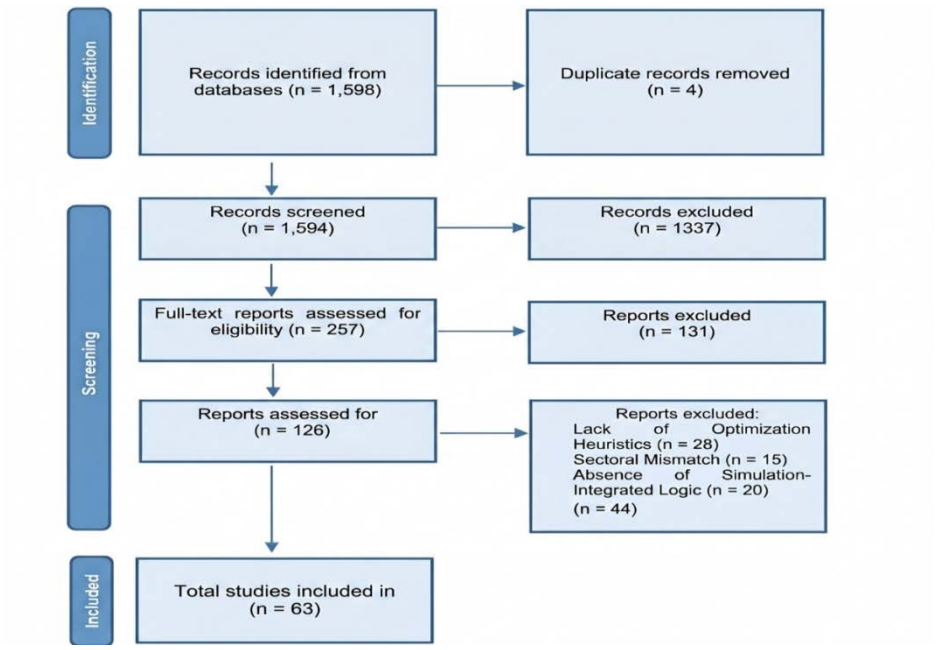


Figure 1. PRISMA 2020 flow diagram of the systematic literature selection process.

3.1. Preferences and ımpacts of machine learning algorithms (RQ1)

The PRISMA-based analysis revealed that Machine Learning (ML)-supported forecasting approaches represent the dominant methodological category within the reviewed studies.

Approximately 65.1% (41 out of 63 studies) utilized ML-based models for demand forecasting and inventory parameter optimization. Among these approaches, Random Forest, XGBoost, and reinforcement learning-based methods were identified as the most frequently preferred algorithms due to their ability to model non-linear demand structures and stochastic inventory environments. The findings indicate that ML-supported forecasting improves prediction accuracy and enhances the adaptability of inventory decision-making processes under uncertain demand conditions.

3.2. Dynamic Inventory Management on Costs and Service Levels (RQ2)

The findings demonstrate that dynamic inventory policies, particularly continuous-review and stochastic (r, Q) models, are widely preferred over static inventory approaches in industrial applications. Approximately 39.7% (25 studies) reported that dynamic inventory models contributed to reducing operational costs while simultaneously improving service-level performance. The reviewed literature indicates that integrating service-level constraints into optimization models improves inventory responsiveness and operational flexibility under stochastic demand and lead-time uncertainty.

3.3. Reliability of discrete-event simulations as digital twins (RQ3)

The analysis showed that 55.6% (35 studies) employed Discrete-Event Simulation (DES) as a simulation-based decision-support tool for complex inventory systems. The reviewed studies emphasized that DES approaches provide reliable operational evaluations under uncertainty, particularly in environments involving lead-time variability, safety stock constraints, and stochastic demand structures. In addition, simulation-supported digital twin models were frequently used to validate inventory strategies in situations where analytical optimization models become difficult to implement.

3.4. Comparative success of grid search vs. bayesian optimization (RQ4)

The reviewed studies indicate a growing transition from traditional search techniques toward intelligent optimization approaches in inventory parameter tuning. Approximately 38.1% (24 studies) employed Bayesian or heuristic optimization techniques for stochastic inventory optimization problems (Figure 2). The findings suggest that Bayesian Optimization methods, particularly Optuna-based approaches, provide more computationally efficient parameter tuning compared to exhaustive search techniques such as Grid Search, especially in high-dimensional stochastic optimization environments.

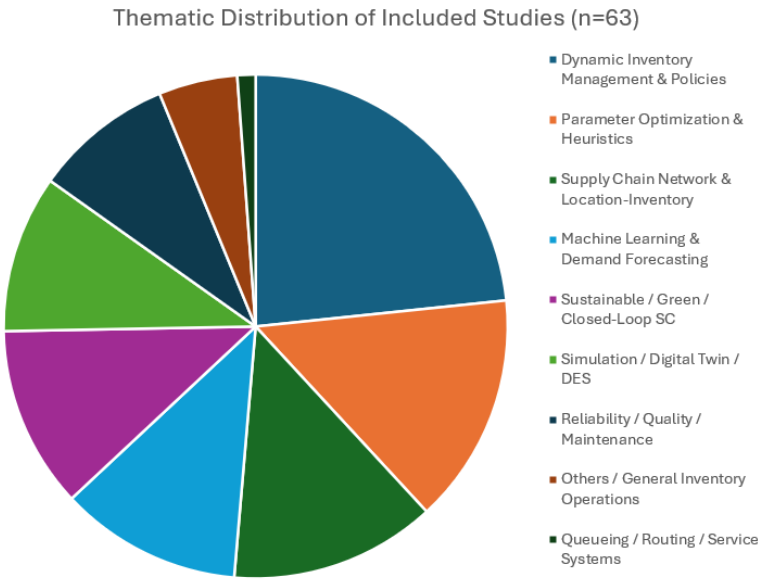


Figure 2. Thematic distribution of included studies

4. CONCLUSION

This study presented a systematic literature review (SLR) on stochastic inventory optimization by following the PRISMA 2020 guidelines and analyzing 63 selected high-quality studies obtained from an initial dataset of 1,598 records. The findings reveal a clear methodological transition from traditional static inventory models toward data-driven, simulation-supported, and intelligent optimization approaches in modern inventory management literature.

The reviewed studies indicate that Machine Learning-based forecasting approaches are increasingly utilized to improve demand prediction accuracy and support adaptive inventory decision-making under stochastic demand conditions. In addition, dynamic inventory policies, particularly continuous-review and stochastic (r, Q) models, were found to contribute significantly to operational cost reduction and service-level improvement in industrial applications. The analysis also confirmed that Discrete-Event Simulation (DES) approaches are widely adopted as reliable decision-support and digital twin tools for evaluating inventory systems under operational uncertainty and lead-time variability.

Furthermore, the reviewed literature demonstrates a growing preference for Bayesian and heuristic optimization techniques over traditional exhaustive search approaches in inventory parameter tuning problems. The findings suggest that intelligent optimization methods provide improved computational efficiency and better adaptability in high-dimensional stochastic optimization environments.

Despite these contributions, the study has several limitations. First, the review included only English-language publications indexed in selected databases, which may limit the generalizability of the findings across different regions and industrial contexts. Second, the study focused primarily on inventory optimization applications related to industrial and manufacturing systems, particularly within automotive-oriented supply chain environments.

Future studies may expand this research by investigating multi-echelon supply chain structures, real-time ERP-integrated inventory systems, and hybrid AI-supported optimization frameworks. In addition, broader sectoral analyses and comparative empirical validations may further strengthen the applicability of intelligent inventory optimization approaches in complex industrial environments.

DINAMIČKA KONFIGURACIJA PARAMETARA I INTEGRISANA OPTIMIZACIJA ZALIHA: PRIMENA U AUTOMOBILSKOJ INDUSTRIJI

Büşra Çil, İrem Çelik, Sevde Sözden
Univerzitet Gazi, Fakultet inženjerstva, Departman za industrijsko inženjerstvo, Turska

Izvod

Upravljanje zalihama u automobilskoj industriji izuzetno je složeno zbog izražene nestabilnosti tražnje i raznovrsnog portfolija proizvoda. Ovo istraživanje predstavlja strukturisanu metodologiju zasnovanu na optimizaciji zaliha, stohastičkom modelovanju tražnje, optimizaciji zasnovanoj na simulacijama i kreiranju okvira vođenog podacima. Kroz sistematski pregled literature sproveden u skladu sa PRISMA smernicama, od početnog skupa od 1.598 publikacija odabrana su i analizirana 63 ključna rada. Analiza je pokazala da postojeće metodologije retko pružaju mogućnost dinamičke optimizacije parametara za operacije velikog obima sa više od 20.000 skladišnih jedinica (SKU). Kako bi se prevazišao ovaj istraživački jaz, razvijena je inovativna arhitektura koja povezuje stohastičku simulaciju zasnovanu na SimPy platformi i Bajesovu optimizaciju podržanu alatom Optuna. Ovaj integrisani sistem detaljno je testiran kroz empirijsku studiju slučaja sprovedenu u globalnoj automobilskoj kompaniji. Empirijski rezultati potvrdili su da predložena metodologija uspešno minimizuje ukupne troškove zaliha i unapređuje efikasnost procesa, bez ugrožavanja propisanih nivoa usluge.

Ključne reči: *kontrola zaliha, nestabilnost tražnje, SimPy simulacija, Bajesova optimizacija, PRISMA metodologija*

LITERATURA / REFFERENCES

Abad, H., Schogster, J., & Östberg, G. (2020). Benders decomposition for large-scale green supply chain optimization. Journal of Cleaner Production, 254, 120054. 10.24200/sci.2020.53412.3249

Abdi, F., Abolmakarem, S., Yazdi, A. K., Popescu, V., Birau, R., & Mitroi, A. T. (2025). A machine learning-based approach for multi-objective, multi-product, and multi-period supply chain optimization via demand forecasting. Computers & Industrial Engineering. 10.1109/ACCESS.2025.3600092

Azoury, K. S., & Miyaoka, J. K. (2020). Inventory models with mixed stochastic demand types. Operations Research Letters, 48(3), 320-325. https://doi.org/10.1016/j.ejor.2020.03.009

Berling, P., & Sonntag, D. (2023). Cost minimization under random yield and substitution dynamics in inventory systems. European Journal of Operational Research, 305(2), 712-725. 10.1111/poms.13706

Bersani, C., Dagdougui, H., Roncoli, C., & Sacile, R. (2019). Distributed product flow control in a network of inventories with stochastic production and demand. IEEE Access, 7, 22414-22428. https://doi.org/10.1109/ACCESS.2019.2898648

Bhuiya, S. K., & Chakraborty, D. (2020). On the distribution-free continuous-review production-inventory model with service level constraint. Sādhanā, 45(1), 1-12. https://doi.org/10.1007/s12046-020-01383-5

Braglia, M., Castellano, D., Marrazzini, L., & Song, D. (2019). A continuous review, (Q, r) inventory model for a deteriorating item with random demand and positive lead time. Computers & Operations Research, 109, 102-121. https://doi.org/10.1016/j.cor.2019.04.019

Corlu, C. G., Akcay, A., & Xie, W. (2020). Stochastic simulation under input uncertainty: A review. Operations Research Perspectives, 7, 100162. https://doi.org/10.1016/j.orp.2020.100162

Cunha, P. S. A., Raupp, F. M. P., & Oliveira, F. (2017). A two-stage stochastic programming model for periodic replenishment control system under demand uncertainty. Computers & Industrial Engineering, 110, 296-308. https://doi.org/10.1016/j.cie.2017.03.025

Darendeliler, A., Claeys, D., & Aghezzaf, E.-H. (2023). Integrated condition-based maintenance and multi-item lot-sizing with stochastic demand. Journal of Industrial and Management Optimization. https://doi.org/10.3934/jimo.2022245

Dbouk, W., Tarhini, H., & Nasr, W. (2023). Re-ordering policies for inventory systems with a fluctuating economic environment: Using economic descriptors to model the demand process. International Journal of Production Research. https://doi.org/10.1080/01605682.2022.2122735

Dehaybe, H., Catanzaro, D., & Chevalier, P. (2024). Deep reinforcement learning for inventory optimization with non-stationary uncertain demand. Computers & Industrial Engineering. https://doi.org/10.1016/j.ejor.2023.10.007

Han, M., & Ouyang, L. (2022). A novel Bayesian approach for multi-objective stochastic simulation optimization. Simulation Modelling Practice and Theory, 118, 102547. https://doi.org/10.1016/j.swevo.2022.101192

Horng, S.-C., & Lin, S.-S. (2017). Ordinal optimization based metaheuristic algorithm for optimal inventory policy of assemble-to-order systems. Applied Soft Computing, 61, 958-971. https://doi.org/10.1016/j.apm.2016.10.002

Horng, S.-C., & Lin, S.-S. (2025). Adapted skill optimization algorithm to solve constrained discrete stochastic optimization problems. Expert Systems with Applications. https://doi.org/10.1016/j.matcom.2025.06.016

Kourentzes, N., Trapero, J. R., & Barrow, D. K. (2020). Optimising forecasting models for inventory planning. International Journal of Production Economics, 225, 107597. https://doi.org/10.1016/j.ijpe.2019.107597

Liu, Y. Y., Chang, K. H., & Chen, Y. Y. (2023). Simultaneous predictive maintenance and inventory policy in a continuously monitoring system using simulation optimization. Reliability Engineering & System Safety, 233, 109121. https://doi.org/10.1016/j.cor.2023.106146

Maheshwari, P., & Kamble, S. (2022). The application of supply chain digital twin to measure optimal inventory policy. International Journal of Production Research. https://doi.org/10.1016/j.ifacol.2022.10.055

Meisheri, H., Sultana, N. N., Baranwal, M., Baniwal, V., Nath, S., Verma, S., Ravindran, B., & Khadilkar, H. (2022). Scalable multi-product inventory control with lead time constraints using reinforcement learning. Engineering Applications of Artificial Intelligence, 110, 104679. 10.1007/s00521-021-06129-w

Rahdar, M., Wang, L., & Hu, G. (2018). A tri-level optimization model for inventory control with uncertain demand and lead time. Applied Mathematical Modelling, 63, 96-112. https://doi.org/10.1016/j.ijpe.2017.10.011

Sbai, N., & Berrado, A. (2020). Simulation models for multi-echelon inventory management problem: A literature review. IFAC-PapersOnLine, 53(2), 10704-10709.

Stranieri, F., Stella, F., & Kouki, C. (2024). Performance of deep reinforcement learning algorithms in two-echelon inventory control systems. Computers & Industrial Engineering. https://doi.org/10.1016/j.ijpe.2023.109099

Zabraoui, O., Hmamou, Y., Chafi, A., & Alami, S. K. (2025). A comparative study of multi-algorithm optimization for inventory analytics in supply chains. Expert Systems with Applications. https://doi.org/10.1016/j.sca.2025.100154

Ziarnetzky, T., Moench, L., & Uzsoy, R. (2020). Simulation-based performance assessment of production planning models with safety stock and forecast evolution in semiconductor wafer fabrication. International Journal of Production Research, 58(21), 6505-6524.10.1109/TSM.2019.2958526

Engineering management 12 (1) (2026) 43-54

Engineering management

A COMPARATIVE STUDY OF PRIMARY ENERGY PRODUCTION AND ENERGY DIVERSIFICATION IN SERBIA AND SLOVENIA*

Mihailo Džoković, Teodora Radivojević, Iva Savić

University of Belgrade, Faculty of Mechanical Engineering, Serbia

Abstract

The way a country generates its primary energy shapes its economic trajectory, the stability of its supply and its environmental footprint, which is why understanding this structure has become a central concern of our time. Against this backdrop, this paper traces how primary energy production evolved in two geographically close yet developmentally distinct countries: 1.Serbia, classified as developing, and 2. Slovenia, classified as advanced, across a ten-year span from 2014 to 2024. Secondary data drawn from the official statistical offices of both countries were examined through descriptive statistics, trend analysis and Pareto charts. The findings point to two markedly different energy models. Serbian production is dominated by coal throughout the entire period, reflecting a heavy concentration on non-renewable sources, whereas Slovenian production rests on a more balanced combination of three pillars - nuclear energy, solid fuels and renewables. This confirms that Slovenia has reached a higher degree of diversification, while Serbia remains tied to fossil fuels. The study adds to the comparative literature on national energy structures and underscores the need for Serbia to accelerate diversification and strengthen investment in renewable sources. Although the analysis carries certain limitations, it offers useful guidance for energy policy and opens avenues for future research grounded in broader datasets and more sophisticated analytical models.

Keywords: *energy, production, structure, renewable sources, diversification, Pareto analysis, Serbia, Slovenia*

1. INTRODUCTION

Energy is considered to be one of the most important factors of the modern civilization. As stated by the United Nations "energy is central to nearly every major challenge and opportunity the world faces" (United Nations, 2025). Nowadays, energy is known to have an important role in everyday environment and is closely connected to economic growth and living standards of societies (Siirola, 2014). A subcategory of energy, known as primary energy, refers to energy which is derived from both renewable and non-renewable sources in its initial form, before any conversion or transformation (European Parliament, 2018; Bilardo et al., 2022). Primary energy production includes solid fossil fuels, natural gas, crude oil, nuclear energy, renewable energy, renewable energy sources, peat and non-renewable waste (Zhao et al., 2023; Kosowski, 2024). They can be further transformed into secondary energy sources, like electricity (Zhao et al., 2023). Although energy itself offers substantial benefits, it still has serious downfalls. Energy production negatively impacts human health and the environment in three main ways: air pollution, accidents, and greenhouse gas emissions. Even though every energy source has its

* *Paper presented at the XXII Student Symposium on Strategic Management*

negative impact, fossil fuels by far have the biggest negative impact on both the environment and human health (Ritchie, 2020). Fossil fuels emit the most greenhouse gasses per unit of energy, whereas both nuclear energy and renewable energy are far better options (Radosavljević et al., 2022). Given the anticipation of further growth in primary energy demand, it is necessary to utilize all available energy sources efficiently, including coal (Balat, 2009). As the most cost-effective fuel source globally, coal maintains a dominant position in the global market for electricity production (Radosavljević et al., 2022). Coal is often seen as a necessary alternative choice in situations where cleaner and cheaper energy sources cannot meet the demand (Balat, 2009). Unfortunately, since it does emit the most amount of greenhouse gasses, it is considered to be the biggest cause of global warming (Radosavljević et al., 2022). On the other hand, renewable energy is produced from indigenous natural resources that are continuously restored and are environmentally friendly. Global investments in research and development have further made renewable energy more accessible, available and acceptable (Gökgöz & Güvercin, 2018).

However, the geographical positioning and the market imbalance make it difficult for developing countries, where Serbia is currently listed, to have access to modern energy services (Legro et al., 2009; International Monetary Fund, 2023). Furthermore, energy consumption is rising dramatically, due to population expansion, developments in different industries and the countries' efforts to improve their living standards (Albayrak, 2010). This rising trend is present around the world, due to industrialisation and urbanisation, which additionally contributes to the increase of waste generation (Ouda et al., 2016), indicating that advanced countries, such as Slovenia (International Monetary Fund, 2023), are also affected. Consequently, energy production has significantly increased over the past three decades in order to meet this growing demand worldwide (United Nations Department of Economic and Social Affairs, 2024).

