



ENTROPY-BASED ENVIRONMENTAL PERFORMANCE ASSESSMENT OF EU TOURISM SYSTEMS: A DECISION SUPPORT PERSPECTIVE

Nikola Pantović
Danko Milenić
Danijela Pantović¹

Received 16.04.2026.
Revised 30.07.2026.
Accepted 20.08.2026.

Keywords:

Entropy method, Environmental performance assessment, EU tourism systems.

ABSTRACT

The EU Tourism Dashboard provides a comprehensive set of indicators for monitoring the sustainability performance of the European tourism ecosystem, supporting the green transition of tourism systems. This study focuses on the green pillar of the Dashboard and examines key environmental performance indicators, including (1) Air travel emission intensity, (2) Excellent bathing water, (3) Dependence on distant origins and (4) Tourism greenhouse gas intensity. To evaluate disparities in environmental performance across EU Member States, the study applies the entropy method as an objective sustainability assessment and decision support tool for measuring the variability and informational significance of selected indicators. The analysis covers the period from 2020 to 2023 and aims to identify patterns of divergence and convergence in the environmental performance of EU tourism systems. The findings reveal that the highest level of divergence among EU Member States is associated with dependence on distant markets. The study contributes to the development of sustainability oriented assessment frameworks and provides decision support insights for policymakers, planners and tourism stakeholders involved in the green transition of European tourism systems.



© 2026 Published by Faculty of Engineering

1. INTRODUCTION

Tourism is one of the key sectors of the European economy, but at the same time a significant source of pressure on natural resources (Stanišić et al., 2022), a local infrastructure systems (Al-Romeedy et al., 2025) and the built environment (Allwinkle & Speed, 2003; Khater et al., 2025). The intensive development of tourism activities affects the spatial organization of destinations, the load on transport and municipal infrastructure, energy and water consumption, as well as

the overall environmental performance of tourism systems. In this context, the green transition of tourism in the European Union is becoming an important segment of a broader transformation towards sustainable and circular models of development of the built environment. Contemporary policies of the European Union are increasingly aimed at reducing greenhouse gas emissions, improving resource efficiency and developing sustainable infrastructure systems. Tourism occupies a special place in that process due to its strong connection with mobility, energy consumption, spatial planning and

¹ Corresponding author: Danijela Pantović
Email: danijela.durkalic@kg.ac.rs

natural resource management. Tourist destinations can be seen as complex socio-technical systems in which natural resources, built environment, transport networks and various forms of economic activities are interconnected. Therefore, the green transition of tourism implies not only the reduction of negative impacts on the environment, but also the transformation of management models, infrastructural development and use of space in tourist regions.

In such a framework, the evaluation of the ecological performance of tourism systems becomes an important instrument for shaping sustainable development policies and making decisions based on data. The EU Tourism Dashboard represents an important analytical and monitoring framework for monitoring the various dimensions of tourism sustainability in the European Union member states, enabling a comparative assessment of performance and the identification of key challenges in the green transition process.

Starting from this perspective, the paper analyzes the indicators of the green pillar of the EU Tourism Dashboard with the aim of assessing the environmental performance of tourism systems in the member states of the European Union. Special attention is paid to indicators that reflect emissions related to tourist mobility, energy intensity, quality of natural resources and patterns of tourist demand, since these factors directly affect the sustainability of the built environment and the development of circular models of management of tourist areas. The research uses the entropy method as an objective tool for evaluating the variability of indicators and supporting sustainable decision-making in the process of the green transition of European tourism.

2. LITERATURE REVIEW

Contemporary literature increasingly views tourism as a complex socio-technical system in which natural resources, the built environment, infrastructure networks and various forms of economic activities are interconnected. Within the European Union's industrial ecosystem approach, the tourism ecosystem includes interconnected value chains, transport systems, energy infrastructure and spatial development patterns that have a significant impact on the sustainability of tourist regions (Hillebrand, 2022; Polukhina et al., 2024). Such an approach indicates the need for an integrated view of tourism through the perspective of sustainability, infrastructural development and resource management.

