AN EFFICIENCY MODEL OF A MEDIUM-SIZED ENTERPRISE AND THE TRANSFORMATION FROM A CONVENTIONAL TO A SUSTAINABLE ECOSYSTEM USING A HYBRID DEA-MCDM MODEL

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Abstract

In conditions where information and communication technologies (ICT) dictate the "rules" of the market, the strong promotion and development of innovation-oriented small and medium-sized enterprises (SMEs) are essential. The transition from a traditional, linear system of waste management and fleet management in utility companies to a digital and circular-oriented system represents not only a significant challenge, but also a necessity. This paper analyses the potential transition of a medium-sized enterprise from a conventional to a sustainable business ecosystem by examining the vehicle fleet of a utility company and proposing its optimisation using the DEA-LOGSTA-MARCOS model. The hybrid DEA-MCDM model, developed and presented in this form for the first time in the literature, represents a methodological contribution of this research. The paper analyses a fleet of utility vehicles used for waste collection and transport that are 15 years old or older. The aforementioned methods are applied to highlight the importance of operationally efficient vehicles that can potentially be integrated into a digital ecosystem (DE), thereby strengthening the company's comparative advantage. In the first stage, the DEA model was applied to determine the efficiency of the vehicles, followed by the LOGSTA method in the second stage to calculate the criteria weights, and finally, the MARCOS method to rank the vehicles according to their overall efficiency. The research results indicate that the most significant barriers to the transformation toward a digital ecosystem within the observed enterprise are regulatory, financial, and technical in nature. From the perspective of the vehicle fleet and its limiting factors, the results indicate the need for an iterative

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transformation of the fleet structure, aligned with current efficiency levels and future electrification trends. In this context, the findings identify which types of vehicles should be retained during the initial phase of the transformation.

Keywords: DEA, digital ecosystems (DE), digital transformation (DT), efficiency, financial barriers, MCDM, small and medium-sized enterprises (SMEs).

JEL Classification: C44, C55, D11, L25, L91, Q5.

Introduction

The continuous growth in the number of enterprises worldwide adopting digital business models has become an increasingly prominent focus of the academic community (Zentner, Spremic and Zentner, 2021). Studies indicate that digital transformation (DT) drives organisational changes through the integration of digital technologies, which are embedded not only in business models, but also in operational processes (Teece, 2018). In contrast, digital ecosystem (DE) theory emphasises the interconnectedness of participants, digital coordination, and improvement through systemic value validation (Marino-Romero, Palos-Sánchez and Velicia-Martín, 2024). DT establishes the prerequisites for an irreversible transformation of intangible assets, viewed through the lens of continuous improvement and business adaptation. This implies the necessity of circular interactions among human resources, technological advancements, and artificial intelligence, operating in a synchronised manner to enhance local and regional impact, while gradually achieving global visibility (Savastano et al., 2022).

The digital transformation of small and medium-sized enterprises (SMEs), especially in today’s highly turbulent business environment, represents not only an opportunity, but also a potential threat, with outcomes that should enhance not only innovation-driven SMEs but also their competitive advantage in the observed market (Restrepo-Morales et al., 2024). The sustainability of the SME sector also depends on the implementation of digital solutions in everyday business tasks, particularly due to limited financial resources and varying readiness to adopt new technologies (Verhoef et al., 2021). SMEs face numerous challenges in the adoption of digital innovations, which further reduces their ability to safely transition from a traditional to a sustainable ecosystem (Reim et al., 2022).