2. LITERATURE REVIEW

Energy has a strong connection with problems and opportunities on a global level, including issues regarding affordability, supply security, resilience, environmental pollution, climate change, and global sustainability. On the other side, the energy sector has a role in the development of new technologies and industries and can create opportunities for sustainable energy production, especially in regions where drastic economic growth is recorded. (Pfenninger, 2014). The importance of incorporating both traditional and renewable sources, in order to achieve diversification of primary energy production, which has direct influence on reducing the risk of supply disruptions is acknowledged by Shipkovs et al., (2011). Having said that, previous academic literature has covered the topic of primary energy consumption (Bozsik et al., 2023) and production, with a focus on the importance of sustainable and multiple energy systems around the world (Shalaeva et al., 2020), on European countries level (Kosowski, 2024; Balaras et al., 2022) and in the case of European Union countries (Dacko et al., 2020). Furthermore, renewable energy production and its production in European regions has become relevant in academic research (Perpiñá Castillo et al., 2024; Trębska & Gromada, 2017). Shalaeva et al. (2020) analyzed the changes of energy production and consumption in the period between 1990 and 2018 by world regions, with one of the conclusions being that, due to climate policy changes, the coal consumption in Europe achieved a declining rate over time. Further analysis, on a dataset including European countries, from 1990 to 2020 was conducted by Kosowski (2024), who examined the changes in primary energy production in these countries in terms of their sources and effects on energy security and sustainability. Kosowski (2024) grouped European countries by their similarities into multiple clusters. Extracted from results obtained in 1990, Serbia was categorized into "Coal Countries" cluster, and Slovenia "Coal Countries with Nuclear Components". Three decades later, in 2020, Serbia was still considered as the predominantly "Coal" country, while Slovenia obtained a change in its primary energy production and got

categorized as a part of the "Nuclear Countries" grouping. Energy situation (Brkić, 2018), potential for the growth of renewable energy sources (Dragović et al., 2019) and the status of Serbia regarding waste to energy process (Bajić et al., 2015) are explored by authors. Previous studies assessed patterns of energy consumption, energy efficiency indicators across economic sectors and reviews relating energy efficiency policies and measures (Al-Mansour, 2011), the future chances of Slovenia lowering the levels of fossil and nuclear sources by the year of 2050 (Senegačnik & Sekavčnik, 2024) and energy management in Slovenia, with a focus on renewable sources, nuclear energy and decrement of coal use (Crnčec, 2022). Given the previously stated, primary energy production is a relevant and important topic for further academic research, and this paper aims to give contribution by analyzing primary energy productions of two geographically close countries, Serbia and Slovenia, which are differently categorized in terms of their levels of economic advancement and this paper aims to fill the identified research gap in current literature. While both Serbia and Slovenia have been individually analyzed in the existing literature, no direct comparative analysis of their primary energy production structures over the 2014-2024 period has been conducted. In this paper, descriptive statistics, trend analysis and the Pareto chart are applied in order to give detailed comparison of primary energy productions between these countries and to confirm key energy sources for each of them using the newest datasets available.

3. DATA AND METHODOLOGY

The purpose of this research is to compare secondary data obtained from the official national statistical databases of Serbia and Slovenia. The analysed dataset includes the period from 2014 to 2024 and includes primary energy production by source, ensuring comparability between two countries. The methods of analysis that were used throughout this research were descriptive statistics, trend graph and Pareto plot. All data regarding primary energy production in Serbia and Slovenia were retrieved from the databases of the Statistical Office of the Republic of Serbia (2024) and the Statistical Office of the Republic of Slovenia (2024). The available statistical data are presented according to Eurostat standards and the International Energy Agency, which gives the opportunity to cross examine data from different countries, supporting the analysis conducted in this paper (Statistical Office of the Republic of Serbia, 2024; Statistical Office of the Republic of Slovenia, 2024). Descriptive statistical methods and SPSS version 26.0.0.0 software was used to summarise the dataset, which helped provide an overview of the primary energy production in both Serbia and Slovenia. The results of descriptive statistics provide data of the number of samples (N), mean value (Mean), median (Med), minimum values (Min), maximum values (Max), range (R), standard deviation (SD) and coefficient of variation (CV) for both analysed countries. The importance (dominance) of each source was assessed using a Pareto analysis as a tool useful to showcase and identify the relative importance of problems. It contains both bars and lines, where bars represent individual values and the curved line presents the cumulative total of the sample. A cut off line is also included where the most vital factors sit under it. In the context of the primary production in Slovenia and Serbia, the cut off line was approximately 80% which follows the Pareto principle 80/20 that states that roughly 80% of the effects come from 20% of causes (Pyzdek, 2021). In some cases, the cut off line exceeds 80% in order to obtain the most important sources in a logical manner. Additionally, a trend graph covering a ten-year period was created to illustrate changes in primary energy production over time.

4. RESULTS AND DISCUSSION

The results of the analysis reveal dominant energy sources and indicate differences in the dynamics and structure of primary energy production between Serbia and Slovenia. Firstly, descriptive statistics were performed and the results are presented in Table 1 and Table 2. Based on the obtained results (Table 1), it can be stated that the total mean value of non-renewable

primary energy sources, consisted of coal, oil and oil derivatives, natural gas, non-renewable industrial waste and non-renewable municipal waste (326930.36), is significantly higher than renewable energy sources in Serbia (99482.82), which includes wood fuel, hydro energy, geothermal energy, biogas, renewable industrial waste, solar photovoltaic energy, wind energy and renewable municipal waste. Coal achieved the overall highest mean value (270294.82).

Table 1. Descriptive statistics - Serbia (in TJ)

Energy source	N	Mean	Med	Min	Max	R	SD	CV (%)
Coal	11	270294.82	276720	227048	302127	75079	29599.09	10.95
Oil and oil derivatives	11	40376.09	38990	35940	50592	14652	4652.40	11.52
Wood fuel	11	56346.36	49151	45395	68918	23523	11111.27	19.72
Hydro energy	11	39227.91	38819	33388	47090	13702	4106.99	10.47
Natural gas	11	15963.82	16247	11000	21207	10207	3620.81	22.68
Geothermal energy	11	166.82	215	61	257	196	82.61	49.52
Biogas	11	1321.73	1190	215	2587	2372	900.12	68.10
Renewable industrial waste	11	91.36	93	73	105	32	10.93	11.96
Non-renewable industrial waste	11	191.27	51	34	1613	1579	471.61	246.57
Solar photovoltaic energy	11	105.09	48	22	586	564	163.96	156.02
Wind energy	11	2145.36	3234	0	4875	4875	1948.62	90.83
Non-renewable municipal waste	11	104.36	0	0	1083	1083	325.16	311.57
Renewable municipal waste	11	78.18	0	0	813	813	244.12	312.24

The obtained results from Table 2 show that nuclear energy sources, which are in this case represented by nuclear energy (64181), obtained the highest total mean value in the Slovenian dataset. Renewable energy sources, which include: renewable energy, hydro energy and geothermal energy, had a total mean value of 48856.45, while non-renewable energy sources: solid fuels, natural gas, crude oil and petroleum products, obtained the lowest total mean value (33809.64).

Table 2. Descriptive statistics - Slovenia (in TJ)

Energy source	N	Mean	Med	Min	Max	R	SD	CV (%)
Nuclear	11	64181	63016	61124	69459	8335	3280.84	5.11
Solid	11	33592.64	34252	24504	39433	14929	5053.42	15.04
Renewable	11	27620.09	27235	24222	30585	6363	2151.85	7.80
Hydro	11	16561.91	16936	11335	21929	10594	2873.71	17.35
Geothermal	11	4674.45	3888	2925	8936	6011	1935.82	41.41
Natural gas	11	200.91	164	92	546	454	127.29	63.36
Crude oil	11	16.09	16	4	37	33	9.10	56.58
Petroleum products	11	0	0	0	0	0	0	0.00

Figure 1 illustrates the trends in primary energy production by source in Serbia during the period from 2014 to 2024. The analysis confirms that coal remained the dominant source of primary energy production throughout the entire period. Other energy sources, including hydro energy, oil derivatives and renewable energy sources contributed significantly less to the overall energy structure. Although certain variations can be observed over time, the overall structure of energy

production in Serbia remained strongly dependent on conventional energy (non-renewable) sources such as coal.

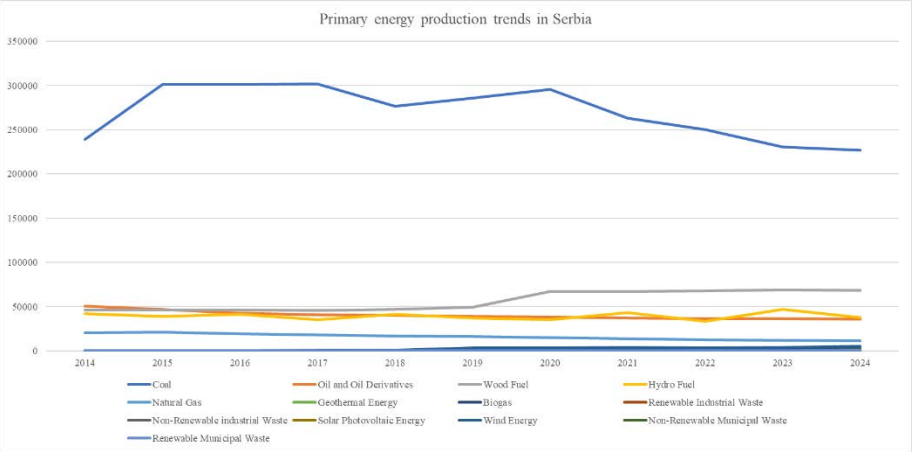


Figure 1. Primary energy production trends in Serbia

The analysis of Figure 2 presents a diversified energy structure, with nuclear energy representing the dominant source throughout the entire period. Although certain fluctuations can be observed over time, solid fuels and renewable sources of energy contributed significantly to total energy production. Overall, the analysis indicates a relatively stable energy production structure with increasing importance of sustainable energy sources. The results indicate that Slovenia achieved a higher level of diversification in primary energy production compared to Serbia, whose energy sector remains largely dependent on fossil fuels, mostly coal. Such dependence may have negative environmental implications due to high greenhouse emissions and reduce the sustainability of the energy sector. Therefore, greater investment in renewable energy sources and diversification of energy production could contribute to a more sustainable energy system in Serbia. Trend analysis illustrated the dynamics of primary energy production during the observed period, whereas Pareto analysis provides a clearer understanding of dominant energy sources and their cumulative contribution to the energy sector.

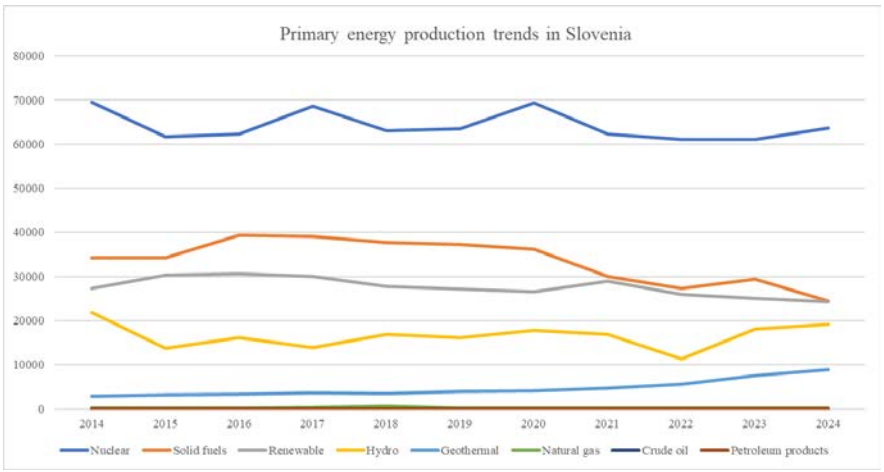


Figure 2. Primary energy production trends in Slovenia

Figure 3 and Figure 4 present the Pareto analysis of primary energy production sources in Serbia for 2014 and 2024. In both years that limit the period under consideration, coal remained the

dominant energy source, accounting for the largest share of total primary energy production. The pareto diagrams show that a small number of energy sources contributed to the majority of total production, indicating a concentrated energy structure. Although slight changes can be observed between 2014 and 2024, Serbia continued to rely heavily on fossil fuels, particularly coal. Such dependence may present environmental challenges, suggesting the need for greater development of renewable energy sources in the future.

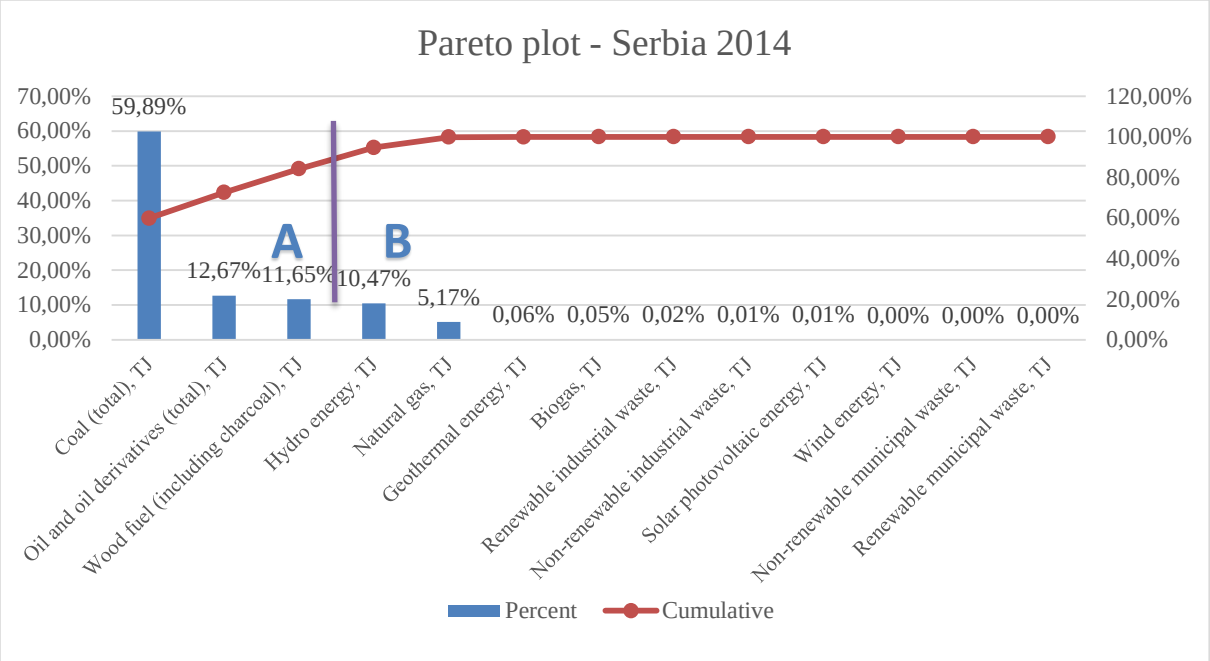


Figure 3. Pareto plot - Serbia 2014

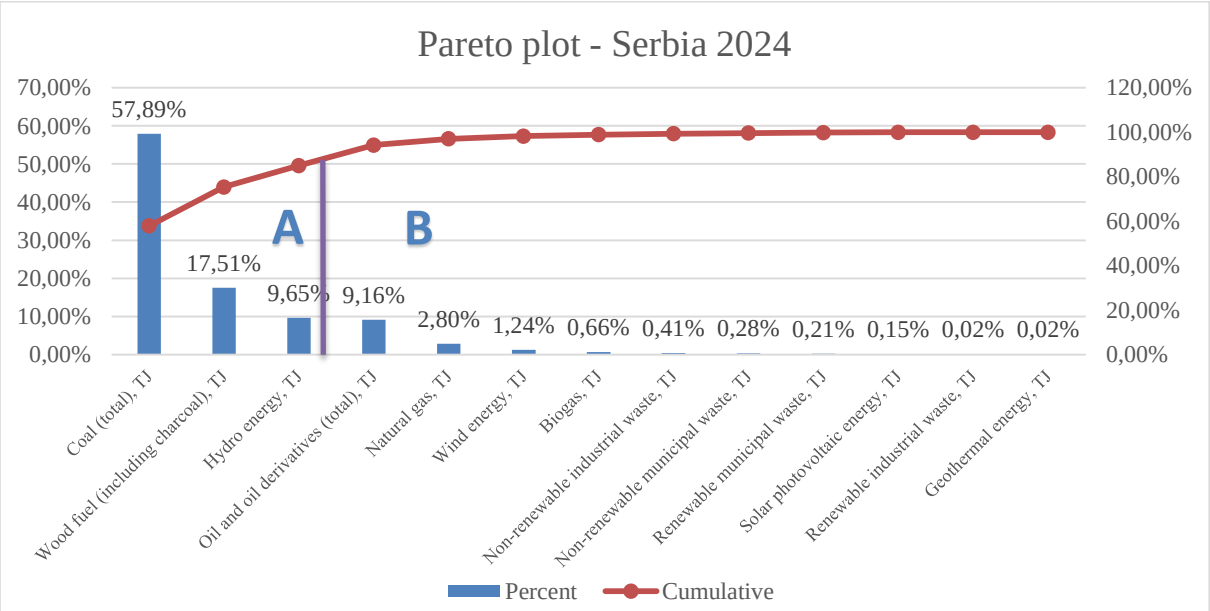


Figure 4. Pareto plot - Serbia 2024

Figure 5 and Figure 6 show the Pareto analysis of primary energy production sources in Slovenia for 2014 and 2024. Results indicate that nuclear energy, solid fuels and renewable source of

energy contributed significantly to total primary energy production. Unlike Serbia, where one source is dominant, Slovenia demonstrates a more balanced distribution of energy production.

