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AHP-BASED STATISTICAL EVALUATION OF DIGITALIZATION CHALLENGES IN THE GREEN ECONOMY

Violeta Dimić
University Alfa BK, Faculty of Information Technology, Belgrade, Serbia
e-mail: violeta.dimic@alfa.edu.rs
https://orcid.org/0000-0002-0157-436X

Mimica R. Milošević
University Alfa BK, Faculty of Information Technology, Belgrade, Serbia
e-mail: mimica.milosevic@alfa.edu.rs
https://orcid.org/0000-0002-9524-9663

Dušan M. Milošević
University of Niš, Faculty of Electronic Engineering,
Department of Mathematics, Niš, Serbia
e-mail: dusan.milosevic@elfak.ni.ac.rs
https://orcid.org/0000-0003-2248-6809

Abstract: The adoption of digital technologies that improve productivity, sustainability and resource management is essential for the transition to a green economy. However, the digitisation process also brings with it complicated technological, economic, social and environmental issues that need to be prioritised methodically. To statistically evaluate and rank 25 indicators categorised according to five basic criteria – technological, economic, environmental, socio-institutional, and implementation risk indicators – this study employs the Analytic Hierarchy Process (AHP). The results show that technological indicators have the highest relative weight, highlighting the role that automation, artificial intelligence and digital infrastructure play in promoting green transitions. The environmental impacts underscore the necessity of energy-saving and emissions-free technologies, while the economic aspects are less important, since they are at the stage of showing the influence of investment costs and returns on digital growth. The outcomes authenticate the statistical reliability of the AHP matrix and offer a quantitative tool for decision-makers to outline the key areas in the digital-green transformation that require their attention. Overall, the study provides a structured approach to decision support for balancing technological innovation and sustainability goals.

Keywords: *green economy, Analytic Hierarchy Process (AHP), technological innovation, digital infrastructure, statistical evaluation.*

1. INTRODUCTION

The digitisation process is one of the key drivers of the modern green economy, offering opportunities to improve energy efficiency, reduce harmful gas emissions, and promote more rational use of resources (IEA, 2025). At the same time, the transition to a digital-green economy model faces numerous challenges arising from technical, economic, environmental, institutional and social limitations. Understanding and ranking these challenges becomes essential for defining sustainable development policies and effective digital transition strategies.

Digital technologies, such as automation systems, the Internet of Things (IoT), and artificial intelligence, are increasingly being integrated into green processes; however, their application depends on the availability of infrastructure, cybersecurity, and the interoperability of different sectors (Ma, 2023; Huang, 2021). High implementation costs and the need for funding are significant economic obstacles. However, empirical evaluation is still needed to determine how digitisation affects the environment, including lowering CO2 emissions and fostering the circular economy (Vinuesa et al., 2019). In addition, institutional and social factors, such as digital literacy, regulatory framework and citizen trust, largely determine the success of the digital-green transformation (Wang et al., 2024).

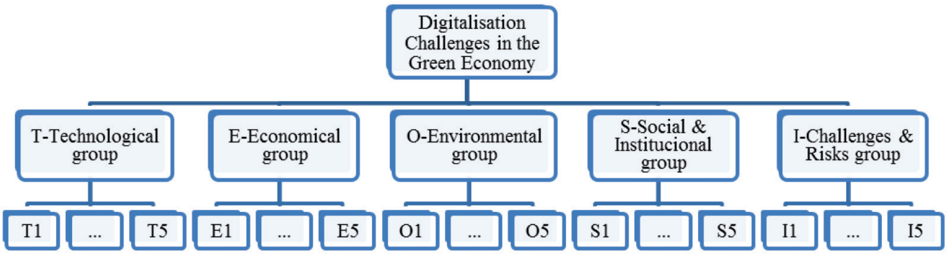
There is still a lack of an integrated analytical approach that allows for a quantitative comparison of the relative importance of various elements, despite numerous studies examining individual aspects of sustainability and digitisation (Monideepa et al., 2024). To statistically evaluate and rank 25 indicators categorised according to five basic criteria – technological, economic, environmental, socio-institutional, and implementation risk factors – this study employs the Analytic Hierarchy Process (AHP). Using the AHP technique, this article aims to identify and prioritise the main digitalisation concerns in the green economy through a statistical assessment of the impact of technological, economic, environmental, social, and institutional indicators, as well as indicators associated with implementation risks. Research results serve as a basis for creating national and corporate policies that support sustainable digital transformation and more effectively align technological innovation with environmental goals.