In recent years, the number of studies analyzing the connection between tourism and climate change (Sharma et al., 2025; Gerber et al., 2025), energy efficiency (Wang, S., & Cheablam, 2025), greenhouse gas emissions (Driha et al., 2025; Segarra et al., 2026) and the transformation of the built environment (Ciampa et al., 2025; Li et al., 2025) has been growing. Numerous

studies indicate that tourist mobility, especially air traffic, is one of the dominant sources of emissions associated with tourist activities, while at the same time the development of tourist infrastructure increases the pressure on water resources, energy consumption and spatial capacities of destinations. That is why the green transition of tourism is increasingly associated with the concepts of sustainable mobility, resource efficiency, circular economy and sustainable management of the built environment.

In addition, recent research emphasizes the importance of sustainability indicator systems for monitoring the performance of tourism systems (Đurić et al., 2025; Pereira et al., 2025) and supporting the decision-making process (Schianetz & Kavanagh, 2008; Font et al., 2023). In this context, the EU Tourism Dashboard represents an important framework for monitoring the green, digital and socio-economic dimensions of tourism development in the member states of the European Union. Its indicators enable a comparative assessment of the performance of tourism systems and the identification of key challenges in the green transition process, especially in the areas of mobility, resource management and environmental quality.

Although there is a growing number of researches on the sustainability of tourism, there is a relatively limited number of studies that systematically analyze the environmental performance indicators of tourism at the European Union level and relate them to the implications for a sustainable and circular built environment. In particular, the application of quantitative methods for assessing the variability and relative importance of tourism sustainability indicators in comparative analyzes among EU member states is insufficiently researched.

Although there is a growing number of researches on the sustainability of tourism, there is a relatively limited number of studies that systematically analyze the environmental performance indicators of tourism at the European Union level and relate them to the implications for a sustainable and circular built environment (Rios et al., 2021). In particular, the application of quantitative methods for assessing the variability and relative importance of tourism sustainability indicators in comparative analyzes among EU member states is insufficiently researched.

In this context, the entropy method represents an important analytical and decision-support tool for the objective assessment of the distribution and information value of sustainability indicators (Ding et al., 2016; Guo et al., 2024; Yin et al., 2025). The application of the entropy method enables the identification of indicators with the highest degree of divergence among the observed systems, which ensures a more accurate evaluation of ecological performance and support for the sustainable management of tourism systems.

Starting from the identified research gaps, this paper complements the existing literature through a systematic and comparative analysis of the indicators of the green pillar of the EU Tourism Dashboard at the level of all member states of the European Union. Unlike previous research, which mainly focuses on individual aspects of tourism sustainability or partial analysis of environmental indicators, in this paper the ecological performance of tourist systems is viewed through an integrated framework that connects tourist mobility, resource management and characteristics of the built environment.

An additional contribution of the paper is reflected in the application of the entropy method as an objective analytical and decision-support tool for evaluating the variability and relative importance of sustainability indicators, which enables a more precise overview of the differences in the twin transition process among EU member states (Garay-Tamajón & Torrent-Sellens, 2025). In this way, the research contributes to the development of approaches for evaluating the ecological performance of tourism systems and provides a basis for shaping policies for the sustainable and circular development of tourist regions.

3. METHODOLOGY AND DATA

3.1. Data used

Table 1 shows the indicators used in the survey for the period 2019–2023, together with their labels, units of measure and data source. All indicators are taken from the EU Tourism Dashboard and refer to the indicators of the green pillar Tourism Dashboard. The selected time period includes years for which fully available and comparable data are available for all member states of the European Union, in order to achieve a consistent and reliable comparative analysis of the analyzed indicators.

Table 1. Used indicators and data source (2019-2023)

Name of the indicator	Code	Unit of measure	Data sources
Air travel emission intensity	ATEI	kg CO ₂ per passenger	EU Tourism Dashboard
Excellent bathing water	EBW	%	
Dependence on distant origins	DDO	%	
Tourism GHG intensity	TGHG	tonnes CO ₂ -eq / Million EUR	

Source: European Commission (n.d.).

3.2. Tools and techniques

This study employs a quantitative methodological framework based on the entropy method for the assessment of environmental performance disparities among EU tourism systems. Following Czyż & Hauke

(2015), the entropy method is applied as an objective sustainability assessment and decision-support tool for evaluating the variability and informational significance of selected indicators across EU Member States.

The methodological approach is grounded in Shannon's entropy theory (1948), which assumes that indicators with greater variability contain a higher level of information, while more homogeneous distributions provide less discriminative value. In the context of sustainability assessment, the entropy method enables the identification of indicators that contribute most significantly to differentiating environmental performance among observed tourism systems.