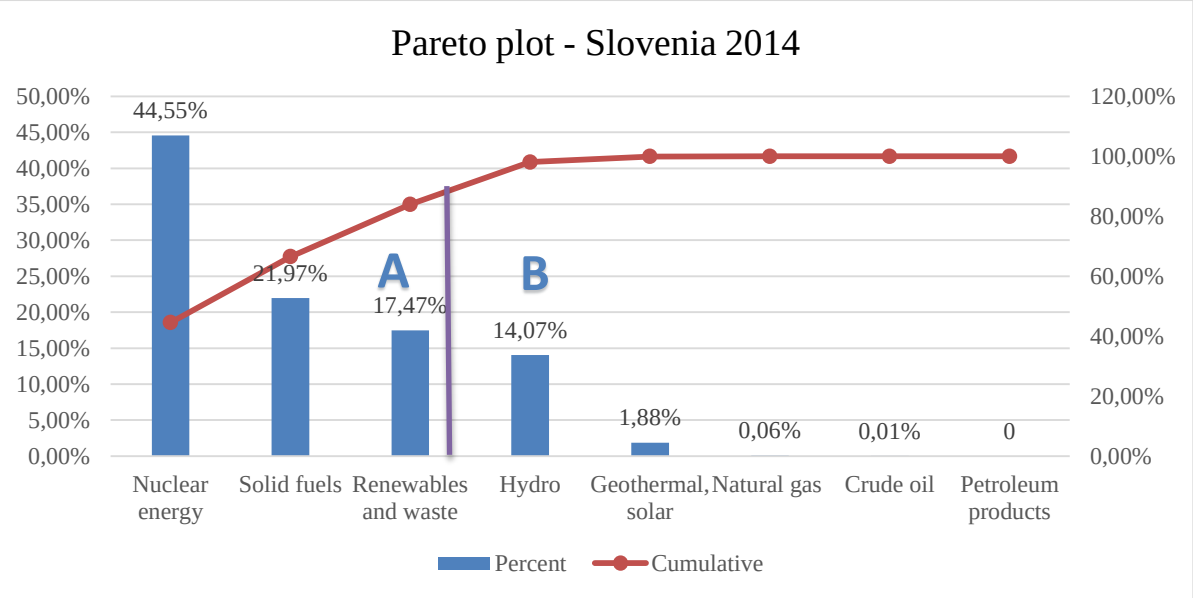


Figure 5. Pareto plot - Slovenia 2014

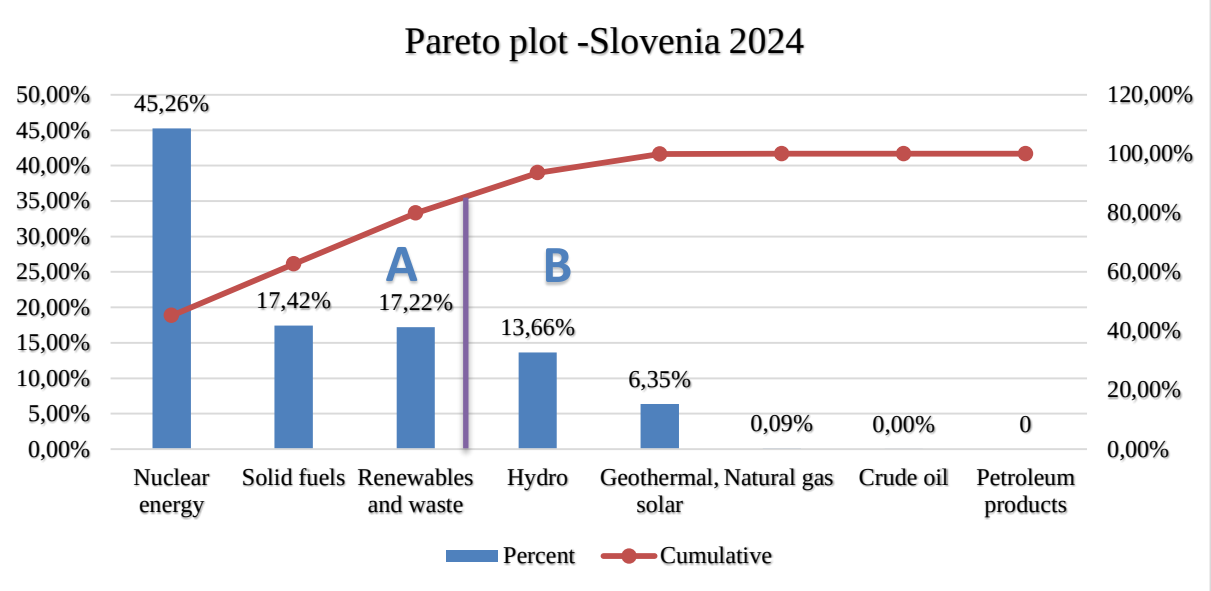


Figure 6. Pareto plot - Slovenia 2024

A more structured comparison between the two countries can be drawn by grouping the analysed energy sources into three categories: non-renewable, renewable and nuclear. Regarding non-renewable sources, Serbia exhibits an overwhelming dominance of coal, which alone contributes the majority of total primary energy production, complemented by oil and oil derivatives and minor amounts of natural gas, non-renewable industrial waste and non-renewable municipal waste. In Slovenia, non-renewable sources are also present, primarily in the form of solid fuels, with marginal contributions from natural gas and crude oil; however, their relative share is considerably lower than in Serbia and is consistent with broader European decarbonisation trends. With respect to renewable sources, Serbia's renewable portfolio is led by hydro energy and wood fuel, while wind, solar photovoltaic, biogas and geothermal energy remain marginal contributors despite some growth in recent years. Slovenia displays a comparatively more stable

renewable structure, anchored by renewables, hydro and geothermal energy, which together provide a more consistent contribution to the overall energy mix. The most pronounced difference between the two countries lies in the third pillar - nuclear energy. Slovenia's primary energy production is led by nuclear energy, which provides a stable, low-carbon baseload throughout the entire analysed period and accounts for the highest mean value among all sources. Serbia, by contrast, produces no nuclear energy, leaving a structural gap in low-carbon baseload capacity. This three-pillar comparison further confirms that Slovenia's energy mix benefits from the complementarity of nuclear, renewable and non-renewable sources, while Serbia's structure remains highly concentrated on a single non-renewable source, indicating a higher concentration of energy production in Serbia compared to Slovenia.

The structural difference between the two countries with respect to nuclear energy invites a brief reflection on the broader academic debate. On one side, several studies emphasise the systemic advantages of nuclear capacity in low-carbon energy systems. Aszódi et al. (2023), based on high-time-resolution electricity supply models for fifteen European countries with nuclear capacity, find that scenarios retaining nuclear power achieve the lowest CO_2 emissions, while phase-out scenarios increase emissions and storage requirements even when compensated by additional solar and wind capacity. Hjelmeland et al. (2025), using the EMPIRE model for European power systems, similarly show that the role of nuclear becomes more pronounced as baseload demand increases, with higher nuclear shares contributing to lower system-wide needs for storage, transmission, curtailment and land use. On the other side, studies emphasise the economic and timing challenges associated with new nuclear capacity. Steigerwald et al. (2023), through a Monte Carlo cost analysis of nineteen small modular reactor concepts, find that none are profitable under their tested assumptions, with median levelized costs of electricity starting at 116 USD/MWh, suggesting that significant cost reductions would be required for new nuclear projects to be economically competitive with alternative low-carbon technologies. The differing positions of Serbia and Slovenia with respect to nuclear capacity place the two countries on different sides of this ongoing academic and policy debate, and the choices each country makes regarding the future structure of its primary energy production represent an open area for further research.

5. CONCLUSION

This paper gives contribution by providing descriptive statistics, trend analysis and Pareto chart analysis for primary energy production comparison of a developing country, Serbia and advanced country, Slovenia. The results present changes in primary energy production between years 2014 to 2024. In the case of Serbia, the most dominant primary energy source is coal throughout the analyzed period. However, the second and third most dominant sources had changed over the decade: oil and oil derivatives have been exceeded by hydro energy, while wood fuel maintained its position in the most influential Pareto zone (A) in both cases. There were no drastic changes in the Pareto A zone for Slovenia: minimal variations were noticed, nevertheless the three dominant sources remained throughout the decade: nuclear energy as the most dominant, followed by solid fuels and renewables and waste. While this study is limited by its descriptive nature and reliance on secondary data from two countries, it provides valuable insights for energy policy decision-makers. Future research should expand the geographical scope and employ dynamic models and inferential tests to deepen the understanding of these relationships.

KOMPARATIVNA STUDIJA PROIZVODNJE PRIMARNE ENERGIJE I DIVERZIFIKACIJE ENERGETSKIH IZVORA U SRBIJI I SLOVENIJI

Mihailo Džoković, Teodora Radivojević, Iva Savić
Univerzitet u Beogradu, Mašinski fakultet, Srbija

Izvod

Način na koji jedna zemlja proizvodi primarnu energiju oblikuje njen ekonomski razvoj, stabilnost snabdevanja i uticaj na životnu sredinu, zbog čega je razumevanje ove strukture postalo jedno od ključnih pitanja savremenog doba. Polazeći od toga, u radu se analizira razvoj proizvodnje primarne energije u dve geografski bliske, ali razvojno različite zemlje: Srbiji, koja se svrstava u zemlje u razvoju, i Sloveniji, koja se smatra razvijenom zemljom, u periodu od deset godina (2014-2024). Korišćenjem sekundarnih podataka prikupljenih iz zvaničnih statističkih izvora obe zemlje, sprovedene su deskriptivna statistička analiza, analiza trendova i Pareto analiza. Rezultati ukazuju na postojanje dva značajno različita energetska modela. Proizvodnjom energije u Srbiji tokom celog posmatranog perioda dominira ugalj, što ukazuje na visoku zavisnost od neobnovljivih izvora energije. Nasuprot tome, energetska proizvodnja u Sloveniji zasniva se na uravnoteženijoj kombinaciji tri ključna izvora – nuklearne energije, čvrstih goriva i obnovljivih izvora energije. Ovi nalazi potvrđuju da je Slovenija dostigla viši nivo diverzifikacije energetskih izvora, dok Srbija i dalje ostaje snažno oslonjena na fosilna goriva. Rad doprinosi komparativnim istraživanjima nacionalnih energetskih struktura i ukazuje na potrebu da Srbija ubrza proces diverzifikacije i intenzivira ulaganja u obnovljive izvore energije. Iako istraživanje ima određena ograničenja, ono pruža korisne smernice za kreiranje energetske politike i otvara prostor za buduća istraživanja zasnovana na obuhvatnijim skupovima podataka i naprednijim analitičkim modelima.

Ključne reči: *energija, proizvodnja, struktura, obnovljivi izvori, diverzifikacija, Pareto analiza, Srbija, Slovenija*

LITERATURA / REFFERENCES

Albayrak, A. S. (2010). ARIMA forecasting of primary energy production and consumption in Turkey: 1923-2006. Enerji, Piyasa ve Düzenleme, 1(1), 24-50.

Aszódi, A., Biró, B., Adorján, L., Dobos, Á. C., Illés, G., Tóth, N. K., Zagyi, D., & Tas Zsiborás, Z. (2023). The effect of the future of nuclear energy on the decarbonization pathways and continuous supply of electricity in the European Union. Energy, 278, 127813. https://doi.org/10.1016/j.energy.2023.127813

Balaras, C. A., Dascalaki, E. G., Psarra, I., & Cholewa, T. (2022). Primary energy factors for electricity production in europe. Energies, 16(1), 93. https://doi.org/10.3390/en16010093

Bajić, B. Ž., Dodić, S. N., Vučurović, D. G., Dodić, J. M., & Grahovac, J. A. (2015). Waste-to-energy status in Serbia. Renewable and Sustainable Energy Reviews, 50, 1437-1444. https://doi.org/10.1016/j.rser.2015.05.079

Balat, M. (2009). Coal in the global energy scene. Energy Sources, Part B: Economics, Planning, and Policy, 5(1), 50-62. https://doi.org/10.1080/15567240701758927

Bilardo, M., Galatà, S., & Fabrizio, E. (2022). The role of Primary Energy Factors (PED) for electricity in the evaluation and comparison of building energy performance: An investigation on European nZEBs according to EN 17423:2020. Sustainable Cities and Society, 87, 104189. https://doi.org/10.1016/j.scs.2022.104189

Bozsik, N., Magda, R., & Bozsik, N. (2023). Analysis of primary energy consumption, for the european union member states. Acta Polytechnica Hungarica, 20(10), 89-108. https://doi.org/10.12700/APH.20.10.2023.10.6

Brkić, D. (2018). Energy situation in the Republic of Serbia. Preprints. https://doi.org/10.20944/preprints201808.0279.v1

Crnčec, D. (2022). Energy governance in Slovenia. In M. Knodt & J. Kemmerzell (Eds.), Handbook of Energy Governance in Europe (pp. 1083-1119). Springer International Publishing. https://doi.org/10.1007/978-3-030-43250-8_28

Dacko, M., Paluch, L., Mickiewicz, B., Mickiewicz, P., & Nowak, M. (2020). Energy production and consumption in the European Union-Assessment of changes in the aspects of sustainability and energy self-sufficiency. European Research Studies Journal, 23(Special Issue 1), 1100-1112. https://doi.org/10.35808/ersj/1873

Dragović, N. M., Vuković, M. D., & Riznić, D. T. (2019). Potentials and prospects for implementation of renewable energy sources in Serbia. Thermal Science, 23(5 Part B), 2895-2907. https://doiserbia.nb.rs/Article.aspx?id=0354-98361900056D

European Parliament. (2018). Directive (EU) 2018/844 of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. Official Journal of the European Union. https://eur-lex.europa.eu/eli/dir/2018/844/oj

Gökgöz, F., & Güvercin, M. T. (2018). Energy security and renewable energy efficiency in EU. Renewable and Sustainable Energy Reviews, 96, 226-239. https://doi.org/10.1016/j.rser.2018.07.046

Hjelmeland, M., Nøland, J. K., Backe, S., & Korpås, M. (2025). The role of nuclear energy and baseload demand in capacity expansion planning for low-carbon power systems. Applied Energy, 377(A), 124366. https://doi.org/10.1016/j.apenergy.2024.124366

International Monetary Fund. (2023). World Economic Outlook database: Groups and aggregates information. https://www.imf.org/en/publications/weo/weo-database/2023/april/groups-and-aggregates

Kosowski, P. (2024). From Fossil Fuels to Renewables: Clustering European Primary Energy Production from 1990 to 2022. Energies, 17(22), 5596. https://doi.org/10.3390/en17225596

Legros, G., Havet, I., Bruce, N., & Bonjour, S. (2009). The energy access situation in developing countries (K. Holmes, Ed.). United Nations Development Programme. https://www.undp.org/publications/energy-access-developing-countries

Ouda, O. K. M., Raza, S. A., Nizami, A. S., Rehan, M., Al-Waked, R., & Korres, N. E. (2016). Waste to energy potential: A case study of Saudi Arabia. Renewable and Sustainable Energy Reviews, 61, 328-340. https://doi.org/10.1016/j.rser.2016.04.005

Perpiñá Castillo, C., Hormigos Feliu, C., Dorati, C., Kakoulaki, G., Peeters, L., Quaranta, E.,Taylor, N., Uihlein, A., Auteri, D., & Dijkstra, L. (2024). Renewable energy production and potential in EU rural areas. Publications Office of the European Union. https://doi.org/10.2760/458970

Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. Renewable and Sustainable Energy Reviews, 33, 74-86. https://doi.org/10.1016/j.rser.2014.02.003

Pyzdek, T. (2021). Pareto Analysis. The Lean Healthcare Handbook, 157-164. https://doi.org/10.1007/978-3-030-69901-7_14

Radosavljević, S., Ille, N., Radosavljević, M., & Radosavljević, I. (2022). Coal as a sustainable resource of serbia and risk potentials of world energy needs for energies. In International May Conference on Strategic Management-IMCSM22,(1) (pp. 310-320).

Ritchie, H. (2020, February 10). What are the safest and cleanest sources of energy? Our World in Data. https://ourworldindata.org/safest-sources-of-energy

Senegačnik, A., & Sekavčnik, M. (2024). The illusion of a green transition in slovenia by 2050. Strojniški Vestnik - Journal of Mechanical Engineering, 70(9-10), 405-416. https://doi.org/10.5545/sv-jme.2024.1007

Shalaeva, D. S., Kukartseva, O. I., Tynchenko, V. S., Kukartsev, V. V., Aponasenko, S. V., & Stepanova, E. V. (2020). Analysis of the development of global energy production and consumption by fuel type in various regions of the world. IOP Conference Series: Materials Science and Engineering, 952(1), 012025. https://doi.org/10.1088/1757-899X/952/1/012025

Shipkovs, P., Pelite, U., Kashkarova, G., Lebedeva, K., Migla, L., & Shipkovs, J. (2011). Policy and strategy aspects for renewable energy sources use in latvia. 2438-2445. https://doi.org/10.3384/ecp110572438

Siirola, J. J. (2014). Speculations on global energy demand and supply going forward. Current Opinion in Chemical Engineering, 5, 96-100. https://doi.org/10.1016/j.coche.2014.07.002

Statistical Office of the Republic of Serbia. (2024). Annual energy balances and energy statistics. https://data.stat.gov.rs/Home/Result/040201?languageCode=sr-Cyrl

Statistical Office of the Republic of Slovenia. (2024). Energy balances and energy statistics database. SiStat Database. https://pxweb.stat.si/SiStatData/pxweb/en/Data/-/1817901S.px/chart/chartViewLine/

Steigerwald, B., Weibezahn, J., Slowik, M., & von Hirschhausen, C. (2023). Uncertainties in estimating production costs of future nuclear technologies: A model-based analysis of small modular reactors. Energy, 281, 128204. https://doi.org/10.1016/j.energy.2023.128204

Trębska, P., & Gromada, A. (2017). Energy production and consumption from renewable sources in poland and 28 countries of the european union. Annals of the Polish Association of Agricultural and Agribusiness Economists, 19(2), 263-269. https://doi.org/10.5604/01.3001.0010.1210

United Nations. (2025). Ensure Access to Affordable, Reliable, Sustainable and Modern Energy. United Nations Sustainable Development; United Nations. https://www.un.org/sustainabledevelopment/energy/

Zhao, L., Zhang, T., Li, W., Li, T., Zhang, L., Zhang, X., & Wang, Z. (2023). Engineering of sodium-ion batteries: Opportunities and challenges. Engineering, 24, 172-183. https://doi.org/10.1016/j.eng.2021.08.032

Engineering management 12 (1) (2026) 55-69

Engineering management

INVESTIGATING THE SUSTAINABILITY OF KENYA'S ECONOMY: BENCHMARKING ANALYSIS OF ENVIRONMENTAL, KNOWLEDGE AND ECONOMIC PERFORMANCE INDICES*

Diana Lukela Wataka, Zsuzsanna Deák

Obuda University, Keleti Károly Faculty of Business, Hungary

Abstract

This study evaluates sustainability performance across environmental, knowledge and economic dimensions in Kenya and selected Sub-Saharan African countries (South Africa, Tanzania and Uganda) over the period 2019-2024 using an integrated analytical framework. A quantitative short-panel design is employed, utilizing secondary data from internationally recognized indices, including the Environmental Performance Index (EPI), Global Innovation Index (GII) and GDP per capita, alongside key determinants such as foreign direct investment, trade openness, renewable energy use, research and development expenditure and government effectiveness. Descriptive statistics, trend analysis, correlation and panel regression techniques are applied to examine comparative performance, interrelationships and causal effects. The results show that Kenya demonstrates moderate performance across all dimensions, while South Africa leads in economic and knowledge sustainability, Tanzania shows environmental improvement and Uganda maintains stability. Strong positive relationships are observed between economic sustainability and both environmental and knowledge dimensions, although weak integration exists between environmental and knowledge factors. Regression results reveal that foreign direct investment drives economic performance, trade openness negatively affects knowledge sustainability and government effectiveness influences environmental outcomes. The study contributes to the literature by offering an integrated, cross-dimensional assessment model and provides policy-relevant insights for enhancing coordinated sustainability strategies in developing economies.

Keywords: *cross dimensional assessment, innovation, development economics, environmental performance, integrated sustainability framework*

1. INTRODUCTION

1.1. Background

Sustainable economic development remains a central concern for countries seeking to balance economic growth, environmental stewardship and knowledge-based innovation. National performance is no longer assessed solely by GDP, but also by environmental sustainability and innovation capacity, which determine long-term resilience, competitiveness and inclusive growth (World Bank, 2025; Sachs, 2022). Sustainability is commonly understood through three interrelated dimensions: environmental, economic and knowledge-based whose interdependence the triple bottom line framework makes explicit:

*Paper presented at the XXII Student Symposium on Strategic Management

long-term value creation depends on balancing all three rather than prioritizing economic performance alone (Elkington & Rowlands, 1999; Nogueira et al., 2022). Environmental sustainability focuses on resource conservation and climate resilience; economic sustainability on stable and inclusive growth; and knowledge sustainability on human capital, innovation and technological capability (Fathollahi et al., 2017; Westlund, 2006).

Kenya, East Africa's largest economy, has experienced steady economic growth in recent years (World Bank, 2024). However, this growth has not been matched by equivalent progress in environmental sustainability and knowledge-based development. Environmental challenges such as land degradation, deforestation and climate variability continue to affect productivity and ecosystem stability (Mganga, 2022; Kipkemboi et al., 2021; Njora & Yılmaz, 2022), while limitations in R&D investment and human capital development constrain the transition to a knowledge-based economy (Adeyemi et al., 2018; Sairmaly, 2023). The use of internationally recognized indices the Environmental Performance Index (EPI), the Global Innovation Index (GII) and GDP-based World Development Indicators (WDI) provides a structured, multidimensional basis for cross-country comparisons (Wendling et al., 2022; WIPO, 2025). A comparative approach including Tanzania, Uganda and South Africa allows for a clearer understanding of Kenya's relative position and highlights structural differences in sustainability outcomes.