2. RANKING USING THE AHP METHOD

For this research, the Analytical Hierarchy Process (AHP) method was applied because it enables a systematic and quantitative assessment of complex decisions that include multiple criteria of different natures. Digitisation in the context of the green economy encompasses interconnected technological, economic, environmental and social factors, the relative importance of which cannot be readily determined by traditional statistical approaches. The AHP method makes it possible to break down the problem into a hierarchical structure of criteria and sub-criteria, conduct comparative assessments and calculate weights that reflect subjective and objective priorities. Its application contributes to better transparency of the decision-making process and enables the integration of expert assessments with quantitative analysis (Dimić et al., 2017). In this way, AHP is a suitable tool for identifying and ranking the key challenges of digitisation within the green economy.

The sum of the weights at each level is equal to one, which allows for a clear ranking of all elements both horizontally (within levels) and vertically (between levels). Hierarchical structure of decision-making for digitalisation challenges in the green economy is shown on Figure 1.

Figure 1. Hierarchical structure for digitalisation challenges in the green economy



Source: The authors structure the problem of decision making

To carry out a systematic analysis of digitalisation challenges within the green economy, a set of criteria and sub-criteria has been defined that include key technological, economic, environmental, social-institutional and risk dimensions. These indicators enable a comprehensive assessment of digital technology's effects on sustainable development and provide a basis for the application of the AHP method in ranking their importance. Any comparison of two elements of the hierarchy is done using Satie's scale (Forman & Gass, 2001):

$$S = \left\{ \frac{1}{9}, \frac{1}{8}, \frac{1}{7}, \frac{1}{6}, \frac{1}{5}, \frac{1}{4}, \frac{1}{3}, \frac{1}{2}, 1,2,3,4,5,6,7,8,9 \right\} \quad (1)$$

Descriptive values express the priority that one alternative has in relation to another. The structure of the criteria is based on modern research in the field of digital transformation and green economy, and is shown in Table 1.

Table 1. Criteria and sub-criteria for the statistical evaluation of digitalisation challenges in the green economy

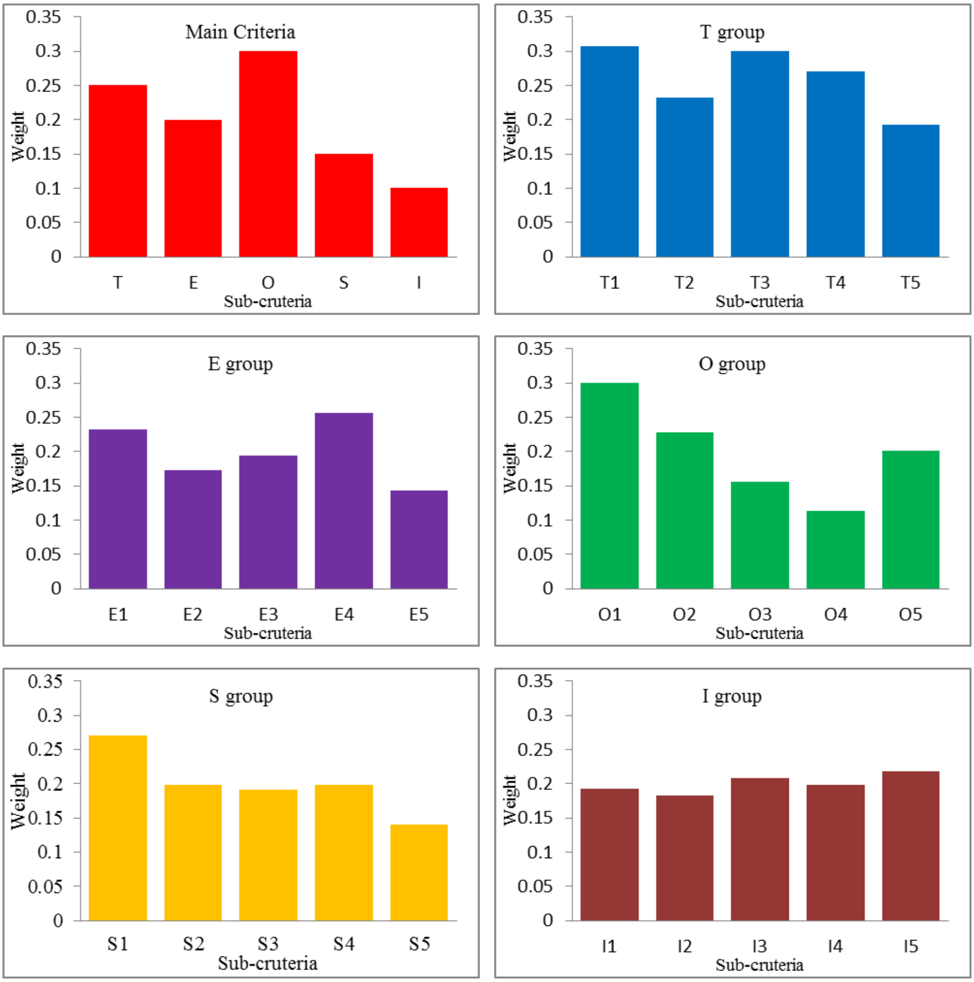
Main Criteria	Label	Sub-criteria (indicators)
T - Technological group	T1	Availability of Digital Infrastructure: Internet, 5G, IoT, (Milošević et al., 2025))
	T2	Automation and Smart Technologies, (Almusharraf, 2025; Hassan, et al., 2025).
	T3	AI Application in Environmental Processes (Chen, 2024).
	T4	Digital Interoperability across Systems (Cavalieri et al., 2022)
	T5	Cybersecurity and System Resilience (Zegzhda et al., 2021; Chukwurah et al., 2024)
E - Economical group	E1	Cost of Implementing Digital Solutions (DiLellio et al., 2025)
	E2	Economic Profitability (ROI) of Green Digital Technologies (Chen, 2025)
	E3	Access to Financing and Subsidies (Chen, 2025)
	E4	Impact of Digitalization on Productivity and Cost Reduction (Hasan, 2025)
	E5	New Market Opportunities and Digital Jobs (Bustos, 2024).
O - Environmental group	O1	CO_2 Emission Reduction through Digital Solutions (Tabe-Ojong et al., 2024)
	O2	Energy Efficiency through Digital Technologies (Khaleel et al., 2023)
	O3	Waste Management and Circular Economy (Digital Tools) (Luttenberger, 2020).
	O4	Conservation of Natural Resources (Foo, 2025)
	O5	Environmental Monitoring and Reporting (Digital Tools) (EPA, 2025)