The application of the entropy method in this study supports a comparative evaluation of green tourism indicators by objectively measuring the degree of divergence among EU Member States. Such an approach provides a reliable analytical basis for environmental performance assessment and contributes to evidence-based decision-making in the process of green transition and sustainable tourism system management.

Mathematically, entropy can be expressed as:

$$H(x) = - \sum_{i=1}^n p(x_i) \log p(x_i)$$

Or

$$H(x) = \sum_{i=1}^n p(x_i) \log_2 \frac{1}{p(x_i)}$$

The entropy statistic $H(x)$ used in this study represents a measure of uniformity in the distribution of a given indicator and serves as the foundation for calculating the inequality measure $I(x)$. In the context of Green Pillar, $I(x)$ reflect the differences in the values of the selected performance parameters.

This measure of inequality is particularly useful for analysing spatial disparities among countries or regions and can be expressed by the following equation:

$$\begin{aligned} I(x) &= H(x)_{max} - H(x) \\ &= \log_2 n - \sum_{i=1}^n p(x_i) \log_2 \frac{1}{p(x_i)} \\ &= \sum_{i=1}^n p(x_i) \log_2 [n p(x_i)] \end{aligned}$$

For

$$0 \leq I(x) \leq \log_2 n$$

where $I(x) = 0$ indicates the absence of inequality (or uniform distribution), while

$I(x) = \log_2 n$ indicates the maximum non-uniformity of the selected parameters x .

The entropy values are then used to determine the weights of indicators for aggregation: lower entropy indicates higher variability and thus greater importance in the composite measure. This method provides an objective way to account for differences in the distribution of indicators among EU member states.

4. RESULTS

This part of the paper presents the results of a descriptive and comparative analysis of selected indicators of the green pillar of the EU Tourism Dashboard for the member states of the European Union.

Table 2 shows the average values of selected indicators for the EU member states in the period from 2019 to 2023, which enables insight into general trends and changes in the observed dimensions of tourism sustainability. The analysis of average values indicates significant changes in certain indicators, especially during the period of the COVID-19 pandemic and the gradual recovery of the tourism sector. Air travel emission intensity (ATEI) shows a sharp increase in 2020 and 2021 compared to 2019, followed by a decline in 2022 and 2023, when values approach pre-pandemic levels. This trend can be associated with changes in the volume and structure of air traffic (Zhang et al., 2025) during the pandemic and the gradual normalization of tourist flows (Shi et al., 2026).

Table 2. Average values of selected indicators

Indicator	2019	2020	2021	2022	2023
ATEI	80.61481	129.493	126.6626	82.95037	76.73259
EBW	85.19667	84.0263	84.66	84.98333	84.2037
DDO	12.34	6.374074	5.805926	10.53704	12.12556
TGHG	72.87815	89.80185	76.50926	59.76519	55.39

Source: Authors

The proportion of excellent bathing water (EBW) remains relatively stable throughout the period, with values around 84–85%, indicating a high and uniform level of bathing water quality in the EU member states.

The indicator of dependence on distant tourism markets (DDO) shows a pronounced decline in 2020 and 2021, reflecting the restrictions on international travel during the pandemic. After that, there is a recovery, so the values in 2023 again approach the level of 2019.

On the other hand, the intensity of greenhouse gas emissions in tourism (TGHG) shows a continuous decline after 2020, which may indicate a gradual reduction in the emission intensity of tourism activities and potential shifts towards more sustainable patterns of tourism consumption and resource management. These trends provide an important context for further analysis of divergence (convergence) and relative importance of indicators within the application of the entropy method.

Table 3 shows the entropy values for the analyzed indicators in the period from 2019 to 2023. Within the entropy method, higher values indicate greater uniformity in the distribution of indicators among countries, while lower values indicate greater variability and more pronounced differences between the observed countries.

Table 3. Entropy of selected indicators

Indicator	2019	2020	2021	2022	2023
ATEI	0.0988740	0.0805542	0.0892117	0.0471805	0.0497754
EBW	0.0114586	0.0139006	0.0117490	0.0097052	0.0105072
DDO	0.4549332	0.9996602	0.9444117	0.7865695	0.6516957
TGHG	0.127621	0.195314	0.164183	0.158101	0.166229

Source: Authors

The results show that aviation emission intensity (ATEI) records relatively low entropy values throughout the entire period, with a particularly low level in 2022 and 2023. This indicates significant differences among EU member states in terms of aviation-related emissions, which may be related to different levels of dependence on air transport in the tourism sector.