1.2. Problem statement

Despite its economic growth, Kenya demonstrates relatively weak performance in key sustainability indicators. Kenya ranks 145th out of 180 countries in the 2024 Environmental Performance Index (EPI) with a score of 36.9, indicating significant environmental challenges (Yale Center for Environmental Law and Policy, 2024). In addition, Kenya ranks 102nd out of 133 countries in the Global Innovation Index, reflecting constraints in innovation capacity and knowledge development (WIPO, 2025).

These rankings contrast with its economic standing and suggest that GDP growth does not translate into proportional improvements in environmental and knowledge outcomes.
This imbalance highlights a structural disconnect between economic development and sustainability. Economic growth that is not supported by environmental protection and knowledge-based innovation may lead to long-term vulnerabilities, including resource depletion, reduced productivity, and limited competitiveness (Zhang & Wu, 2022). In Kenya, dependence on climate-sensitive sectors such as agriculture increases exposure to environmental risks, while limited investment in research and development restricts innovation and technological advancement (Kipkemboi et al., 2021; Adeyemi et al., 2018).

Existing literature provides valuable insights into individual sustainability dimensions, but often examines them separately. This fragmented approach restricts understanding of how interactions among environmental, knowledge, and economic factors influence overall sustainability performance. The absence of an integrated framework also creates policy challenges, as policymakers lack a unified tool to assess sustainability performance across multiple dimensions, identify trade-offs, and design coordinated strategies (Weaver & Rotmans, 2006; Golinucci et al., 2022; Candelaria et al., 2023).

1.3. Research objectives

To compare environmental, knowledge, and economic sustainability across Kenya, Tanzania, Uganda, and South Africa using standardized international indicators over the period 2019-2024.

To analyze the relationships among environmental, knowledge and economic sustainability indicators across the selected countries.

To estimate the effects of environmental, knowledge and economic factors on overall sustainability performance across the selected countries.

2. LITERATURE REVIEW

2.1. Three pillars of sustainability and sustainable development

Sustainability is a multidimensional concept that satisfies present needs without compromising the ability of future generations to meet their own needs (Brundtland, 1987). It maintains a balance among environmental, economic and social factors that are closely interconnected (Elkington & Rowlands, 1999). The environmental dimension ensures ecological balance, resource conservation and renewable energy adoption; the social dimension emphasizes equity, inclusion and human rights; and economic sustainability ensures long-term financial stability and equitable wealth distribution (Enel Group, 2025). The triple bottom line framework operationalizes this by linking all three dimensions, while the knowledge economy complements it by emphasizing education, research, innovation and technology adoption as drivers of productivity and national resilience (Gimenez et al., 2022; Nogueira et al., 2022). Integrating these dimensions into national policy frameworks allows countries like Kenya to assess trade-offs, identify synergies and implement strategies for holistic development. Kenya performs moderately compared to Tanzania and Uganda in SDG implementation and slightly below South Africa (United Nations, 2024), reflecting the need to improve sustainability performance across all three dimensions to achieve a balanced, sustained economy.

2.2. Theoretical framework

The Triple Bottom Line Theory, developed by Elkington (1999), emphasizes the need to balance three dimensions: environmental protection, economic growth and knowledge outcomes (Elkington & Rowlands, 1999). It states that long-term value creation requires integrating ecological stewardship and human capital development into strategic planning.

Sustainability Transition Theory focuses on the long-term changes required to shift societies and industries from unsustainable to sustainable pathways (Köhler et al., 2019). It emphasizes the dynamic processes of change with coordination across multiple sectors and actors, as transition occurs gradually.

Knowledge Economy Theory explains how investments in education, research and development and innovation systems contribute to national competitiveness and sustainable development (Westlund, 2006). Knowledge-based innovation supports efficiency, technological adoption, and the creation of new industries, strengthening both economic and social sustainability (Fathollahi et al., 2017). These three theories collectively provide a comprehensive framework for assessing Kenya's sustainability, with

TBL offering a balanced view of the three dimensions, Sustainability Transition Theory highlighting the processes and policies needed for systemic change, and Knowledge Economy Theory emphasizing the role of human capital and innovation.

2.3. Kenya's comparative sustainability performance

Kenya's sustainability performance can be evaluated using global indices that measure environmental, knowledge and economic dimensions. The EPI evaluates environmental health, ecosystem vitality, and climate policy implementation. In 2024, Kenya scored 36.9 on the EPI, ranking 145th globally, reflecting challenges in forest conservation and water management, despite progress in renewable energy adoption (Yale Center for Environmental Law and Policy, 2024). The GII assesses knowledge and innovation capacity; Kenya ranks 102nd globally, indicating improvements in ICT adoption, entrepreneurship, and mobile technology applications, while research and development outputs remain limited (WIPO, 2025). Table 1 shows the varying performance levels across dimensions for Kenya and the selected peers.

Table 1. Africa Comparative Sustainability Analysis

Country	EPI 2024 score	EPI 2024 Rank	GII 2024 Rank	SDG Index 2024 score
Kenya	36.9	145	102	61.93
Tanzania	43.6	102	121	56.80
Uganda	35.8	154	124	55.84
South Africa	42.7	106	61	64.11

Source: WIPO, 2025; SDG Transformation Center, 2025

Although Kenya ranks the best in East Africa on the SDG Index, gaps still exist in ecological protection and knowledge deepening, underscoring the need for coordinated policies linking environmental, knowledge, and economic development to strengthen Kenya's sustainability outcomes.

2.4. The integrated sustainability framework and research gaps

The Integrated Sustainability Assessment (ISA) framework provides a method for evaluating environmental, economic and knowledge dimensions together in a single model (Weaver & Rotmans, 2006). According to Candelaria et al. (2023), combining multiple indicators allows policymakers to assess trade-offs and synergies among the three pillars, supporting informed and balanced decision-making. Most literature, however, focuses on one dimension of sustainability without integrating them to explain sustainability at the national level, particularly in developing countries. This fragmented approach reduces understanding of trade-offs and synergies among the three dimensions (Nogueira et al., 2022), while inconsistent measurement approaches and limited use of panel data methods further restrict comprehensive assessment. This study addresses these gaps by integrating multiple indicators and applying descriptive, correlation and panel regression methods to examine sustainability performance across countries.

3. RESEARCH METHODOLOGY

3.1. Research design

The study employed a quantitative short-panel research design covering the period 2019-2024. According to Creswell and Creswell (2017), quantitative methods are suitable for testing relationships and patterns using statistical procedures. This design combined descriptive and explanatory components: the descriptive component enabled comparison of sustainability performance across countries using standardized indicators, while the explanatory component examined the determinants of sustainability outcomes. The panel design allowed the analysis of both cross-sectional differences among countries and temporal changes over time, providing a more robust analytical framework than purely cross-sectional or time-series approaches.

3.2. Target population and sampling

The target population consisted of Sub-Saharan African countries with economic and structural characteristics comparable to Kenya. A purposive sampling strategy was applied to ensure that selected countries were relevant for comparative analysis. The selection criteria included regional proximity, similarity in economic structure and availability of consistent sustainability data over the study period. Four countries were selected: Kenya, Tanzania, Uganda, and South Africa, providing a balanced representation of regional peers and a relatively advanced economy for benchmarking purposes. The dataset formed a balanced panel consisting of four countries observed over six years, resulting in 24 country-year observations.

3.3. Data collection and study variables

The study relied exclusively on secondary data from internationally recognized databases. Environmental sustainability data were obtained from the Environmental Performance Index. Knowledge sustainability indicators were sourced from the Global Innovation Index. Economic and control variables were obtained from the World Development Indicators and Worldwide Governance Indicators databases. Data was collected for the period 2019-2024, compiled into Microsoft Excel and screened for completeness and consistency. The final dataset was exported in CSV format for statistical analysis using JASP software. Table 2 presents a summary of all study variables.

Table 2. Summary of study variables

Variable	Measurement	Source	Role
Environmental Sustainability	EPI Score	EPI Reports	Dependent
Knowledge Sustainability	GII Score	WIPO	Dependent
Economic Sustainability	GDP per capita (USD)	World Bank WDI	Dependent
R&D Expenditure	% of GDP	World Bank WDI	Independent
Foreign Direct Investment	% of GDP	World Bank WDI	Independent
Renewable Energy	% of total energy use	World Bank WDI	Independent

Trade Openness	% of GDP	World Bank WDI	Independent
Government Effectiveness	Governance index / CPI	WGI	Independent

Source: World Bank, WDI, 2024

3.4. Data analysis

The data were analyzed using a structured sequence of statistical techniques aligned with the research objectives. To address Objective 1, descriptive statistics (mean, standard deviation, minimum, maximum) were computed and trend analysis examined temporal changes in EPI, GII and GDP per capita. To address Objective 2, Pearson correlation analysis examined relationships among the three sustainability dimensions. To address Objective 3, fixed effects panel regression models were estimated separately for each dependent variable. The general model was specified as:

$$Y_{it} = \beta_0 + \beta 1RDE_{it} + \beta 2FDI_{it} + \beta 3REN_{it} + \beta 4TRADE_{it} + \beta 5GOV_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

Where Yit is the dependent variable for country i at time t;
β0 is the intercept;
β1-β5 are coefficients of independent variables;
μi represents unobserved country-specific fixed effects;
and εit is the error term.

Multicollinearity was assessed using Variance Inflation Factor (VIF) values, with a threshold below 5 considered acceptable. Model diagnostics included tests for normality, homoscedasticity and model fit using R-squared and adjusted R-squared statistics.

3.5. Validity, reliability and limitations

Construct validity was ensured through the use of internationally recognized indices with standardized methodologies. Internal validity was strengthened through the use of panel regression techniques which controlled for unobserved heterogeneity. Reliability was supported by the consistency of secondary data sources. The study faced several limitations. The relatively short panel period limited the ability to capture long-term sustainability trends. The small sample size reduced the statistical power of regression analysis. Reliance on secondary data limited the inclusion of qualitative and context-specific factors. In 2020, COVID-19 affected overall sustainability performance across the four countries, particularly in economic and knowledge dimensions. High VIF values for renewable energy (VIF = 66.09) and government effectiveness (VIF = 8.353) indicated multicollinearity, warranting cautious interpretation of those coefficients.

4. RESULTS

4.1. Descriptive statistics and trend analysis

Descriptive statistics revealed notable variation in sustainability performance across the four countries. Kenya exhibited moderate performance across all dimensions, with an average EPI score of 34.12, GII score of 24.93 and GDP per capita of approximately USD 2,022. South Africa consistently recorded the highest GDP per capita (mean USD 6,296) and GII scores (mean 33.35). Tanzania demonstrated relatively strong environmental

performance (mean EPI 36.30) and Uganda showed the highest renewable energy usage (mean 91.00%) alongside the lowest GDP per capita (mean USD 932). Table 3 presents a comparative summary of mean values for all study variables across the four countries.

Trend analysis revealed that environmental performance (EPI) fluctuated across countries, with Kenya and South Africa experiencing declines in 2020-2022 due to the effects of COVID-19, followed by recovery. Tanzania showed sharp improvement in 2024, while Uganda remained relatively stable. Knowledge sustainability (GII) generally declined across most countries after 2020, reflecting disruptions in research, education and technological progress. South Africa maintained higher GII levels despite fluctuations. In 2020, Kenya and South Africa experienced a decrease in GDP per capita owing to decreased economic activities because of lockdowns and disruption of trade as a result of COVID-19 shocks.

Table 3. Comparative Descriptive Statistics - All Countries (2019-2024)

Variable	Kenya	South Africa	Tanzania	Uganda
EPI (mean)	34.12	41.00	36.30	35.72
GII (mean)	24.93	33.35	21.65	18.78
GDP per cap USD (mean)	2,022	6,296	1,160	932
R&D % GDP (mean)	0.600	0.612	0.510	0.300
FDI % GDP (mean)	0.415	2.633	1.883	4.933
Renewable % (mean)	68.28	9.40	79.82	91.00
Trade % GDP (mean)	36.47	58.85	34.27	38.10
Gov. Effectiveness (mean)	59.90	66.13	57.33	49.25

Source: WIPO; EPI; WDI; WGI, 2025

4.2. Correlation analysis

Pearson correlation analysis was conducted to examine the relationships among the sustainability indicators (Table 7). A positive but moderate relationship between environmental and knowledge sustainability ($r = 0.389$, $p = 0.060$) was found, although the relationship was not statistically significant at the 5% level, suggesting that improvements in environmental performance were not strongly associated with innovation capacity across the selected countries. A strong and statistically significant positive relationship was observed between environmental sustainability and economic performance ($r = 0.642$, $p < 0.001$), indicating that higher environmental performance was associated with higher GDP per capita. Similarly, knowledge sustainability was strongly and positively correlated with economic sustainability ($r = 0.721$, $p < 0.001$), suggesting that countries with stronger innovation systems tended to achieve better economic outcomes.

Table 4. Pearson Correlation matrix

Pair		Pearson's r	p-value	Significance
EPI	GII	0.389	.060	n.s.
EPI	GDP per capita	0.642	< .001	***
GII	GDP per capita	0.721	< .001	***

*Note: *** p < .001; n.s. = not significant*

4.3. Panel regression results

Three fixed-effects panel regression models were estimated separately for each dependent variable. Table 5 summarizes the key results across all three models. Full coefficient tables are available from the authors on request.

The EPI model was statistically significant ($F = 5.718$, $p = 0.002$; $R^2 = 0.753$), with government effectiveness as the only significant predictor ($\beta = -1.884$, $p = 0.007$). This counterintuitive negative effect may reflect that institutional development in the region has not yet translated into environmental policy effectiveness, consistent with findings on fragmented policy implementation in Kenya (Mulinge et al., 2016). The GII model was highly significant ($F = 8.787$, $p < 0.001$; $R^2 = 0.824$), with trade openness as a significant negative predictor ($\beta = -0.633$, $p = 0.002$), suggesting that greater trade exposure may displace local R&D with imported technology (Adeyemi et al., 2018). The GDP per capita model was highly significant ($F = 433.1$, $p < 0.001$; $R^2 = 0.996$), with FDI as a significant positive predictor ($\beta = 84.775$, $p = 0.001$), consistent with the development economics literature on FDI as a driver of capital formation and technology transfer in developing economies (Magomere et al., 2025).

Table 5. Panel regression results - all three models

Predictor	EPI β (p)	GII β (p)	GDP pc β (p)
Model fit (R^2)	0.753	0.824	0.996
Adjusted R^2	0.621	0.730	0.993
F-statistic (p)	5.718 (.002)	8.787 (<.001)	433.1 (<.001)
(Intercept)	234.58 (.011)	-12.12 (.932)	6853.3 (.331)
R&D Expenditure	6.524 (.406)	-2.701 (.840)	-313.8 (.631)
FDI	-0.087 (.738)	-0.647 (.163)	84.775 (.001)**
Renewable Energy	-1.336 (.169)	0.141 (.931)	-86.09 (.285)
Trade Openness	-0.007 (.946)	-0.633 (.002)**	12.137 (.172)
Gov. Effectiveness	-1.884 (.007)*	0.875 (.413)	12.657 (.806)
Country (S. Africa)	-59.75 (.282)	26.876 (.774)	-1330.2 (.771)
Country (Tanzania)	13.452 (.218)	-3.345 (.855)	36.832 (.967)
Country (Uganda)	14.237 (.499)	3.122 (.931)	503.49 (.774)

*Note: * p < .05; ** p < .01; VIF for Renewable Energy = 66.09; Gov. Effectiveness = 8.353 - interpret with caution*

5. EVALUATION OF RESULTS

5.1. Comparative sustainability performance (Objective 1)

The descriptive and trend analysis demonstrate that Kenya's sustainability performance is moderate across all three dimensions from 2019 to 2024, consistent with its global rankings: EPI score of 36.9 (rank 145), GII rank of 102 and SDG Index score of 61.93. South Africa leads consistently in both economic and knowledge areas, reflecting its advanced institutional infrastructure, higher R&D investment and more diversified economy (WIPO, 2025; World Bank, 2024). Tanzania's EPI improvement to 43.6 in 2024 suggests successful conservation and land management policy implementation, while Uganda's high renewable energy use (91.0%) demonstrates effective harnessing of hydroelectric resources despite the lowest economic output in the sample. Declines in GDP per capita and GII scores in 2020 across all countries, particularly in trade-integrated economies like Kenya and South Africa, align with the broader literature on the vulnerability of Sub-Saharan African economies to global shocks (Mugamba, 2024).

5.2. Relationships among sustainability dimensions (Objective 2)

The Pearson correlation findings show a strong and statistically significant positive correlation between economic sustainability with environmental sustainability ($r = 0.642$, $p < 0.001$) and knowledge sustainability ($r = 0.721$, $p < 0.001$). These results are in line with Triple Bottom Line Theory (Elkington & Rowlands, 1999), according to which economic performance, environmental stewardship and knowledge outcomes are connected and reinforcing. The strong correlation between knowledge sustainability and economic performance is consistent with Knowledge Economy Theory (Westlund, 2006; Fathollahi et al., 2017). South Africa's leadership in both GII and GDP per capita illustrates how innovation, technology, and infrastructure investment translate into measurable economic advantages and justifies policy claims for more funding in R&D and ICT infrastructure.

The non-significant correlation between environment and knowledge sustainability ($r = 0.389$, $p = 0.060$) indicates that environmental improvements do not necessarily lead to innovation gains across the four countries. This may indicate the comparatively low level of knowledge-environment integration in Sub-Saharan African economies, in which environmental conservation has traditionally been prompted by regulatory requirements and community involvement as opposed to technological innovation (Mganga, 2022; Njora & Yilmaz, 2022).

5.3. Determinants of sustainability outcomes (Objective 3)

Panel regression findings identify the key determinants of each sustainability dimension. For environmental sustainability, government effectiveness was a significant negative predictor ($\beta = -1.884$, $p = 0.007$). This counterintuitive result may reflect those countries with higher governance scores such as South Africa have lower EPI scores than Tanzania, which benefited from community-led conservation with less institutional formalization. Alternatively, it may suggest that institutional development in the region has not yet resulted in corresponding environmental policy effectiveness, as noted in findings on fragmented environmental policy implementation in Kenya (Mulinge et al., 2016).

For knowledge sustainability, trade openness was a major negative influence on GII scores ($\beta = -0.633$, $p = 0.002$). This aligns with arguments that increased exposure to trade in

developing economies can make local innovation less competitive due to the replacement of local R&D with imported technology (Adeyemi et al., 2018). For economic sustainability, FDI was a considerable positive predictor of GDP per capita ($\beta = 84.775$, $p = 0.001$), aligning with the development economics literature that has established FDI as a significant source of capital formation, technology transfer and employment in developing economies (Magomere et al., 2025). These results are consistent with Sustainability Transition Theory (Köhler et al., 2019) which postulates that systemic sustainability change should be delivered through sector-specific interventions organized at institutional, technological and social levels.

6. CONCLUSIONS

6.1. Conclusion

This study assessed and compared sustainability performance across Kenya, South Africa, Tanzania and Uganda from 2019 to 2024. Kenya performed moderately across all three sustainability dimensions. Tanzania showed significant environmental improvement, Uganda showed steady environmental performance and the highest renewable energy usage, while South Africa consistently led in economic and knowledge sustainability. COVID-19 underscored the need for developing countries to build economic resilience against global shocks.