Main Criteria	Label	Sub-criteria (indicators)
S - Social & Institutional group	S1	Digital Literacy and Workforce Training (Ramli et al., 2020)
	S2	Accessibility of Digital Solutions for All Social Groups (Nowak et al., 2024)
	S3	Regulatory Framework and Policy Support (Agupugo, 2022)
	S4	Public–Private–Academic Collaboration (Abramo & D'Angelo, 2022).
	S5	Public Trust in Digital Green Systems (Liu et al., 2019)
I - Challenges & Risks group	I1	Resistance to Technological Change (Noroozi, 2024).
	I2	Lack of Qualified Workforce in Digital-Green Sectors (Ghinararu et.al., 2025).
	I3	High Initial Investments and Payback Period (Yard, 2000)
	I4	Digital Inequality Risk (Zhao & Zhu, 2025)
	I5	Regulatory and Ethical Barriers (Privacy, AI Ethics) (Kesavan, 2024)

Source: The authors used criteria and sub-criteria based on modern research

The selection of presented criteria is based on the need to cover all key aspects of digital transformation in the green economy, in accordance with the principles of sustainable development and existing research in this area. Economic criteria examine market effects and financial profitability, whereas technological criteria enable the evaluation of preparedness and the ability to deploy digital solutions. Ecological criteria, on the other hand, show the actual contribution to lowering adverse environmental effects (Dimić et al., 2019). The social-institutional dimension includes aspects of digital literacy, inclusiveness and institutional support, which are necessary for a successful transition. Finally, the introduction of the group of challenges and risks allows the identification of obstacles that can limit the effectiveness of digitisation, such as high costs, regulatory barriers and lack of professional staff. This structure offers a multifaceted, well-balanced framework for applying the AHP method and determining the relative significance of various digitisation factors in the green economy. The weights for the main criteria and sub-criteria are shown on Figure 2.