The indicator of the share of excellent quality bathing water (EBW) has the lowest entropy values compared to other indicators. This result suggests a relatively stable distribution and less variability among countries, which indicates a uniform level of bathing water quality in the EU.

In contrast, dependence on distant tourism markets (DDO) shows the highest entropy values, especially during 2020 and 2021, when it reaches almost maximum values. This indicates a high uniformity among countries in terms of reduced dependence on distant markets during the pandemic, when international travel was significantly restricted. After that, there is a gradual decrease in entropy, which indicates the reappearance of differences between countries in the structure of tourist arrivals.

The intensity of greenhouse gas emissions in tourism (TGHG) shows moderate entropy values during the observed period, with a slight increase after 2020. This result indicates a certain level of similarity between countries in terms of emission intensity of tourism, but also the presence of differences that may be related to different models of tourism development and energy efficiency of tourism activities.

The Figure 1 shows a parallel overview of average indicator values (solid lines on the secondary axis) and entropy values (dashed lines on the primary axis) for the period 2019–2023. This approach allows for the simultaneous observation of changes in the overall level of observed indicators in the EU, as well as changes in their distribution among member states. Combining these two aspects is particularly important for understanding the dynamics of the transition towards a sustainable and circular built environment, as it indicates not only the direction of changes but also the degree of their spatial uniformity.

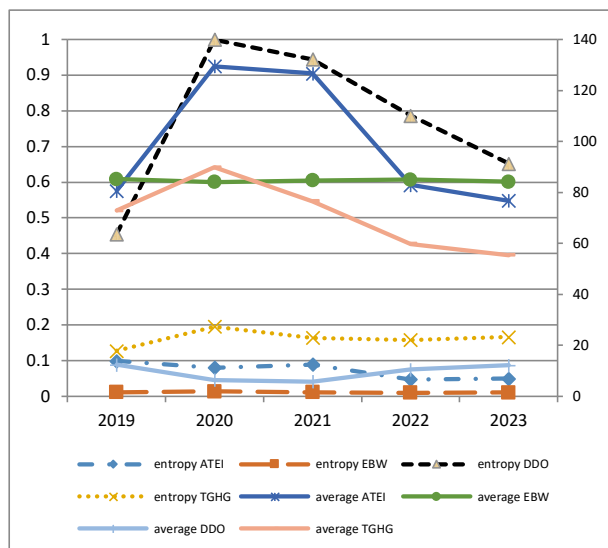


Figure 1. Final average and entropy results

The ATEI indicator shows a sharp increase in average values in 2020 and 2021, followed by a decrease in 2022 and 2023. At the same time, the entropy of this indicator is decreasing, which indicates increasingly pronounced differences between member states in terms of emissions related to aviation. These results indicate different patterns of reliance on air transport in tourism, which has significant implications for planning sustainable mobility and reducing emissions in tourism-intensive regions.

The EBW indicator shows stable average values throughout the entire period, while the entropy values are very low and almost unchanged. This indicates a relatively uniform and high level of bathing water quality in the EU, which represents an important basis for the sustainable management of natural resources and the preservation of ecological components of the built environment in tourist destinations.

The DDO indicator shows a significant drop in the average value during 2020 and 2021, with a gradual recovery in the following period. In parallel, entropy rises sharply in 2020 and reaches the highest level among all indicators, indicating a high uniformity among countries in terms of reduced dependence on distant markets during the pandemic. In the context of sustainable and circular development, this indicator indicates the potential of strengthening regional and local tourist flows, which can contribute to the reduction of transport emissions and more sustainable use of space.

TGHG shows a continuous decline in average values after 2020, while entropy remains at moderate levels. This suggests a gradual reduction in the emission intensity of tourism activities in the EU, but also the existence of differences between countries in terms of the efficiency of resource use and the energy structure of the tourism sector.

4. CONCLUSION

This research analyzed the indicators of the green pillar of the EU Tourism Dashboard in the period 2020-2023 with the aim of assessing the environmental performance of the tourism systems of the European Union member states and looking at their implications for the transition to a sustainable and circular built environment. The application of the entropy method enabled an objective assessment of the variability and relative importance of the observed indicators, providing an analytical framework for the comparative evaluation of environmental performance among EU member states.