Correlation analysis depicted a strong, statistically significant positive relationship between economic sustainability and both environmental performance ($r = 0.642$, $p < 0.001$) and knowledge sustainability ($r = 0.721$, $p < 0.001$). However, the positive but not statistically significant environmental-knowledge relationship ($r = 0.389$, $p = 0.060$) indicates little cross-dimensional integration in the current sample. Regression analysis identified FDI as a significant positive predictor of economic performance, trade openness as a significant negative predictor of knowledge performance, and government effectiveness as a significant negative predictor of environmental performance. This study contributes to the sustainability literature by providing an integrated cross-dimensional benchmarking framework and demonstrating the usefulness of combining internationally standardized metrics in a panel design.

6.2. Recommendations

The following recommendations are proposed for developement practitioners, academic researchers and policy makers;

1) Improve environmental governance and enforcement through cross-regional regulatory coordination, increased budgetary allocations for environmental agencies and support for community-based conservation programs like Kenya Forest Service's community forest associations.
2) Strengthen the investment climate for FDI by streamlining regulatory processes, improving contract enforcement and upgrading infrastructure in economic zones like Konza Technopolis, facilitating technology transfer and employment growth.
3) Invest in domestic R&D and innovation by increasing public R&D spending as a percentage of GDP, creating specialized innovation funds for environmental technology and strengthening university-industry research collaborations to reduce dependency on imported technology.

4) Adopt integrated sustainability policies combining environmental conservation, human capital development and economic diversification, ensuring cross-dimensional spillovers, supported by improved sustainability monitoring systems and digital inclusion programs such as M-Pesa and DigiFarm.

6.3. Directions for future research

Extension of the research period beyond 2024 would enable long-term sustainability trend evaluation and reduce the impact of the COVID-19 anomaly. Incorporating qualitative methodologies such as stakeholder interviews and policy document analysis would deepen contextual understanding. Expanding the country sample would improve statistical power and generalizability. Future research should explore non-linear and threshold effects in sustainability dimensions and apply advanced panel econometric techniques, including dynamic panel models, instrumental variable estimation or spatial econometric methods to resolve endogeneity concerns and yield more reliable causal estimates.

ISTRAŽIVANJE ODRŽIVOSTI PRIVREDE KENIJE: BENČMARKING ANALIZA EKOLOŠKIH, ZNANJEM ZASNOVANIH I EKONOMSKIH INDEKSA PERFORMANSI

Diana Lukela Wataka, Zsuzsanna Deák
Univerzitet Óbuda, Keleti Károly Fakultet za poslovne studije, Mađarska

Izvod

Ova studija procenjuje performanse održivosti kroz ekološku, znanjem zasnovanu i ekonomsku dimenziju u Keniji i odabranim zemljama podsaharske Afrike (Južna Afrika, Tanzanija i Uganda) u periodu od 2019. do 2024. godine, primenom integrisanog analitičkog okvira. Korišćen je kvantitativni dizajn kratkog panel istraživanja, zasnovan na sekundarnim podacima iz međunarodno priznatih indeksa, uključujući Indeks ekoloških performansi (EPI), Globalni inovacioni indeks (GII) i bruto domaći proizvod po glavi stanovnika (BDP po glavi stanovnika), kao i ključne determinante poput stranih direktnih investicija, trgovinske otvorenosti, korišćenja obnovljivih izvora energije, izdvajanja za istraživanje i razvoj i efektivnosti vlade. Za ispitivanje komparativnih performansi, međusobnih odnosa i uzročno-posledičnih efekata primenjene su deskriptivna statistika, analiza trendova, korelaciona analiza i panel regresione tehnike. Rezultati pokazuju da Kenija ostvaruje umerene performanse u svim posmatranim dimenzijama, dok Južna Afrika prednjači u ekonomskoj i znanjem zasnovanoj održivosti, Tanzanija beleži napredak u oblasti životne sredine, a Uganda održava stabilne rezultate. Uočene su snažne pozitivne veze između ekonomske održivosti i ekološke, odnosno znanjem zasnovane dimenzije, dok je integracija između ekoloških i znanjem zasnovanih faktora relativno slaba. Rezultati regresione analize pokazuju da strane direktne investicije podstiču ekonomske performanse, trgovinska otvorenost negativno utiče na održivost zasnovanu na znanju, dok efektivnost vlade ima značajan uticaj na ekološke ishode. Studija doprinosi literaturi kroz primenu integrisanog modela za procenu održivosti između različitih dimenzija i pruža preporuke relevantne za kreatore politika u cilju unapređenja koordinisanih strategija održivog razvoja u zemljama u razvoju.

Ključne reči: *međudimenzionalna procena, inovacije, razvojna ekonomija, ekološke performanse, integrisani okvir održivosti*

LITERATURA / REFFERENCES

Adeyemi, R. A., Joel, A., Ebenezer, J. T., & Attah, E. Y. (2018). The effect of brain drains on the economic development of developing countries: Evidence from selected African countries. Journal of Health and Social Issues, 7(2), 66-76.

Candelaria, J. L., Sharifi, A., Simangan, D., & Tabosa, R. M. R. (2023). A critical analysis of selected global sustainability assessment frameworks. World Development Perspectives, 32, 100539.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approach (5th ed.). SAGE Publications.

Elkington, J., & Rowlands, I. H. (1999). Cannibals with forks: The triple bottom line of 21st century business. Capstone Oxford.

Enel Group. (2025). The 3 pillars of sustainability: Environmental, social, and economic. https://www.enel.com/learning-hub/sustainable-development/three-pillars-sustainability

Fathollahi, Momeni, F., Elahi, N., & Najafi, S. M. S. (2017). Appropriate theoretical framework for understanding and analyzing economic issues in knowledge-based economy. Journal of the Knowledge Economy, 8(3), 957-976.

Gimenez, C., Sierra, V., & Rodon, J. (2012). Sustainable operations: Their impact on the triple bottom line. International Journal of Production Economics, 140(1), 149-159.

Golinucci, N., et al. (2022). Comprehensive and integrated impact assessment framework for development policies evaluation: Application to Kenyan coffee sector. Energies, 15(9), 3071.

Kipkemboi, K. B., Kumar, L., & Koech, R. (2021). Climate change and variability in Kenya: A review of impacts on agriculture and food security. Environment, Development and Sustainability, 23(1), 23-43.

Köhler, J., et al. (2019). An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions, 31, 1-32.

Magomere, J. M., Omboto, P., & Kemboi, I. (2025). Macroeconomic stability factors and trade competitiveness nexus Kenya. African Journal of Empirical Research, 6(4), 303-309.

Mganga, K. Z. (2022). Agricultural land degradation in Kenya. In Impact of Agriculture on Soil Degradation I (pp. 273-300). Springer International Publishing.

Mugamba, E. (2024). Financial technology as a catalyst for post-COVID-19 financial inclusion in East Africa. Available at SSRN 5278857.

Mulinge, W., et al. (2016). Economics of land degradation and improvement in Kenya. Springer International Publishing, pp. 471-498.

Njora, B., & Yılmaz, H. (2022). Analysis of the effects of deforestation on the environment and agriculture in Kenya. International Journal of Water Management and Diplomacy, 1(4), 91-110.

Nogueira, E., Gomes, S., & Lopes, J. M. (2022). The key to sustainable economic development: A triple bottom line approach. Resources, 11(5), 46.

Sachs, J. D., Lafortune, G., & Fuller, G. (2024). Sustainable development report 2024. SDG Transformation Center.

SDG Transformation Center. (2025). The overall performance of all 193 UN member states. https://dashboards.sdgindex.org/rankings/

United Nations. (2025). The 17 goals. https://sdgs.un.org/goals

Weaver, P. M., & Rotmans, J. (2006). Integrated sustainability assessment: What is it, why do it and how? International Journal of Innovation and Sustainable Development, 1(4), 284-303.

Westlund, H. (2006). Social capital in the knowledge economy. Springer.

World Bank. (2024). Kenya. https://data.worldbank.org/country/kenya

World Bank. (2025). World Development Indicators. https://data.worldbank.org

World Intellectual Property Organization. (2025). GII 2025 ranks. https://www.wipo.int/gii-ranking/en/rank

Yale Center for Environmental Law and Policy. (2024). Environmental Performance Index Report 2024. https://epi.yale.edu/measure/2024/EPI

Zhang, Y., & Wu, J. (2022). Environmental governance and economic performance: Empirical evidence from developing countries. Sustainability, 14(3), 1234.

APPENDIX: RAW DATA SUMMARY (EXTRACT)

The table below presents the complete country-level indicator values used in the panel dataset for the study period 2019-2024 (Kenya full series shown; first and last year for remaining countries). Full dataset available from the authors on request.

Appendix Table 1. Country-level indicator values - selected years

Country	Year	EPI	GII	GDP pc	R&D%	FDI%	Renew%	Trade%	Gov
Kenya	2019	34.1	31.1	1960	0.6	0.5	68.1	31.8	59.2
Kenya	2020	34.7	26.1	1928	0.6	-0.01	69.0	30.4	59.2
Kenya	2021	34.1	27.5	2061	0.6	0.4	67.7	35.0	59.9
Kenya	2022	30.8	22.7	2110	0.4	0.7	68.3	40.3	60.5
Kenya	2023	34.1	21.2	1943	0.8	0.5	68.3	41.1	60.3
Kenya	2024	36.9	21.0	2132	0.6	0.4	68.3	40.2	60.3
Tanzania	2019	36.3	26.6	1063	0.51	2.0	80.4	33.0	57.3
Tanzania	2024	43.6	15.3	1187	0.51	2.2	79.8	41.5	54.5
Uganda	2019	35.7	25.6	822	0.3	3.7	90.5	39.4	50.4
Uganda	2024	35.8	14.9	1078	0.3	6.0	91.0	42.7	48.5
South Africa	2019	41.0	34.0	6534	0.61	1.3	8.7	53.9	66.5
South Africa	2024	42.7	28.3	6267	0.61	0.6	9.4	61.6	65.8

Source: EPI, 2024; WIPO, 2025; World Bank WDI, 2025

Engineering management 12 (1) (2026) 70-80

Engineering management

BETWEEN INSTITUTIONAL EXPECTATIONS AND LIVED PRACTICES: EMPLOYEE REPRESENTATIONS OF MANAGERIAL ROLES IN A BELGIAN CONSULTING FIRM*

Oumayma Zoubai
University of Liège, HEC Liège, Belgium

Abstract

This article examines how employees construct, assess, and interpret the figure of the "good manager" in an organizational setting where managerial expectations are formalized through an internal competency framework. Adopting a constructivist perspective rooted in structuration theory, this study focuses on the perceived misalignment between institutional norms and employee representations. Based on thirteen semi-structured interviews with employees in a Belgian consulting firm and an inductive analysis inspired by grounded theory, the findings highlight three ideal-typical figures: the structuring manager, the coach-like manager, and the facilitating manager. The results also reveal critical tensions, particularly concerning insufficient feedback, the taboo of upward feedback, and a prioritization of business objectives over human concerns. These tensions are interpreted as consequences of a managerial framework that remains abstract and incomplete, failing to adequately address well-being, relational reciprocity, and the recognition of interpersonal qualities.

Keywords: *managerial roles, competency frameworks, employee perceptions, organizational norms, managerial bricolage, employee well-being*

1. INTRODUCTION

Today, "*managers are confronted with the increasing complexity of organisations, activities and social relations"* (Bonnet and Bonnet, 2007, p. 248) and the question of management has become a central issue for the sustainability and development of companies. Many academic and professional works have tried to define what a "good manager" should be and to identify the skills considered essential for team engagement, mobilisation and performance (Harding et al., 2014). For example, managerial frameworks such as the one used in the firm studied here highlight "leadership" qualities such as the ability to inspire or influence.

However, this idealised figure has been criticised. Many researchers question the limits of this normative construction and underline the recurring gap between prescribed skills and the managerial practices actually observed in the field. The work of Mintzberg (1973) already helped challenge the traditional image of a rational and planning manager by

* *Paper presented at the XXII Student Symposium on Strategic Management*

showing a type of work that is fragmented, informal and constantly adjusted. In the same way, Giddens' structuration theory (1984) invites us to see management as a socially constructed reality, emerging from the interaction between institutional rules and the concrete actions of actors.

In this context, it becomes necessary to shift the focus and to understand management by analysing how employees build, assess and above all interpret the managerial figures they are confronted with. Throughout this research, a constructivist approach is adopted. Social structures do not exist before individuals, they are constantly reproduced or transformed through their practices. From this point of view, we focus on the way employees in a Belgian consulting firm build their own image of the "good manager" and on the way this image resonates, or on the contrary comes into conflict, with the practices observed in their daily work.

The organisation studied, formalises its managerial expectations through an internal framework called "*Talent Standards*". This framework lists fifteen competencies grouped into three main dimensions, leadership capacities, professional capacities and technical capacities. What matters here, however, is to observe how employees, through their daily interactions, validate, question or challenge these normative standards and to identify the perceived gaps between institutional expectations and concrete managerial experiences.

This research is guided by the following central question, *how do employees build an image of the "good manager" and how does this image come into conflict, or not, with the practices observed in their daily work?* To explore this question, we adopt an inductive methodology based on semi structured interviews and on an analysis inspired by grounded theory (Lejeune, 2019).

2. LITERATURE REVIEW

Organisations now operate in an unstable environment, where uncertainty, structural changes and competitive pressure are reshaping expectations toward managers (Heyden et al., 2015). Managers are expected to meet strategic, human, operational and emotional demands at the same time (Mintzberg, 1973), which leads to an accumulation of expectations. As a result, a lasting tension appears between the managerial ideal promoted in institutional discourse and the lived reality of management in everyday work.

This tension can be expressed in a clear way. On the one hand, the organisation defines a set of behaviours, attitudes and qualities expected from the "good manager". On the other hand, subordinates experience daily interactions and behaviours that often move away from this ideal norm (Frenkel et al., 2013; Nielsen and Yarker, 2023). This gap is central and shows the difference between the prescribed image and actual practices. A purely objectivist reading of managerial skills is therefore not enough. The issue is not only to describe what managers do but also to understand how their figure is perceived, built, interpreted and evaluated by employees.

Contemporary expectations and their normative effects can then be analysed. Current demands are not only descriptive, they also have a prescriptive dimension and impose norms of behaviour and attitudes that shape managerial practices (Bonnet and Bonnet, 2007). These prescriptions help build a normative framework that can guide managerial behaviour toward certain expectations, without reflecting the real complexity of professional situations. At the same time, real management is marked by fragmented time, multiple tasks and the tension between what is prescribed and what is actually done. Faced

with complexity and contradictions, managers do not simply undergo constraints in a passive way. They develop discreet adjustments and become "*experts in bricolage*" (Bonnet and Bonnet, 2007, p. 260).

Finally, from a constructivist point of view, the image of the "good manager" cannot be seen as a fixed or universal framework. It results from a dynamic process of co-construction in which employees play a central role (Gioia and Chittipeddi, 1991; Bonnet and Bonnet, 2007; Watson, 2008). This construction develops through interactions, internal discourses and shared interpretations. It also involves collective mechanisms of sense making.

In short, in order to answer the central question of this research, the literature leads to five main findings. First, the image of the "good manager" is a social construction influenced by normative discourses that change over time. Second, frameworks such as "*Talent Standards*" set ideal expectations that may be far from the reality of the field. Third, this gap can create tensions. Fourth, employees take part in defining the managerial role through their experiences and perceptions. Fifth, the way a manager is perceived influences engagement, well-being and the work climate. Thus, these theoretical contributions form the core of the analytical framework used in the empirical study carried out in the firm.

3. DATA AND METHODOLOGY

The initial intention was to study managerial practices in the firm by directly interviewing "*Managers and Up*" profiles, including managers, directors and partners. However, this project faced access difficulties, such as overloaded schedules and time constraints, which made the number of possible interviews too limited. After discussion with the supervisor, the focus of the fieldwork shifted toward employees and their perceptions of management. In fact, they are the ones who experience the effects of managerial practices on a daily basis, whether they undergo them, interpret them, agree with them or resist them. Their testimonies provide direct access to the gap between official discourse and lived realities. This change also reflects an epistemological shift. The objective was no longer to model "good practices" but to understand representations of the managerial role in a specific environment.

The research was carried out during a final internship in the Human Capital department of the firm. The fieldwork was later extended to a few members from another related team. The sample was defined with a target of ten to fifteen interviews which was considered ambitious in this context. Thanks to constant follow up, thirteen semi-structured interviews were finally conducted over a period of two months. This allowed us to reach a reasonable level of data to support our analysis, despite strong availability constraints.

It is important to note that the figure of the "manager" mentioned by employees does not necessarily refer to one single person or to one fixed hierarchical role. In the firm's matrix structure, employees work on several projects at the same time, with different points of reference depending on the assignment. As a result, "managers" are often described as project leaders or project contacts, which leads to the coexistence of several managerial figures.

The analysis followed an inductive approach inspired by the principles of grounded theory in a pragmatic version (Lejeune, 2019). The aim was not to test a hypothesis but to make structures of meaning emerge from the interviews. Once transcribed, the interviews were coded in several stages. First, a first round of coding (open coding) was used to identify

key elements such as expectations, implicit criticism, emotions and dissonances. Then, a second round of coding (axial coding) was used to group together converging themes. Finally, a third round of coding (selective coding) was used to refine the analysis and identify the main interpretive lines. A reflexive posture was also adopted, especially regarding the position of the researcher as an intern, the relationship with participants and the context in which the interviews took place. The analysis therefore offers a situated and argued reading of rich and sensitive material.

4. RESULTS AND DISCUSSION

4.1. *Talent Standards* in the firm: the organisational norm and its practical status

The results section aims to understand how employees build the image of the "good manager" from their lived experience and how this image confronts the practices they observe and the institutional norms promoted by the organisation. Before looking in detail at these perceptions, the study first recalls how the organisation itself defines the figure of the "good manager". It does so through an internal framework called "*Talent Standards*", which structures the expected skills around three main categories, leadership, professionalism and technical expertise.

The internal framework can be summarised through the following dimensions:

Table 1. Managerial competency framework

Category	Main competencies
Leadership capacities	Inspiring, creating goals, encouraging agility, developing diverse capabilities, influencing, collaborating, delivering value, developing the business
Professional capacities	Analytical thinking, effective communication, engagement management, change management, quality and risk management, business excellence, strategic thinking and problem solving, use of technologies
Technical capacities	Providing core offer expertise, implementing the transformation plan, implementing the strategic vision of the organisation

This normative framework, presented as common to managers, is then examined in the light of the empirical gaps observed in the field. One important point also appears. In practice, some employees see *Talent Standards* mainly as a tool used in promotion processes rather than as an operational guide for everyday work. As one interview extract shows,

"For me, they only take the Talent Standards into account for your promotion [...] But for the rest, what the Talent Standards say has no importance." (Interview 1, Consultant.)

This perception supports the central argument of the article. The norm (in this case the *Talent Standards*) does exist and officially structures expectations but its appropriation and its translation into lived experience appear to be problematic.

4.2. Ideal figures of the "good manager": what employees expect

Three complementary figures emerge from the interviews, the structuring manager, the human manager (or coach) and the facilitating manager.

4.2.1. The structuring manager: clarifies, organises and protects

This first ideal reflects an expectation of structure, anticipation and clear task distribution. The structuring manager defines roles, organises time, makes objectives explicit, filters external pressure and provides a sense of security while coordinating the team.