Figure 2. Weights for the main criteria and sub-criteria



Source: Results of the applied AHP method. The authors used a consistent matrix based on the weights shown for the main criteria and sub-criteria

The AHP method enables monitoring of consistency at any moment in the process of comparing pairs of criteria and sub-criteria using an index:

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad CR = \frac{CI}{RI}, \qquad (2)$$

where: CI – consistency index, CR – consistency ratio, RI – random index (matrix consistency index), n – dimension of the comparison matrix, l_{max} – maximum eigenvalue of the matrix. If CR < 0.10 is valid for the comparison matrix, the priorities of the alternatives are considered acceptable (Zhou, Q. & Du, C. 2021). while the results for l_{max}, CI, CR are displayed in Table 2.

Table 2. Monitoring consistency in the procedure of comparing pairs for groups of sub-criteria

Groups of Sub-criteria	λmax	CI	CR
T – Technological	»5.0056	»0.00139	»0.00124
E – Economic	»5.0073	»0.00183	»0.00164
O – Environmental	»5.0095	»0.00236	»0.00211
S – Social & Institutional	»5.0133	»0.00331	»0.00296
I – Challenges & Risks	»5.0082	»0.00205	»0.00183

Source: Results of the applied AHP method

Given that for the main criteria and each group of sub-criteria (indicators), CR < 0.10, the comparison matrices are consistent. Ranking indicators into groups and their interpretation are displayed in Table 3.

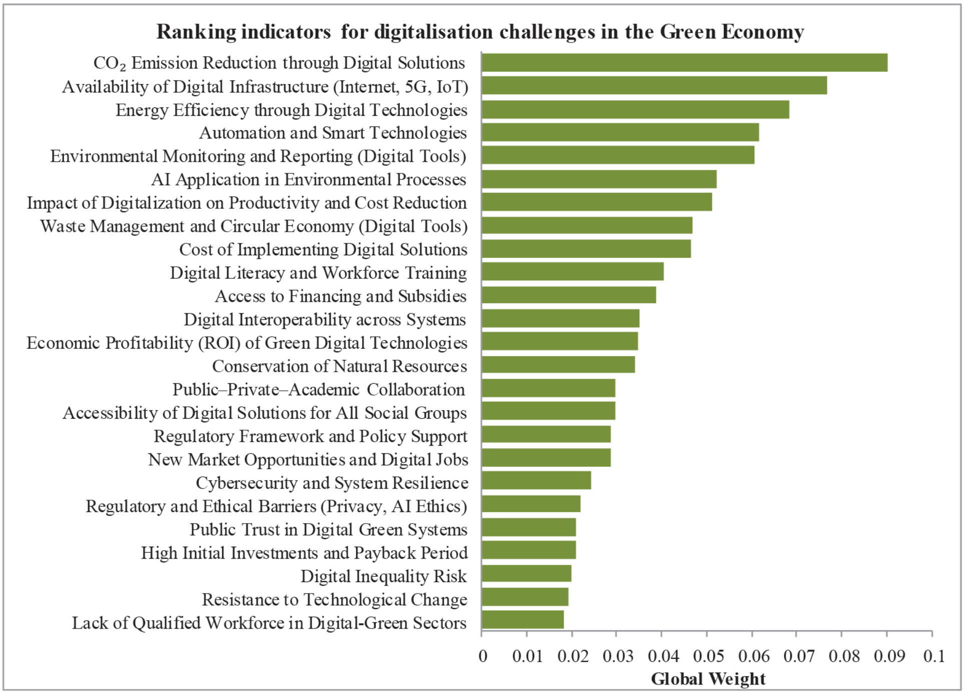
Table 3. Ranking indicators into groups and their interpretation

Rank	Group	Key Aspect	Interpretation
1–3	O – Environmental	CO_2 reduction, energy efficiency, monitoring	Main focus on measurable decarbonization effects achieved through digital solutions.
2–6	T – Technological	Infrastructure, automation, AI	Confirms that a strong digital foundation is essential for the green transition.
7–13	E – Economic	Productivity, costs, financing	Economics remain important but are secondary to environmental objectives.
10–17	S – Social and institutional	Digital literacy, collaboration, regulation	Indicates the need to strengthen human and institutional capacities.
20–25	I – Implementation challenges and risks	Ethics, investments, inequality	Shows that risks are recognized but assigned lower importance compared to positive factors.

Source: Results of the applied AHP method

Environmental and technological indicators have the highest weights - this means that digital transformation is valued most in terms of environmental impact and availability of technology. Social and inhibitory dimensions are ranked lower, which may indicate that less attention is paid to the human factor and potential obstacles in this framework. The balance between economy, ecology, technology and society is essential, but this table shows a clear priority: digital solutions that directly contribute to sustainability and reducing emissions. The final ranking of all indicators in relation to the global weight is presented in Figure 3.