The countries of the Western Balkans (WB) continuously face challenges in performing everyday business activities, particularly in the provision of public utility services of general interest to all citizens. Undeveloped municipal infrastructure, the lack of modern utility vehicles, and limited logistics hinder progress toward prosperity and the accelerated transition of the sector. Globalisation and global changes lead to the *rapid development of information and communication technologies*, as well as advanced technological solutions. Developing countries must now adapt more quickly than ever to these *global trends* to maintain competitiveness in both domestic and international markets. Bosnia and Herzegovina (B&H) represents one of the Western Balkan countries with both the potential and infrastructural capacity, as well as a high level of human resource expertise, necessary for the potential implementation of the most significant infrastructure projects in the country. However, differences in political views and principles, the administrative division into two entities – the Republic of Srpska and the Federation of Bosnia and Herzegovina (RS, FB&H) – and the Brčko District, along with the presence of three constituent peoples, slow the progress not only of national-level projects but also of individual initiatives in cities and municipalities. Namely, one of the issues that is fundamentally important and requires a prompt response from all relevant stakeholders is comprehensive waste management (Duan et al., 2025) in B&H. In particular, outdated and non-competitive municipal equipment and transport infrastructure limit the overall operational efficiency and performance of utility companies.

The Green Deal (Tritto, Dias and Bassi, 2024) promotes a shift from a simple linear to a circular waste management model. Rather than merely collecting and disposing of waste at registered sanitary landfills, waste is properly separated at the household level, with the aim of ensuring adequate treatment and generating new usable value. The goal is to optimise the recovery of secondary raw materials from waste by rationalising the 3R strategy (Reduce, Reuse and Recycle), i.e., prioritising reduction and reuse over recycling (Alberich, Pansera and Hartley, 2023). The Green Agenda for the Western Balkans represents a regional strategy aligned with the European Green Deal, with primary objectives including sustainable economic development, climate neutrality, and the promotion of environmental awareness across the Western Balkan countries (Ignjatović, Filipović and Radovanović, 2024).

The subject of this study is the examination of the efficiency of a fleet composed of vehicles aged 15 years or older from a medium-sized utility company in the city of Doboj (B&H), along with an analysis of *financial, technical and regulatory barriers* that limit SMEs in their transition from traditional to sustainable, digitally oriented ecosystems. Furthermore, *the aim of the research* is to assess the efficiency of the company's utility vehicles using efficiency analysis methods such as Data Envelopment Analysis (DEA),), LOGSTA (LOGarithmic normalisation and STAndard deviation), Measurement Alternatives and Ranking According to Compromise Solution (MARCOS), and others, while also identifying the key financial, regulatory, and technical barriers that limit SMEs in their transition from conventional to digitally sustainable business models. The novelty of the conducted research has been manifested through the integration of three independent methods into one unique model. Also, measuring efficiency in order to create strategies of transformation from conventional to modern system is a novelty from national and local aspect.

There are no digital records of vehicle movements along the transport routes, nor is there coordination between the vehicle monitoring center and the collected waste quantities, for example through sensors monitoring container fill levels or optimisation of total waste collection. Therefore, it is necessary to assess the economic performance of the existing vehicle fleet (maintenance costs, fuel costs, depreciation) and to evaluate the potential economic impact on the utility company in terms of digitalising the ecosystem.

RQ1: Does the transformation from a conventional to a sustainable business ecosystem lead to significant changes in efficiency?

RQ2: Which indicators have the greatest influence on efficiency during the transition to a sustainable ecosystem?

RQ3: Does the application of a hybrid DEA-MCDM approach provide a more reliable performance evaluation compared to the use of each method individually?

The number of studies examining DT through measurable indicators in small and medium-sized utility companies in developing countries remains limited. Although a considerable body of research has addressed DT and ecosystem-related issues, very little attention has been devoted to DE of SMEs operating in the waste management sector, particularly those with outdated vehicle fleets. Existing DT studies have predominantly focused on large business systems and developed countries (Savastano et al., 2024).