One employee explains this expectation:

"[Like] it's someone, for example, who will like really create the folders in Teams to really say OK, here we put this, here we put that. […] To do a backward planning, to know OK this week we will do this, this week we will do that, if at that moment we are late it will impact that. And it's someone who will have the structure in mind." (Interview 4, Business Analyst.)

Another testimony highlights the importance of coordination:

"*Someone [a good manager] who keeps the plan in advance and who involves the stakeholders but also the team members from the beginning of the project […] who really coordinates the projects and assigns the right tasks to the right people."* (Interview 11, Consultant.)

4.2.2. The human manager (or coach): listens, supports and helps people grow

Beyond structure, employees also expect a human dimension. The good manager listens, understands and supports. This posture is often described as a coach or a mentor.

One employee describes it as follows:

"It's someone who will really guide you in your career, give you the right directions for your career, it's less linked to the project but it's more really linked to your development, almost personal or professional." (Interview 2, Senior Consultant.)

This figure is also linked to small daily gestures of recognition:

"For me it's important to have someone who is still like someone who knows how to have fun, who knows, like, you […] when you go into the call, there is like "how are you?" […]" (Interview 3, Business Analyst.)

An important point appears here. This human support is expected but it faces a strong performance oriented norm, as shown in the following extract:

"*These are environments that are extremely structured, extremely compliant and extremely results-driven. It has to be fast, it has to be good […] Managers have to sell projects, you have to report [financially], you have to staff juniors, that is, that's really what they look at during the talent review."* (Interview 2, Senior Consultant.)

4.2.3. The facilitating manager: trusts, empowers and provides security

The third figure is that of a facilitating manager, who gives a framework and then steps back, trusting employees' abilities. The autonomy given becomes a source of motivation and a sign of recognition.

One employee explains this balance:

"So someone who helps you have a structure […] an overview of what you do but while leaving you the possibility to explore on your side without feeling micro-managed […] I had one [manager] who was extremely micro-management […] for me it's a mix between being able to give you freedom, to trust you, to let you do your work […] it really doesn't make you want and so I find it very demotivating." (Interview 3, Business Analyst.)

Thus, other testimonies confirm that autonomy does not mean being left alone but rather having freedom within a clear and secure initial framework.

4.3. Lived tensions: effects of what is missing from the norm (*Talent Standards*)

The reading adopted here follows a reflexive perspective. Each tension is analysed through three main questions, what is missing, what does it produce and what does it say about the system. Four major tensions are developed, the lack of feedback, the impossibility of criticising one's manager, frustrations around promotions and the case of project T.

4.3.1. Tension 1: managerial feedback seen as insufficient and disconnected and the loss of trust in "snapshots"

The expectations of structure, listening and trust come up against the absence of relevant feedback, which is experienced as relational silence and as a disqualification of the formal tool called "*snapshots*".

One consultant describes the uncertainty created by the lack of response:

"It's true that when you send messages or when you don't have an answer or when you send your emails and you don't have an answer, well it's difficult for you […] you don't know if what you did was good or not." (Interview 7, Consultant.)

One employee also criticises the official tool:

"What I miss a bit […] And then you see like what is the point? It's the snapshot, because actually it's very good, it's very nice. […] We are evaluated on a deliverable but we don't have a discussion after, we don't have feedback. […] And no explanation was given." (Interview 5, Consultant.)

4.3.2. Tension 2: the impossibility of criticising one's manager, a silent taboo and the issue of upward feedback

Upward criticism is seen as risky in an organisation where hierarchy remains strong.

One employee sums it up very clearly:

"She, I would not like to work with her and I would never dare tell her the truth to her face." (Interview 13, Senior Consultant.)

Another comparison with another entity of the group makes the criticism even more explicit:

"In other Big Four companies […] for example [this firm in Nederland], they give a 360 degree feedback. So, a junior gives his opinion to his manager. But with us, it is not a good practice […] We don't do it […] The only way to receive feedback is from top to bottom, from manager to junior, from top to bottom. But it is never the opposite so we pretend that managers and senior leaders are perfect." (Interview 1, Consultant.)

4.3.3. Tension 3: "business" before "people", frustrations around promotions

Even if the managerial ideal values human qualities, these dimensions seem to become invisible in promotion processes.

One employee asks:

"Why do you improve yourself as a human if it is not valued? Like you take care of your team, you train them, you listen to them […] but in the end, it is the one who sells the most who gets promoted." (Interview 6, Consultant.)

The lack of clarity in the fast track promotion process also increases frustration and weakens trust.

4.3.4. Tension 4: the case of project T, a concrete example of systemic tensions

Project T brings together overload, lack of structure, hierarchical disconnection and institutional blindness to weak warning signs.

One extract shows the failure of listening:

"[…] I was never listened to or taken seriously. […] two people […] ended up in burnout." (Interview 12, Consultant.)

Beyond these lived tensions, the analysis shows that they do not come only from individual behaviours. They are also rooted in a normative framework that is supposed to structure and guide expected practices, namely *Talent Standards*. When confronted with the field, this norm is described as being out of step, especially because it prescribes behaviours without taking into account dilemmas, emotions, loyalty conflicts and human arbitrations.

In this logic, one extract states:

"For me, they only take the Talent Standards into account for your promotion. […] But for the rest, what the Talent Standards say has no importance." (Interview 1, Consultant.)

Above all, *Talent Standards* seem to ignore three major shortcomings identified in the interviews. The first is well-being and protection, which can be seen as the neglect of care.

The second is relational reciprocity, which can be seen as the neglect of upward feedback. The third is the recognition of interpersonal qualities, which appears as a blind spot in promotion logics.

In fact, these blind spots help explain the lived tensions. What is missing in daily practices is also what the norm struggles to name, support and recognise.

4.4. Discussion: norm, co-construction and "managerial bricolage"

The results invite us to rethink managerial norms by looking at the conditions under which they exist. A norm only becomes structuring if it is collectively appropriated and embodied in practices. From a structuration perspective (Giddens, 1984), a managerial framework, no matter how well designed, only has a real impact if it is understood, used and recognised in daily interactions. However, the field shows a lack of practical anchoring of *Talent Standards*. Some employees are not very familiar with them, others describe them as disconnected and their limited presence in the interviews suggests that they shape representations more than actual practices. This situation creates uncertainty about what it really means to "manage well" and leaves room for implicit references built on a case by case basis.

In this context, the figure of the "good manager" appears as an unstable social construction, shaped at the intersection of institutional norms and situated practices. The process of co-construction is limited by the absence of a shared framework, such as a clear and reflexive reference, spaces for dialogue, or collective feedback. As a result, each person builds their own idea of the "good manager" based on partial references, more rooted in lived experience than in clearly defined norms. This instability weakens mutual recognition and makes it difficult to stabilise a shared understanding of the managerial role.

Finally, the study highlights the central role of "managerial bricolage". In the complexity of everyday organisational life, the role of the manager can not be reduced to the simple application of formal standards. Managerial action relies on empirical adjustments, often invisible, which are necessary to deal with local constraints, urgency and conflicting expectations. The manager therefore becomes a mediator of meaning rather than a simple relay of the norm, someone who is able to interpret, contextualise and adapt general guidelines to make them understandable and workable in daily situations. An important implication is to recognise this adjustment work as a core managerial competence instead of leaving it at the margins of formal recognition systems.

From a methodological perspective, this research is based on thirteen semi-structured interviews conducted with non-managerial employees in a single field. Managers were not directly interviewed and the results therefore reflect a bottom up view of the managerial role. In addition, strong availability constraints within the firm influenced the data collection process. As one situation illustrates: *"in this firm everyone is very kind but no one really has time."*

5. CONCLUSION

This study aimed to answer the following question, *how do employees build an image of the "good manager" and how does this image come into conflict, or not, with the practices they observe in their daily work. B*y adopting a constructivist perspective, the research

highlights the gap between normative managerial frameworks and the lived representations of management in a specific organisational context.

The findings show the coexistence of three ideal figures of the “good manager”, the structuring manager, the human (or coach) like manager and the facilitating manager. These figures are rooted in situated expectations and shaped by everyday professional experience.

These figures often come into tension with formal organisational standards, which are seen as abstract, not sufficiently embodied or difficult to reach. The answer to the research question can be expressed as follows. Employees build their image of the “good manager” through their daily interactions, their relational needs and their relationship to recognition. This process can be understood as a form of situated interpretation. When observed managerial practices are seen as disconnected, too normative or not adapted to concrete situations, a conflict appears. This conflict reveals a gap at both symbolic and identity levels, and shows the difficulty of stabilising a shared figure of the manager.

From an organisational point of view, the study underlines the risk of a disembodied form of management, perceived as rigid and overly normative, which can lead to a loss of meaning and weaken hierarchical relationships. On the other hand, practices of adjustment and managerial bricolage show that employees do not passively accept norms, but actively take part in reshaping them in their daily work.

Finally, our research has several limitations. It is based on a single field, it reflects a bottom-up perspective since managers were not directly interviewed and it was influenced by contextual constraints during data collection.

IZMEĐU INSTITUCIONALNIH OČEKIVANJA I SVAKODNEVNE PRAKSE: PERCEPCIJE ZAPOSLENIH O MENADŽERSKIM ULOGAMA U BELGIJSKOJ KONSULTANTSKOJ KOMPANIJI

Oumayma Zoubai
Univerzitet u Liježu, HEC Liège, Belgija

Izvod

Ovaj rad ispituje način na koji zaposleni doživljavaju, procenjuju i tumače ulogu „dobrog menadžera“ u organizacionom okruženju u kojem su očekivanja od menadžera formalizovana kroz interni model kompetencija. Polazeći od konstruktivističke perspektive zasnovane na teoriji strukturacije, istraživanje je usmereno na sagledavanje uočenog nesklada između institucionalnih normi i percepcija zaposlenih o ulozi menadžera. Empirijska analiza zasniva se na trinaest polustrukturisanih intervjua sa zaposlenima u belgijskoj konsultantskoj kompaniji, dok je obrada podataka sprovedena primenom induktivnog pristupa utemeljenog na metodologiji utemeljene teorije. Rezultati istraživanja identifikuju tri idealna tipa menadžera: menadžera koji usmerava i strukturira rad, menadžera u ulozi mentora i menadžera koji podstiče saradnju i pruža podršku. Nalazi istraživanja ukazuju i na postojanje značajnih izazova koji se prvenstveno odnose na nedovoljno pružanje povratnih informacija, izostanak kulture davanja povratnih informacija nadređenima, kao i stavljanje poslovnih ciljeva ispred potreba zaposlenih. Ovi izazovi tumače se kao posledica menadžerskog okvira koji ostaje nedovoljno precizno definisan i razrađen, jer u dovoljnoj meri ne obuhvata pitanja dobrobiti zaposlenih, međusobnog poverenja i saradnje, kao ni značaj interpersonalnih veština.

Ključne reči: *menadžerske uloge, okviri kompetencija, percepcije zaposlenih, organizacione norme, menadžerska improvizacija, dobrobit zaposlenih*

LITERATURA / REFFERENCES

Bonnet, R., & Bonnet, J. (2007). L’analyse du travail des managers. Au-delà de l’analyse de la prescription et de l’activité, comprendre «l’effet manager» comme production de sens. Communication et organisation. Revue scientifique francophone en Communication organisationnelle, (31), 248-263.

Frenkel, S., Sanders, K., & Bednall, T. (2013). Employee perceptions of management relations as influences on job satisfaction and quit intentions. Asia pacific journal of management, 30(1), 7-29.

Giddens, A. (1984). The Constitution of Society: Outline of the Theory of Structuration. University of California Press.

Gioia, D. A., & Chittipeddi, K. (1991). Sensemaking and sensegiving in strategic change initiation. Strategic management journal, 12(6), 433-448.

Harding, N., Lee, H., & Ford, J. (2014). Who is 'the middle manager'? Human Relations, 67(10), 1213-1237.

Heyden, M. L., Sidhu, J. S., & Volberda, H. W. (2018). The conjoint influence of top and middle management characteristics on management innovation. Journal of Management, 44(4), 1505-1529.

Lejeune, C. (2019). Manuel d'analyse qualitative. De Boeck Supérieur.

Mintzberg, H. (1973). The Nature of Managerial Work. Harper & Row.

Nielsen, K., & Yarker, J. (2023). Employees' experience of supervisor behaviour–a support or a hindrance on their return-to-work journey with a CMD? A qualitative study. Work & Stress, 37(4), 487-508.

Watson, T. J. (2008). Managing identity: Identity work, personal predicaments and structural circumstances. Organization, 15(1), 121-143.

Engineering management 12 (1) (2026) 81-94

Engineering management

ZAŠTITA ZDRAVLJA I BEZBEDNOST ZAPOSLENIH KAO ODGOVORNOST MENADŽMENTA U PROIZVODNO-POSLOVNIM SISTEMIMA

Dejan Milovanović
Univerzitet u Beogradu, Tehnički fakultet u Boru, Odsek za inženjerski menadžment, Bor, Srbija

Izvod

Zdravlje na radu što podrazumeva istovremeno i bezbednost, jeste jedan od uslova uspešnog poslovanja i funkcionisanja savremenih proizvodnih i poslovnih sistema. Složenost proizvodnih procesa, često podrazumeva i različite profesionalne rizike, čime se postavljaju sve veći zahtevi u pogledu organizacione efikasnosti gde se razvijaju savremeni sistemi upravljanja bezbednošću i zdravljem na radu. U okviru ovog rada postavlja se prioritetni cilj, a to je analiza uloge menadžmenta u zaštiti zdravlja i bezbednosti zaposlenih, sa posebnim osvrtom na primenu preventivnih mera i identifikaciju rizika, kao i razvoj bezbednosne kulture u proizvodnom okruženju. Istraživanje je sprovedeno u kompaniji *Elixir Prahovo*, jednom od značajnih predstavnika hemijske industrije u Republici Srbiji, u kojoj su prisutni brojni hemijski, mehanički, fizički i požarno-eksplozivni rizici. U radu su primenjene metode analize, sinteze, komparacije, statističke obrade podataka i anketnog istraživanja sprovedenog na uzorku od 110 zaposlenih. Rezultati ukazuju da efikasnost sistema bezbednosti i zdravlja na radu u velikoj meri zavisi od aktivnog učešća menadžmenta, kvaliteta procene rizika, kontinuirane edukacije zaposlenih i dosledne primene bezbednosnih procedura. Poseban značaj ima razvoj pozitivne bezbednosne kulture, koja doprinosi smanjenju broja povreda na radu, povećanju produktivnosti i unapređenju organizacionih performansi. Zaključuje se da sistematsko upravljanje bezbednošću i zdravljem na radu, zasnovano na principima prevencije i kontinuiranog unapređenja, predstavlja važan faktor održivog poslovanja i zaštite ljudskih resursa u proizvodno-poslovnim sistemima.

Keywords: *zdravlje na radu, bezbednost zaposlenih, uloga menadžmenta, Elixir Prahovo*

1. UVOD

Bezbednost i zdravlje na radu predstavljaju jedan od najznačajnijih elemenata savremenog poslovanja i važan preduslov uspešnog funkcionisanja proizvodno-poslovnih sistema. Savremeni uslovi rada, razvoj tehnologije, složenost proizvodnih procesa i povećani zahtevi tržišta doveli su do potrebe za kontinuiranim unapređenjem sistema zaštite zaposlenih. U takvim uslovima, menadžment ima veliku ulogu u organizovanju, sprovođenju i kontroli mera bezbednosti i zdravlja na radu, sa ciljem stvaranja bezbednog i zdravog radnog okruženja. Proizvodno-poslovni sistemi karakterišu se prisustvom brojnih opasnosti i štetnosti koje mogu dovesti do povreda na radu, profesionalnih oboljenja, materijalnih gubitaka i smanjenja produktivnosti. Zbog toga je neophodno uspostaviti efikasan sistem upravljanja bezbednošću i zdravljem na radu, koji će omogućiti

pravovremeno prepoznavanje rizika, primenu preventivnih mera i kontinuirano praćenje stanja bezbednosti u organizaciji. Pored zakonske obaveze, ulaganje u bezbednost i zdravlje zaposlenih predstavlja i važan faktor unapređenja poslovne efikasnosti i konkurentnosti organizacije.

Poseban značaj u sistemu bezbednosti i zdravlja na radu ima uloga menadžmenta, koji je odgovoran za planiranje aktivnosti, organizaciju rada, obezbeđivanje uslova za bezbedan rad, sprovođenje obuke zaposlenih i primenu zakonskih i internih propisa. Uspešnost sistema bezbednosti i zdravlja na radu u velikoj meri zavisi od posvećenosti menadžmenta, bezbednosne kulture organizacije i saradnje svih zaposlenih.

U ovom radu biće analizirana uloga menadžmenta u sistemu zaštite zdravlja i bezbednosti zaposlenih u proizvodno-poslovnim sistemima, sa posebnim osvrtom na primenu mera bezbednosti, upravljanje rizicima i značaj preventivnog delovanja u cilju očuvanja zdravlja i bezbednosti zaposlenih.

2. TEORIJSKE OSNOVE

2.1. Pojam i značaj bezbednosti i zdravlja na radu

Bezbednost i zdravlje na radu predstavljaju sistem mera, pravila, postupaka i aktivnosti čiji je osnovni cilj sprečavanje povreda na radu, profesionalnih oboljenja i drugih štetnih posledica po zdravlje zaposlenih. Savremeni proizvodno-poslovni sistemi karakterišu se složenim tehnološkim procesima, upotrebom različitih mašina, opasnih materija i radom u specifičnim uslovima, što zahteva kontinuirano unapređenje sistema bezbednosti i zdravlja na radu. Zaštita zaposlenih predstavlja ne samo zakonsku obavezu poslodavca, već i jedan od osnovnih uslova uspešnog i efikasnog poslovanja organizacije (Anđelković, 2010).

Prema Zakonu o bezbednosti i zdravlju na radu Republike Srbije, poslodavac je dužan da obezbedi uslove rada koji neće ugroziti život i zdravlje zaposlenih, kao i da sprovodi preventivne mere u cilju smanjenja rizika na najmanju moguću meru (Zakon o bezbednosti i zdravlju na radu, 2023). Značaj bezbednosti i zdravlja na radu ogleda se u zaštiti ljudskih resursa, smanjenju povreda na radu, povećanju produktivnosti i stvaranju bezbedne radne sredine. Savremeni pristupi bezbednosti i zdravlju na radu zasnivaju se na sistemskom upravljanju rizicima, razvoju bezbednosne kulture i aktivnom učešću menadžmenta i zaposlenih u primeni mera zaštite (Goetsch, 2019). Istraživanja pokazuju da organizacije koje ulažu u sistem bezbednosti i zdravlja na radu imaju manji broj povreda, veću efikasnost i bolje organizacione performanse (Fernández-Muñiz et al., 2009).

2.2. Osnovni principi zaštite zdravlja i bezbednosti zaposlenih

Osnovni principi zaštite zdravlja i bezbednosti zaposlenih zasnivaju se na prevenciji rizika, očuvanju zdravlja zaposlenih i stvaranju bezbednih uslova rada. Primarni cilj sistema bezbednosti i zdravlja na radu jeste sprečavanje povreda na radu, profesionalnih oboljenja i drugih negativnih posledica koje mogu nastati tokom radnog procesa. Savremeni pristup bezbednosti na radu podrazumeva sistemsko upravljanje rizicima i kontinuirano unapređenje mera zaštite (Reese, 2015). Jedan od osnovnih principa jeste princip prevencije, koji podrazumeva identifikovanje opasnosti i preduzimanje mera pre nego što dođe do povrede ili štetnog događaja. Takođe, važan princip je prilagođavanje rada čoveku, što podrazumeva organizaciju radnih mesta i uslova rada u skladu sa fizičkim i psihičkim sposobnostima zaposlenih (Bevilacqua et al., 2016). Značajan princip

predstavlja i učešće zaposlenih u sistemu bezbednosti, jer saradnja između menadžmenta i radnika doprinosi efikasnijoj primeni mera zaštite.