Figure 3. Ranking Indicators



Source: Results of applied AHP method

3. DISCUSSION

Within the framework of the conducted analysis, a total of 25 indicators distributed in five basic categories were evaluated: environmental (O), technological (T), economic (E), social (S) and challenge indicators (I). The range of weights ranged from 0.018220 to 0.090210, with the sum of all weights being 1.0, which confirms the internal consistency of the model and the normalised approach to weight distribution. The average weighting value of 0.04 represents the threshold that separates indicators above and below average importance. Based on this, about 40% of the indicators can be considered above average importance, while the majority (60%) has a lower relative weight in the overall decision-making model. Overview of basic statistical indicators by criteria is given in Table 4. The results show that environmental indicators (O) occupy the highest place in the ranking, with an average weight of 0.05999, which emphasises that the issues of reducing CO_2 emissions, energy efficiency and preserving natural resources are key priorities of the digital-green transition.

Table 4. Overview of basic statistical indicators by criteria

Criteria	Number of Indicators	Sum of Weights	Average weight
T – Technological	5	0.29997	0.05999
E – Economic	5	0.25000	0.05000
O – Environmental	5	0.19996	0.03999
S – Social & Institutional	5	0.14993	0.02999
I – Challenges & Risks	5	0.10014	0.02003
Total	**25**	**≈1.0000**	**0.04000**

Source: Results of the applied AHP method

Technology indicators (T) with an average of 0.05000 follow immediately, which confirm the importance of the availability of digital infrastructure, automation and the application of artificial intelligence in environmental processes.

Economic indicators (E) show an average value of 0.03999, which indicates that financial aspects, although important, play a secondary role in relation to technological and environmental dimensions. Social indicators (S) with an average weight of 0.02999 and challenge indicators (I) with 0.02003 remain at the bottom of the list, although they include factors that can have a decisive impact on the success of implementation, such as digital literacy, citizen trust, and institutional support, as well as obstacles such as staff shortages and digital inequality.

Overall, the analysis confirms that environmental and technological factors are the carriers of the digital-green transition. At the same time, social dimensions and risks are underestimated in relation to their fundamental importance for long-term sustainability. This distribution of weights highlights the need for future policies and strategies that balance technological progress with the human factor, ensuring a stable and inclusive digital-green transformation.

4. CONCLUSION

In this work, the evaluation of parameters was carried out with the help of experts from the field of environmental protection, socio-economic and technical-technological sciences. Based on the conducted statistical analysis, the dominant indicators in the process of digital-green transformation are those belonging to the technological and environmental spheres. The most important weight in the model is given to indicators O1 (reduction of CO_2 emissions), T1 (availability of digital infrastructure), and O2 (energy efficiency through digital solutions). This indicates that the two main pillars of sustainable digital development are emission reduction and technological availability. The presence of indicators such as the application of artificial intelligence in ecology (T3) and savings achieved through digitisation (E4) indicates that the focus of research is still on increasing efficiency and not exclusively on achieving sustainability.

The analysis of the distribution of weight coefficients reveals a significant imbalance between different groups of indicators. Although the average weighting value is 0.04, only 40% of indicators reach or exceed that value. The majority of the rest (60%) have sub-average values, where social indicators, economic obstacles and ethical-confidential aspects stand out. This finding suggests that human factors, regulatory mechanisms and institutional resilience are to a lesser extent recognised as priorities. However, in the real context, they represent key conditions for the successful implementation of digital-green policies. It is particularly worrying that the indicators of risks and obstacles (I1–I5) are systematically underestimated in relation to the other categories. The lowest average values were recorded for indicators related to the lack of qualified personnel, resistance to change and digital inequality, which indicates insufficient understanding of the long-term challenges of digital transformation. If these risks are not addressed proactively, there is a real danger that even the most critical strategic goals, such as reducing CO_2 emissions, will remain at the declarative level without concrete results in practice.

Overall, the results indicate the need for a holistic approach to the digital-green transition, which equally values technological, economic, environmental and social aspects. Only the integrated development of all factors can ensure a stable, fair and long-term sustainable transformation towards a green economy based on digital innovation.

It is recommended that future digital-green transition strategies recognise the importance of the social component through investments in digital literacy, trust and inclusiveness, that barriers are integrated into the design of the strategy as an integral part of planning, and that technological ambitions are balanced with available human capacities.

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