The research results show that certain indicators, especially the quality of bathing water, show a relatively high level of stability and homogeneity among the member states, which points to a significant degree of conservation of key natural resources relevant to the sustainability of tourist areas. At the same time, indicators related to tourist mobility, greenhouse gas emissions and energy intensity show more pronounced divergences, reflecting differences in infrastructure systems, mobility patterns and tourism development models among EU member states.

The obtained results confirm the importance of integrating the green performance of tourism in the processes of spatial planning, development of sustainable infrastructure and management of tourist regions. The need to link policies of sustainable mobility, energy efficiency, natural resource management and the development of circular models of space use is particularly emphasized, since these elements represent key components of a sustainable built environment in tourist intensive areas.

The contribution of the research is reflected in the application of the entropy method as an objective sustainability assessment and decision-support tool for evaluating the green performance of tourism systems at the level of the European Union. In this way, the paper contributes to the development of quantitative approaches for assessing the sustainability of tourism and provides a basis for shaping policies based on data in the process of the green transition of European tourism.

The research is limited by the availability and time coverage of EU Tourism Dashboard data, which is a relatively new framework for monitoring the sustainability of tourism systems. The analysis is focused exclusively on the indicators of the green pillar, while the digital and socio-economic dimensions of the tourism ecosystem are not included in the research. In addition, the entropy method enables an objective assessment of the variability of indicators, but does not explain the cause-and-effect relationships between the observed factors.

Acknowledgement: This research is supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia by the Decision on the scientific research funding for teaching staff at the accredited higher education institutions in 2026 (No.

451-03-34/2026-03/200375 of February 5, 2026) and the bilateral research project “Green Tourism without Borders: Strengthening Sustainability in the Hospitality Industry of Serbia and Slovakia (GRH-CAP)”, project number 001147721/001.

References:

- Allwinkle, S. S., & Speed, C. E. (2003). Sustainability and the built environment: tourism impacts. In *Evaluation of the Built Environment for Sustainability* (pp. 268-280). Taylor & Francis.
- Al-Romeedy, B. S., Hussein, H., & Singh, A. (2025). Peaks and Valleys: Navigating Over-Tourism in Mountain Destinations. In *Balancing Mountain Tourism, Cultural Heritage, and Environmental Stability* (pp. 431-444). IGI Global Scientific Publishing.
- Ciampa, F., Marchiano, G., Girard, L. F., & Angrisano, M. (2025). The rural village regeneration for the European built environment: from good practices towards a conceptual model. *Sustainability*, 17(7), 2787.
- Czyż, T., & Hauke, J. (2015). Entropy in regional analysis. *Quaestiones Geographicae*, 34(4), 69-78. <https://doi.org/10.1515/quageo-2015-0037>
- Ding, L., Shao, Z., Zhang, H., Xu, C., & Wu, D. (2016). A comprehensive evaluation of urban sustainable development in China based on the TOPSIS-entropy method. *Sustainability*, 8(8), 746.
- Driha, O. M., Cascetta, F., Nardini, S., & Bianco, V. (2025). Decomposition and decoupling analysis of carbon emissions of the EU tourism sector. *Science of the Total Environment*, 994, 180075.
- Đurić, Z., Cvijanović, D., Petek, V., & Potočnik Topler, J. (2025). Sustainability struggle: Challenges and issues in managing sustainability and environmental protection in local tourism destinations practices—An overview. *Sustainability*, 17(15), 7134.
- European Commission (n.d.). *EU Tourism Dashboard*. Retrieved February 1, 2026, from <https://tourism-dashboard.ec.europa.eu/?lng=en&ctx=tourism>.
- Font, X., Torres-Delgado, A., Crabolu, G., Palomo Martinez, J., Kantanbacher, J., & Miller, G. (2023). The impact of sustainable tourism indicators on destination competitiveness: The European Tourism Indicator System. *Journal of Sustainable Tourism*, 31(7), 1608-1630.
- Garay-Tamajón, L. A., & Torrent-Sellens, J. (2025). Introduction to sustainable and digital transitions in tourism. In *A Research Agenda for Tourism, Digitalisation and Sustainability* (pp. 3-24). Edward Elgar Publishing.
- Gerber, E., Fournier, J., Salim, E., Fragnière, E., & Kebir, L. (2025). Systems thinking to adapt tourism to climate change: Application to summer glacier skiing in Switzerland. *Annals of Tourism Research Empirical Insights*, 6(1), 100172.
- Guo, Y., Yu, J., Zhu, Y., & Zhang, H. (2024). Research on tourism ecological safety evaluation of Huizhou Cultural and ecological reserve based on entropy-TOPSIS. *Heliyon*, 10(2).
- Hillebrand, B. (2022). An ecosystem perspective on tourism: The implications for tourism organizations. *International Journal of Tourism Research*, 24(4), 517-524. <https://doi.org/10.1002/jtr.2518>
- Khater, M., Ibrahim, O., Sayed, M. N. E., & Faik, M. (2025). Legal frameworks for sustainable tourism: Balancing environmental conservation and economic development. *Current Issues in Tourism*, 28(22), 3693-3714.
- Li, Y., Ye, J., Li, Z., Zhu, M., & Li, Y. (2025). Impact of built environment on commuting carbon emissions using big data: a case study of Jinan's main urban area. *Scientific Reports*, 15(1), 16875.
- Pereira, L. N., Muhs, C., Andraz, J., Nunes, R., Lança, M., & Silva, J. A. (2025). An assessment model of the Algarve as a sustainable tourism destination: A conceptual framework. *Tourism Planning & Development*, 22(3), 367-386.
- Polukhina, A., Sheresheva, M., Napolskikh, D., & Lezhnin, V. (2024). Regional Tourism Ecosystem as a Tool for Sustainable Development during the Economic Crisis. *Sustainability*, 16(2), 884. <https://doi.org/10.3390/su16020884>
- Rios, A. M., & Picazo-Tadeo, A. J. (2021). Measuring environmental performance in the treatment of municipal solid waste: The case of the European Union-28. *Ecological Indicators*, 123, 107328.
- Schianetz, K., & Kavanagh, L. (2008). Sustainability indicators for tourism destinations: A complex adaptive systems approach using systemic indicator systems. *Journal of sustainable tourism*, 16(6), 601-628.
- Segarra, V., Brida, J. G., & Cárdenas-García, P. J. (2026). On the relationships between tourism demand, carbon dioxide emissions and economic growth: a literature review. *Journal of Policy Research in Tourism, Leisure and Events*, 18(1), 236-277.
- Shannon, C. E. (1948). A mathematical theory of communication. *The Bell system technical journal*, 27(3), 379-423.
- Sharma, G. D., Taheri, B., Chopra, R., & Parihar, J. S. (2025). Relationship between climate change and tourism: an integrative review. *The Service Industries Journal*, 45(3-4), 426-453.

- Shi, W., Liu, J., Zhai, C., & Yang, W. (2026). Unveiling the Dynamics of Urban Tourism Flows: Network Evolution and its Determinants in Shanghai, China. *Applied Spatial Analysis and Policy*, 19(1), 42.
- Stanišić, T., Milićević, S., & Krstić, B. (2022). Natural resources in function of sustainable and competitive tourism development of the EU countries. *Problemy ekorozwoju – problems of sustainable development*, 17(1), 64-70. <https://doi.org/10.35784/pe.2022.1.06>
- Wang, S., & Cheablam, O. (2025). Sustainable tourism and its environmental and economic impacts: Fresh evidence from major tourism hubs. *Sustainability*, 17(11), 5058.
- Yin, Y., Song, C., Jing, Y., Zhang, S., Ye, S., Wang, Y., & Gao, P. (2025). EWMS: A software tool for interactively using entropy weight coefficient method for aggregating sustainability indicators. *Environmental Modelling & Software*, 191, 106500.
- Zhang, L., Gong, J., & Yang, Y. (2025). How has the COVID-19 pandemic reshaped the aviation network? A comparative pre-and during-pandemic analysis. *Transport Policy*, 160, 228-244.

Nikola Pantović

CrossRoad Adria,
Belgrade,
Serbia
nikola.pantovic83@gmail.com
ORCID 0009-0003-2422-0008

Danko Milenić

Faculty of Engineering,
University of Kragujevac,
Serbia
danko_1982@yahoo.com
ORCID 0009-0004-4772-4345

Danijela Pantović

Faculty of Hotel Management and
Tourism Vrnjacka Banja,
University of Kragujevac,
Serbia
danijela.durkalic@kg.ac.rs
ORCID 0000-0001-8605-8614