2.3. Rizici i opasnosti u proizvodno-poslovnim sistemima

Proizvodno-poslovni sistemi karakterišu se prisustvom brojnih rizika i opasnosti koje mogu ugroziti zdravlje i bezbednost zaposlenih. Rizici mogu biti mehanički, hemijski, fizički, biološki, ergonomski i psihosocijalni, a njihov intenzitet zavisi od vrste proizvodnog procesa, organizacije rada i uslova radne sredine (Glendon et al., 2016). Mehanički rizici najčešće su povezani sa radom na mašinama, upotrebom alata i mogućnošću povređivanja usled nepravilnog rukovanja opremom. Hemijski rizici nastaju usled izlaganja opasnim materijama, gasovima, prašini i isparenjima, dok fizički rizici obuhvataju buku, vibracije, ekstremne temperature i zračenja. Ergonomski rizici odnose se na nepravilan položaj tela, fizičko opterećenje i ponavljajuće pokrete tokom rada (Bevilacqua et al., 2016).

Savremeni pristup upravljanju bezbednošću zasniva se na identifikaciji i proceni rizika, kao i na primeni preventivnih mera u cilju smanjenja mogućnosti nastanka povreda i profesionalnih oboljenja (Reason, 1997). Značajnu ulogu u upravljanju rizicima ima menadžment, koji je odgovoran za organizaciju bezbednog rada, obezbeđivanje adekvatne opreme i sprovođenje mera zaštite. Istraživanja pokazuju da sistematska procena rizika i kontrola opasnosti značajno doprinose smanjenju broja povreda na radu i unapređenju bezbednosnih performansi organizacije (Shannon et al., 1997).

2.4. Odgovornost menadžmenta za bezbednost i zdravlje zaposlenih

Odgovornost menadžmenta za bezbednost i zdravlje zaposlenih predstavlja jedan od osnovnih elemenata uspešnog sistema bezbednosti na radu. Menadžment je dužan da obezbedi bezbedne uslove rada, organizuje sistem zaštite i preduzme sve neophodne mere u cilju sprečavanja povreda i profesionalnih oboljenja. Zakonska regulativa u oblasti bezbednosti i zdravlja na radu jasno definiše obaveze poslodavca i rukovodilaca u pogledu zaštite zaposlenih (Zakon o bezbednosti i zdravlju na radu, 2023). Odgovornost menadžmenta podrazumeva identifikaciju opasnosti, procenu rizika, obezbeđivanje adekvatne opreme i organizaciju obuke zaposlenih. Pored toga, menadžment je odgovoran za praćenje stanja bezbednosti, sprovođenje kontrole i kontinuirano unapređenje sistema zaštite. Uspešno upravljanje bezbednošću podrazumeva aktivno učešće rukovodilaca u svim bezbednosnim aktivnostima organizacije (Bird & Germain, 1996).

Istraživanja pokazuju da organizacije u kojima menadžment aktivno podržava bezbednost imaju razvijeniju bezbednosnu kulturu i manji broj povreda na radu (Zohar, 1980). Odgovornost menadžmenta nije samo zakonska, već i moralna i organizaciona obaveza, jer očuvanje zdravlja i života zaposlenih predstavlja osnovu uspešnog i održivog poslovanja.

2.5. Upravljanje ljudskim resursima i bezbednost zaposlenih

Upravljanje ljudskim resursima ima značajnu ulogu u obezbeđivanju bezbednosti i zdravlja zaposlenih. Savremeni pristupi upravljanju ljudskim resursima podrazumevaju brigu o zdravlju, motivaciji i bezbednosti radnika kao važnim faktorima organizacionog uspeha. Procesi selekcije, obuke i procene zaposlenih moraju biti usklađeni sa zahtevima bezbednosti na radu. Poseban značaj ima kontinuirana edukacija zaposlenih o rizicima i načinima zaštite, kao i razvoj bezbednosne svesti i odgovornog ponašanja (Burke et al.,

2002).

Organizacije koje ulažu u razvoj ljudskih resursa i bezbednost radnika imaju bolje radne rezultate, manji broj povreda i veću produktivnost. Istraživanja pokazuju da pozitivan odnos menadžmenta prema zaposlenima doprinosi razvoju bezbednosne kulture i većem zadovoljstvu radnika (Neal & Griffin, 2006).

2.6. ISO 45001 standard i njegova primena

ISO 45001 predstavlja međunarodni standard za sisteme upravljanja bezbednošću i zdravljem na radu. Osnovni cilj standarda jeste sprečavanje povreda i profesionalnih oboljenja, kao i kontinuirano unapređenje bezbednosnih performansi organizacije (ISO, 2018). Standard se zasniva na procesnom pristupu i modelu planiraj–uradi–proveri–deluj. ISO 45001 zahteva od organizacija da identifikuju rizike, planiraju mere zaštite, uključe zaposlene u sistem bezbednosti i kontinuirano prate efekte primenjenih mera (Karanikas et al., 2022). Primena standarda doprinosi unapređenju organizacije rada, smanjenju broja povreda i jačanju bezbednosne kulture. Organizacije koje implementiraju ISO 45001 često ostvaruju bolje poslovne rezultate i veću konkurentnost na tržištu (Robson et al., 2007).

3. METODOLOGIJA ISTRAŽIVANJA

Kompanija Elixir Prahovo predstavlja jedan od značajnih proizvodno-poslovnih sistema u oblasti hemijske industrije u Republici Srbiji i značajan je deo poslovnog sistema Elixir Group. U proizvodno-poslovnom sistemu kompanije Elixir Prahovo prisutna su različita radna mesta koja se razlikuju po stepenu rizika i uslovima rada. Proizvodni procesi u kompaniji Elixir Prahovo karakterišu se prisustvom različitih rizika koji mogu ugroziti bezbednost i zdravlje zaposlenih, a proizlaze iz prirode hemijske industrije i složenosti tehnološkog procesa proizvodnje. Pravilna identifikacija i kontrola ovih rizika predstavlja osnov za bezbednost na radu i očuvanje zdravlja zaposlenih. Istraživanje je sprovedeno u kompaniji Elixir Prahovo primenom anketnog upitnika među zaposlenima, sa ciljem identifikovanja osnovnih faktora koji utiču na bezbednost i zdravlje na radu, kao i procene efikasnosti postojećih mera zaštite. Očekuje se da rezultati istraživanja omoguće definisanje smernica za unapređenje sistema bezbednosti i zdravlja na radu i jačanje uloge menadžmenta u upravljanju bezbednosnim procesima. Istraživanje je sprovedeno u kompaniji Elixir Prahovo tokom maja 2026. godine, na uzorku od 110 ispitanika iz različitih organizacionih jedinica, uključujući službu proizvodnje, službu održavanja, BZR službu i administrativnu službu. Na ovaj način obezbeđena je određena raznovrsnost ispitanika u pogledu radnog mesta, obrazovanja, starosne strukture i radnog staža, što omogućava inicijalni uvid u stanje bezbednosti i zdravlja na radu unutar posmatranog sistema.

Upitnik je sadržao dva dela: prvi deo se odnosio na opšte demografske podatke ispitanika, dok je drugi deo obuhvatao tvrdnje u vezi sa poznavanjem i primenom mera bezbednosti, komunikacijom sa nadređenima, uslovima rada, upotrebom zaštitne opreme i opštom bezbednosnom kulturom u kompaniji. Ispitanici su svoje stavove izražavali putem Likertove skale od pet stepeni, što je omogućilo kvantitativnu obradu podataka. Prikupljeni odgovori predstavljaju preliminarnu bazu za dalju statističku analizu i identifikaciju osnovnih trendova u percepciji bezbednosti na radu.

Podaci su prikupljeni putem Google Forms anketnog upitnika a za obradu i analizu podataka korišćen je Microsoft Excel, primenom deskriptivne statistike, tabelarnog

prikaza, grafikona i izračunavanja frekvencija i procenata dobijenih odgovora.

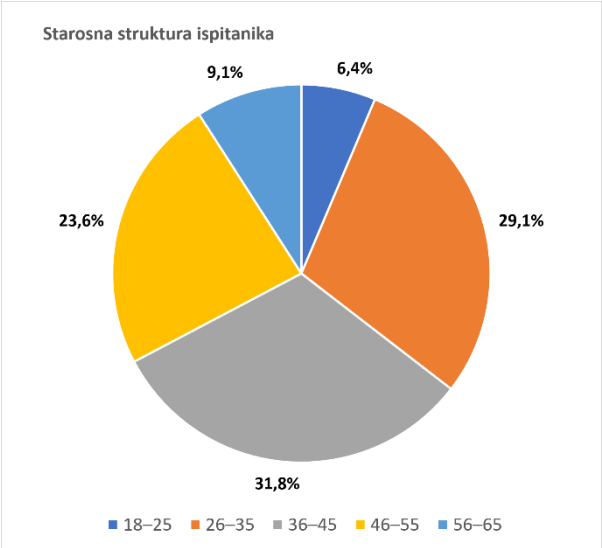
3.1. Analiza i interpretacija rezultata istraživanja

U okviru prvog dela upitnika prate se demografski podaci kao što su polna i starosna struktura ispitanika, zatim ukupni radni staž kao i radno mesto koje obavljaju u kompaniji.

Rezultati pokazuju da većinu ispitanika čine muškarci, koji su zastupljeni sa 69,10%, odnosno 76 ispitanika. Ženski pol zastupljen je sa 30,90%, što obuhvata 34 ispitanice. Ovakva polna struktura uzorka ukazuje na izraženu dominaciju muškog pola unutar proizvodno-poslovnog sistema. Dobijeni rezultati prikazani su na Slici 1.

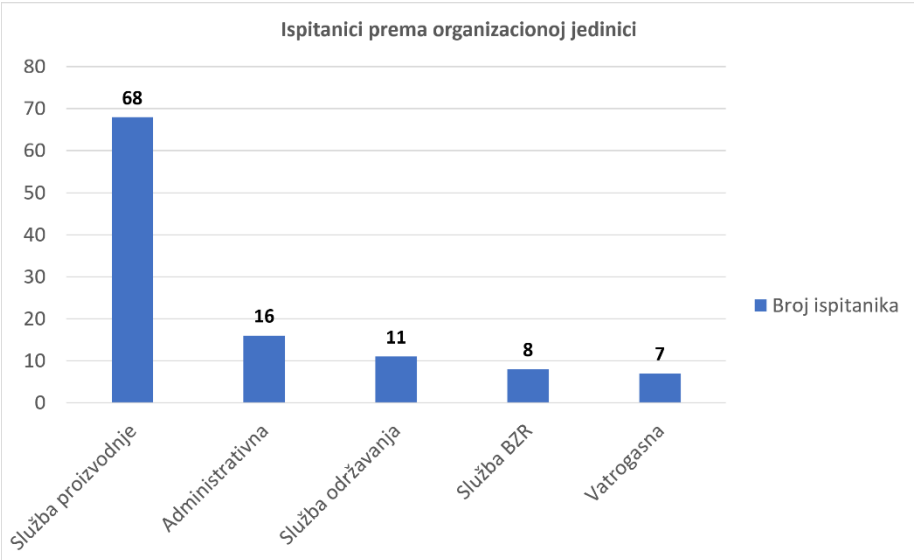
Slika 1. Polna struktura ispitanika
Izvor: Istraživanje autora.

Najveći udeo u uzorku imaju ispitanici starosti od 36 do 45 godina, koji čine 31,80% ukupnog broja anketiranih. Neposredno iza ove grupe nalaze se ispitanici starosti od 26 do 35 godina sa udelom od 29,10%, dok kategorija od 46 do 55 godina učestvuje sa 23,60%. Najmanje su zastupljene krajnje starosne kategorije. Ispitanici starosti od 56 do 65 godina čine 9,10% uzorka, dok najmlađa kategorija od 18 do 25 godina učestvuje sa svega 6,40%. Ovakva struktura ukazuje na dominaciju srednje generacije radno aktivnog stanovništva, što je karakteristično za proizvodno-poslovne sisteme u kojima je neophodna kombinacija radnog iskustva, profesionalne zrelosti i fizičke sposobnosti za obavljanje radnih zadataka. Na Slici 2 prikazana je starosna struktura ispitanika.



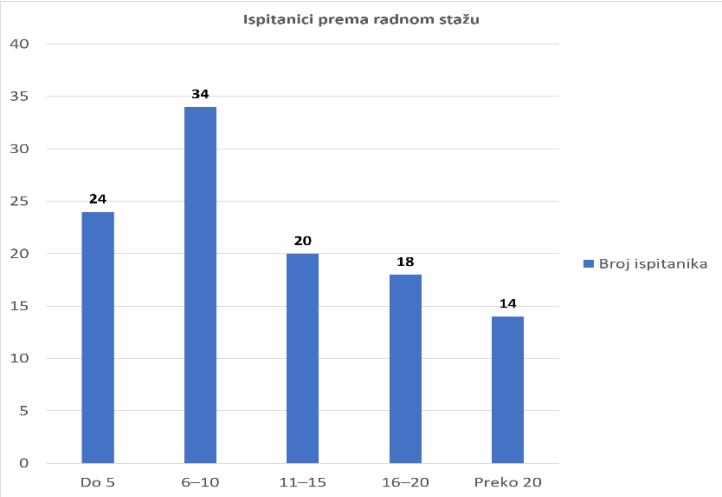
Slika 2. Starosna struktura ispitanika
Izvor: Istraživanje autora.

Najveći broj ispitanika dolazi iz Službe proizvodnje, koja sa 68 ispitanika čini 61,8% ukupnog uzorka. Ovakva zastupljenost je očekivana, s obzirom na to da proizvodni sektor predstavlja osnovnu delatnost kompanije i obuhvata najveći broj zaposlenih. Administrativna služba zastupljena je sa 16 ispitanika, odnosno 14,5% uzorka, dok Služba održavanja obuhvata 11 ispitanika ili 10,0%. BZR služba učestvuje sa 8 ispitanika (7,3%), a Vatrogasna služba sa 7 ispitanika, što predstavlja 6,4% ukupnog uzorka. Dobijeni rezultati prikazani su na Slici 3.



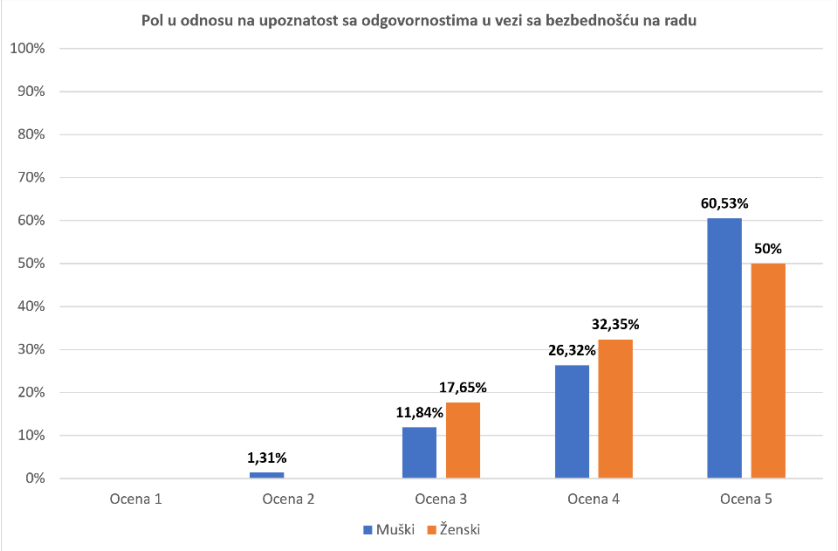
Slika 3. Ispitanici prema organizacionoj jedinici
Izvor: Istraživanje autora.

Na Slici 4 se jasno izdvaja nekoliko zastupljenih grupa zaposlenih. Najbrojniju kategoriju čine zaposleni sa 6 do 10 godina radnog staža (34 ispitanika, odnosno 30,9% uzorka), a slede zaposleni sa stažom do 5 godina (24 ispitanika, 21,8%). Kategorija od 11 do 15 godina obuhvata 20 ispitanika (18,2%), zaposleni sa 16 do 20 godina staža čine 18 ispitanika (16,4%), dok su najmanje zastupljeni radnici sa preko 20 godina staža (14 ispitanika, 12,7%).



Slika 4. Ispitanici prema radnom stažu
Izvor: Istraživanje autora.

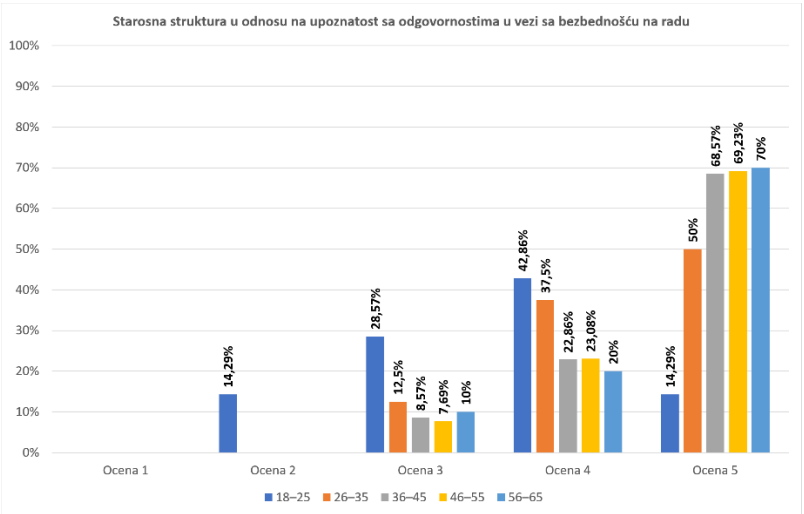
Analiza rezultata, prikazana na Slici 5 prema polu pokazuje da i muškarci i žene iskazuju visok nivo saglasnosti sa tvrdnjom koja se odnosi na poznavanje odgovornosti u oblasti bezbednosti i zdravlja na radu, ali se uočavaju određene razlike u intenzitetu pozitivnih stavova. Kod muških ispitanika dominira najviša ocena, pri čemu se 60,53% u potpunosti slaže sa tvrdnjom, dok se dodatnih 26,32% uglavnom slaže. To znači da čak 86,85% muškaraca ima pozitivan stav i jasno prepoznaje sopstvene odgovornosti u sistemu bezbednosti na radu. Neutralan stav prisutan je kod 11,84% ispitanika, dok je negativan stav zabeležen kod svega 1,31% muškaraca. Potpuno negativni odgovori nisu evidentirani. Kod ženskih ispitanica takođe preovlađuju pozitivni stavovi. Polovina ispitanica (50,00%) u potpunosti se slaže sa tvrdnjom, dok se 32,35% uglavnom slaže. Ukupno pozitivno opredeljenje prisutno je kod 82,35% žena. Neutralni stavovi zastupljeni su u nešto većem procentu nego kod muškaraca i iznose 17,65%, dok negativni odgovori nisu zabeleženi.



Slika 5. Varijabla pol u odnosu na stav upoznatost sa odgovornostima u vezi sa bezbednošću na radnom mestu

Izvor: Istraživanje autora.

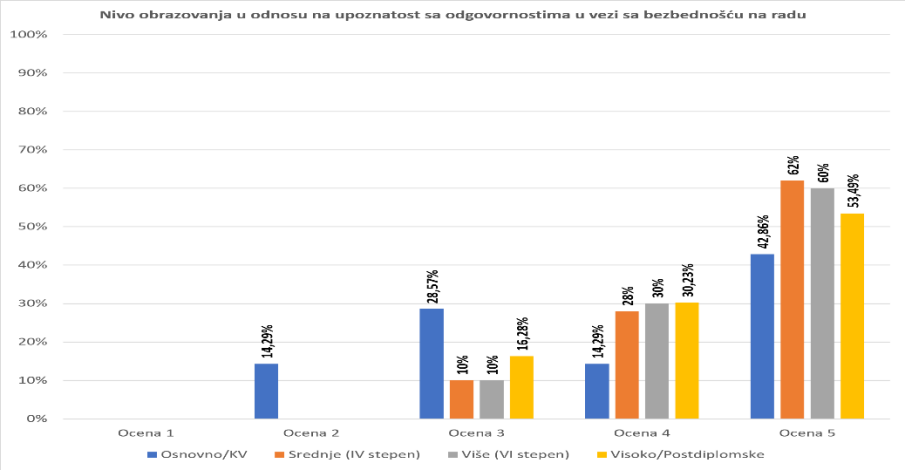
Analiza rezultata, prikazana na Slici 6, pokazuje da u ovoj grupi 42,86% ispitanika uglavnom se slaže sa tvrdnjom, dok se 14,29% u potpunosti slaže. Istovremeno, 28,57% ispitanika ima neutralan stav, a 14,29% uglavnom se ne slaže sa tvrdnjom. Ovakvi rezultati mogu se objasniti kraćim radnim iskustvom i manjom izloženošću obukama i praktičnim situacijama u oblasti bezbednosti na radu. Kategorija ispitanika starosti od 26 do 35 godina pokazuje značajno viši nivo sigurnosti, pri čemu polovina ispitanika u potpunosti potvrđuje poznavanje svojih odgovornosti, dok se 37,50% uglavnom slaže. Negativni odgovori nisu zabeleženi, što ukazuje na stabilan nivo bezbednosne svesti kod mlađih iskusnih radnika.



Slika 6. Varijabla starosna struktura na stav upoznatost sa odgovornostima u vezi sa bezbednošću na radnom mestu

Izvor: Istraživanje autora.

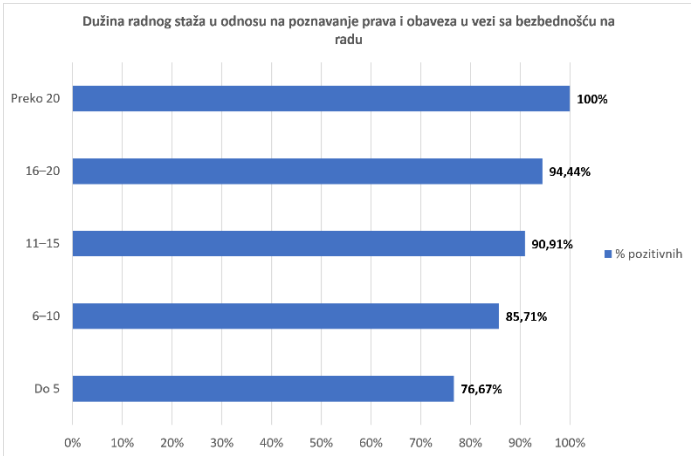
Analiza rezultata, prikazana na Slici 7 prema nivou obrazovanja pokazuje da ispitanici sa osnovnim obrazovanjem i KV kvalifikacijama pokazuju najveći stepen uzdržanosti u odnosu na ostale grupe. U ovoj kategoriji 42,86% ispitanika u potpunosti se slaže sa tvrdnjom, dok se 14,29% uglavnom slaže. Istovremeno, 28,57% ispitanika ima neutralan stav, a 14,29% uglavnom se ne slaže sa tvrdnjom. Ovakav rezultat može se objasniti manjim stepenom formalne edukacije i ograničenijim pristupom informacijama koje se odnose na zakonske i organizacione aspekte bezbednosti na radu. Najveći stepen pozitivnih stavova zabeležen je kod ispitanika sa srednjim obrazovanjem IV stepena, koji ujedno čine i najbrojniju grupu u uzorku. Čak 62,00% ispitanika u potpunosti se slaže sa tvrdnjom, dok se 28,00% uglavnom slaže. Ukupno posmatrano, 90,00% ispitanika iz ove kategorije ima pozitivan stav, što ukazuje na visok nivo razvijene bezbednosne svesti među zaposlenima u proizvodnom sektoru.



Slika 7. Nivo obrazovanja na stav upoznatost sa odgovornostima u vezi sa bezbednošću na radnom mestu

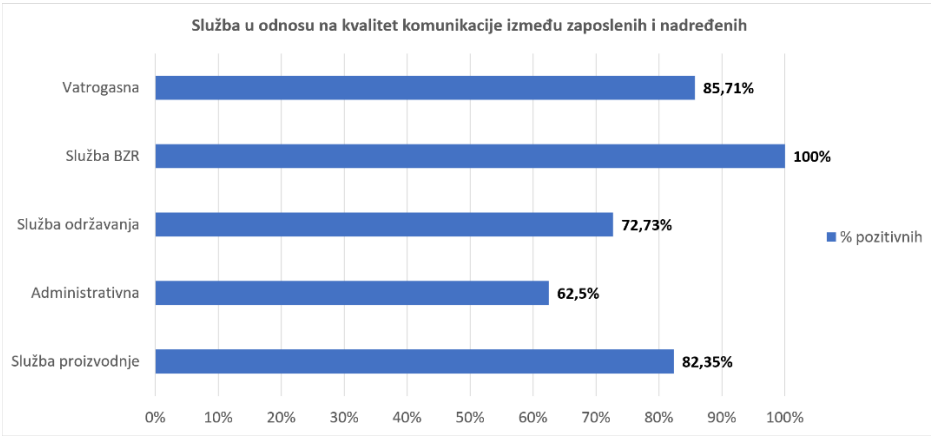
Izvor: Istraživanje autora.

Analiza rezultata, prikazanih na Slici 8, ukrštanja dužine radnog staža sa stavom „Imam saznanja o pravima i obavezama koje se odnose na bezbednost na radu“ pokazuje da zaposleni sa kraćim radnim stažom, posebno do pet godina, pokazuju nešto veći stepen neodlučnosti i manju sigurnost u poznavanje svojih prava i obaveza. Sa druge strane, kod zaposlenih sa srednjim i dugogodišnjim radnim iskustvom primetan je značajno viši nivo slaganja sa navedenom tvrdnjom. Posebno se izdvajaju ispitanici sa više od 15 godina radnog staža, kod kojih dominiraju najviše ocene, što ukazuje na visok stepen internalizacije bezbednosnih pravila i razvijenu svest o značaju poštovanja BZR procedura.



Slika 8. Dužina radnog staža u odnosu na poznavanje prava i obaveza u vezi sa bezbednošću na radu
Izvor: Istraživanje autora.

Ukrštanjem stava o kvalitetu komunikacije sa organizacionim jedinicama, prikazanih na Slici 9, uočava se jasna hijerarhija u percepciji informisanosti i dostupnosti nadređenih u oblasti bezbednosti na radu. Najviši nivo zadovoljstva beleži se u BZR službi (100% pozitivnih odgovora), što je očekivano s obzirom na njihovu ulogu u kreiranju i praćenju bezbednosnih procedura. Veoma visoke vrednosti prisutne su i u Vatrogasnoj službi (85,71%) i Službi proizvodnje (82,36%), što ukazuje da u operativnim i rizičnim sektorima postoji kontinuirana i funkcionalna komunikacija između nadređenih i izvršilaca. Služba održavanja pokazuje nešto niži, ali i dalje zadovoljavajući nivo pozitivnih stavova (72,73%), uz prisutnu veću neodlučnost, što može ukazivati na povremene nedostatke u redovnoj komunikaciji. Najizraženija uzdržanost uočena je u Administrativnoj službi, gde je visok udeo neodlučnih i najniži procenat potpune saglasnosti.



Slika 9. Služba u kojoj zaposleni rade u odnosu na stav o kvalitetu komunikacije između zaposlenih i nadređenih u oblasti bezbednosti na radu
Izvor: Istraživanje autora.

Posmatrano u celini, rezultati pokazuju jasan hijerarhijski obrazac funkcionisanja sistema bezbednosti i zdravlja na radu. Najviši nivo efikasnosti beleži se u domenu pravno-organizacionih i finansijskih inputa, dok se postepeni pad pozitivnih ocena uočava kroz prelaz ka procesnom i individualnom nivou. Ovaj obrazac ukazuje da je sistem strukturno dobro postavljen, ali da se njegova efikasnost postepeno smanjuje pri prelasku sa formalnih mehanizama na ponašanje zaposlenih. Upravo u tom prelazu između organizacionog dizajna i ljudskog faktora nalazi se osnovna tačka daljeg unapređenja bezbednosnog sistema.

U cilju sveobuhvatne naučne interpretacije sistema bezbednosti i zdravlja na radu u analiziranoj organizaciji, svi ispitivani stavovi (ukupno 13 varijabli) grupisani su u četiri međusobno povezane faze, koje odgovaraju logičkoj matrici inputa, procesa, uslova i autputa. Ovakva struktura omogućava sistemski pristup analizi, pri čemu se jasno uočavaju odnosi između upravljačkih odluka, organizacionih mehanizama i krajnjeg ponašanja zaposlenih.

Tabela 1. Vizuelni prikaz sintetizovane logike sve četiri faze u jedinstven sistem upravljanja rizikom

Faza modela	Uloga u BZR sistemu	Obuhvaćeni stavovi	Generalni zaključak faze
FAZA 1: Inputi	Strategija i finansije poslodavca	Stavovi: 7, 8, 12	Izrazito pozitivna. Menadžment i budžet su odlično postavljeni.
FAZA 2: Procesi	Transfer znanja i informisanje	Stavovi: 1, 2, 3	Umereno pozitivna. Pojavljuje se rutina i formalizam u obukama.
FAZA 3: Ambijent	Fizički uslovi i zdravstvena zaštita	Stavovi: 4, 5, 6, 10, 11	Visoko pozitivna. Investicije su uspešno vidljive na radnim mestima
FAZA 4: Autput	Stvarna bezbednosna kultura na delu	Stav: 13	Visoko pozitivna. Investicije su uspešno vidljive na radnim mestima.

4. DISKUSIJA REZULTATA ISTRAŽIVANJA

Dobijeni rezultati istraživanja sprovedenog u kompaniji Elixir Prahovo, na uzorku od N=110 zaposlenih, ukazuju na izrazito visoku ukupnu razvijenost sistema bezbednosti i zdravlja na radu (BZR), ali i na jasno prepoznatljive razlike između organizaciono-strateškog, operativnog i individualnog nivoa funkcionisanja sistema. Deskriptivna statistička analiza pokazuje da se u svim ispitivanim dimenzijama dominantno javljaju pozitivne ocene (4 i 5), što ukazuje na stabilnu bezbednosnu kulturu, ali i na određene unutrašnje disbalanse koji postaju vidljivi pri detaljnijoj dekompoziciji rezultata.

Na nivou pravno-organizacionog okvira, rezultati ukazuju na najviši stepen saglasnosti ispitanika sa tvrdnjama koje se odnose na jasnoću internih dokumenata i definisanost odgovornosti. Kumulativni pozitivni skor od 88,20% za stav o internim aktima pokazuje da zaposleni prepoznaju postojanje jasno strukturisanog sistema pravila i procedura. Ovaj podatak je posebno značajan jer ukazuje da osnova BZR sistema nije formalna, već funkcionalna, odnosno da interni akti imaju stvarnu primenu u praksi. Visok stepen pozitivne percepcije u ovoj fazi ukazuje na razvijenu organizacionu zrelost i dobru vertikalnu hijerarhiju u upravljanju bezbednošću.

Slični rezultati dobijeni su i u domenu strateškog menadžmenta, gde se poslodavac percipira kao aktivno uključen u unapređenje radnih uslova. Kumulativ od 88,20% pozitivnih odgovora ukazuje da zaposleni prepoznaju kontinuirana ulaganja u tehničke i organizacione aspekte bezbednosti. Ovo uključuje modernizaciju opreme, poboljšanje radnog okruženja i usklađivanje sa regulatornim zahtevima. Posebno je značajno što su ove aktivnosti prepoznate od strane većine zaposlenih, što govori u prilog transparentnosti upravljačkih odluka i njihove vidljivosti na operativnom nivou.

U oblasti operativne prevencije rizika (mere zaštite i redovnost lekarskih pregleda), rezultati pokazuju blago smanjenje kumulativnog pozitivnog skora na 86,30%. Iako i dalje visok, ovaj podatak ukazuje na početak diferencijacije u percepciji zaposlenih. Na nivou

individualnog ponašanja zaposlenih, rezultati za upotrebu lične zaštitne opreme pokazuju kumulativ od 82,70% pozitivnih odgovora. Iako i dalje visok, ovaj rezultat predstavlja najniži nivo pozitivne percepcije u okviru svih analiziranih varijabli. Posebno je značajno prisustvo 11,80% neodlučnih i 5,40% negativnih odgovora, što ukazuje na postojanje određenog stepena odstupanja u doslednoj primeni HTZ opreme. Ovaj nalaz je metodološki važan jer ukazuje da se najveći bezbednosni rizici ne nalaze u sistemu ili infrastrukturi, već u domenu ljudskog ponašanja.

5. ZAKLJUČAK

Sprovedeno istraživanje u okviru analize sistema bezbednosti i zdravlja na radu u kompaniji Elixir Prahovo omogućilo je sveobuhvatan uvid u stepen razvijenosti BZR sistema, percepciju zaposlenih, kao i međusobnu povezanost organizacionih, tehničkih i ljudskih faktora koji utiču na nivo bezbednosti u radnom okruženju. Polazeći od činjenice da savremeni sistemi upravljanja bezbednošću i zdravljem na radu više ne predstavljaju samo zakonsku obavezu, već i osnovni element održivog poslovanja i konkurentske prednosti, rezultati ovog istraživanja dobijaju poseban značaj u kontekstu organizacionog razvoja i upravljanja ljudskim resursima.

Dobijeni empirijski podaci ukazuju da je u posmatranoj organizaciji prisutan visoko razvijen nivo formalne uređenosti BZR sistema. To se pre svega ogleda u izuzetno visokom stepenu slaganja ispitanika sa tvrdnjama koje se odnose na jasno definisane interne procedure, raspodelu odgovornosti i organizacionu strukturu u oblasti bezbednosti. Ovaj nalaz ukazuje da su osnovni pravno-normativni okviri sistema čvrsto postavljeni, te da zaposleni u velikoj meri razumeju svoje obaveze, nadležnosti i ulogu u ukupnom sistemu zaštite. Jasnoća internih dokumenata predstavlja jedan od temeljnih preduslova efikasnog funkcionisanja BZR sistema, jer omogućava smanjenje organizacione nejasnoće, sprečava preklapanje odgovornosti i smanjuje rizik od propusta u kritičnim situacijama.

U teorijskom kontekstu, rezultati ovog istraživanja potvrđuju polazne pretpostavke savremenih modela bezbednosti i zdravlja na radu, prema kojima je bezbednost multidimenzionalni sistem koji zavisi od interakcije tehničkih, organizacionih i ljudskih faktora. Posebno se potvrđuje značaj bezbednosne klime, liderstva u oblasti bezbednosti i kontinuiranog unapređenja sistema, kao osnovnih determinanti uspešnog BZR menadžmenta.

EMPLOYEE HEALTH AND SAFETY PROTECTION AS A MANAGEMENT RESPONSIBILITY IN PRODUCTION-BUSINESS SYSTEMS

Dejan Milovanović
University of Belgrade, Technical Faculty in Bor, Engineering Management Department Bor, Serbia

Abstract

Health at work, which implies safety at the same time, is one of the conditions for successful business and the functioning of modern production and business systems. The complexity of production processes often implies various professional risks, which places increasing demands in terms of organizational efficiency where modern safety management systems and occupational health are developed. Within this work, a priority goal is set, which is the analysis of the role of management in protecting the health and safety of employees, with special reference to the application of preventive measures and identification of risks, as well as the development of a safety culture in the production environment. The research was conducted in the company Elixir Prahovo, one of the important representatives of the chemical industry in the Republic of Serbia, where numerous chemical, mechanical, physical and fire-explosive risks are present. In the paper, the methods of analysis, synthesis, comparison, statistical data processing and survey research conducted on a sample of 110 employees were applied. The results indicate that the effectiveness of the occupational health and safety system depends to a large extent on the active participation of management, the quality of risk assessment, continuous education of employees and the consistent application of safety procedures. Of particular importance is the development of a positive safety culture, which contributes to reducing the number of injuries at work, increasing productivity and improving organizational performance. It is concluded that the systematic management of safety and health at work, based on the principles of prevention and continuous improvement, is an important factor of sustainable business and protection of human resources in production and business systems.

Ključne reči: *occupational health, employee safety, role of management, Elixir Prahovo*

LITERATURA / REFFERENCES

Anđelković, B. (2010). Osnovi sistema zaštite. Niš: Fakultet zaštite na radu.

Bevilacqua, M., Ciarapica, F. E., & Giacchetta, G. (2016). Industrial and occupational ergonomics in the petrochemical process industry. European Journal of Industrial Engineering, 10(5), 551–575.

Bird, F. E., & Germain, G. L. (1996). Practical loss control leadership. Det Norske Veritas.

Burke, M. J., Sarpy, S. A., Tesluk, P. E., & Smith-Crowe, K. (2002). General safety performance: A test of a grounded theoretical model. Personnel Psychology, 55(2), 429–457.

Fernández-Muñiz, B., Montes-Peón, J. M., & Vázquez-Ordás, C. J. (2009). Relation between occupational safety management and firm performance. Safety Science, 47(7), 980–991.

Glendon, A. I., Clarke, S., & McKenna, E. (2016). Human safety and risk management (3rd ed.). CRC Press.

Goetsch, D. L. (2019). Occupational safety and health for technologists, engineers, and managers (9th ed.). Pearson.

Karanikas, N., Weber, D., Bruschi, K., & Brown, S. (2022). Identification of systems thinking aspects in ISO 45001: 2018 on occupational health & safety management. Safety Science, 148, 105671.

Neal, A., & Griffin, M. A. (2006). Safety climate and safety behavior. Journal of Applied Psychology, 91(4), 946–953.

Reason, J. (1997). Managing the risks of organizational accidents. Ashgate Publishing.

Reese, C. D. (2015). Occupational health and safety management: A practical approach (3rd ed.). CRC Press.

Robson, L. S., Clarke, J. A., Cullen, K., Bielecky, A., Severin, C., Bigelow, P. L., & Mahood, Q. (2007). The effectiveness of occupational health and safety management system interventions. Safety Science, 45(3), 329–353.

Shannon, H. S., Mayr, J., & Haines, T. (1997). Overview of the relationship between organizational and workplace factors and injury rates. Safety Science, 26(3), 201–217.

Zakon o bezbednosti i zdravlju na radu. (2023). Službeni glasnik Republike Srbije, br. 35/2023.

Zohar, D. (1980). Safety climate in industrial organizations. Journal of Applied Psychology, 65(1), 96–102.

Engineering management 12 (1) (2026) 1-94
The International Student Journal for Theory and Practice of Management Science

CONTENTS