1. Review of the scientific literature

According to Jacobides, Cennamo and Gawer, (2018), a digital ecosystem (DE) represents a specific strategic and infrastructural context in which SMEs operate, facilitating the integration of resources, technologically advanced platforms, and coordinated interaction among participants. The organisational and digital capabilities of SMEs operating within this ecosystem, including dynamic capabilities for resource reconfiguration and business model innovation (Bresciani et al., 2021), act as mediators in the transition from a conventional to a sustainable business model (Merín-Rodrigáñez, Dasí and Alegre, 2024). Furthermore, the digital transformation (DT) of SMEs implies fundamental organisational changes based on the integration of digital technologies, including the adaptation of business policies and the restructuring of business models (Ghobakhloo and Ching, 2019).

The exchange of knowledge regarding technological and organisational improvements through digital communication channels contributes to the development of sustainable business models, particularly for innovation-oriented SMEs (Kahveci, 2025). Moreover, digital ecosystems (DE) support SMEs in overcoming barriers to digitalisation, especially in contexts of limited digital skills and collaboration through networking or clustering (Hu, Filipescu and Pergelova, 2024). According to Korosteleva, Mickiewicz and Parrilli (2025), SMEs contribute to employment growth and the continuous creation of new jobs, a process facilitated by business digitalisation and innovation.

Digital efficiency in SMEs (Crupi et al., 2020) can be understood as the transition from so-called manual to electronic processes, with the specific aim of accelerating business operationalisation, optimising resources and ensuring long-term business sustainability (Vial, 2019). It is widely recognised that global economic trends are increasingly based on knowledge and new technological achievements; therefore, the digitalisation of daily business operations has become essential for the SME sector (Kraus et al., 2019). On the other hand, research (Minh et al., 2025) has shown that SMEs lag behind large enterprises in terms of innovation, and technological and digital progress. Although SMEs play a key role in global economic flows, they face certain limitations in adopting new technologies, primarily due to a lack of knowledge and skills, as well as the growing digital challenges they encounter (Meier, 2021). However, to keep pace with global trends, SMEs face an urgent need for action (Ali et al., 2022). This highlights the necessity of SMEs to step out of their "comfort zone" and actively engage in accelerated global processes, especially today when artificial intelligence (AI) is intensively applied in all areas of business (Forsman, 2021). According to Warner and Wäger (2019), SMEs operating in the sector of municipal services have a greater potential for rapid adaptation in turbulent business environments compared to large business systems. This adaptability significantly facilitates faster integration under conditions of intense globalisation and continuous change, representing a potential long-term opportunity for success. Operational efficiency further enhances this potential, as the application of DAE and MCDM methods enables the assessment of technical efficiency and the ranking of alternative strategies using a multiple-criteria method (Pajić, Andrejić and Kilibarda, 2025). Accordingly, the identified gap, arising from the insufficient integration of digital ecosystem (DE) theory, SME digital transformation (DT), and sustainability, can be addressed through a conceptual framework that links ecosystem integration, organisational and digital capabilities, and operational business sustainability.

Digital transformation (DT) does not merely involve virtual changes; it also implies the creation of new value and the growth of revenue (Kraus et al., 2021). On the other hand, Lokuge and Duan (2022) have shown that a lack of financial resources, a shortage of qualified personnel familiar with digital tools, and the exceptionally high costs of investment represent significant *financial barriers* for SMEs to enter DE. This further implies that the high costs associated with modernising infrastructure in the domain of utility companies – particularly investments in software to support innovation and optimise business processes – pose an even greater challenge. In developing countries, these companies often operate with outdated vehicle fleets and municipal infrastructure, making it particularly difficult to “reshape” them into digital systems (DS). Consequently, the lack of internal capital, combined with limited access to external financing (Kirschenmann, 2016) and high investment costs, contributes to the partial adoption of digitalisation within the SME sector, which further leads to reduced participation of this sector in DE (Manso Laso, Moya-Clemente and Ribes Giner, 2025). On the other hand, the costs associated with maintaining DS and upgrading software impose an even greater financial burden on the SME sector, particularly in the absence of government subsidies, tax incentives, or other forms of support (Martinez, Guercio and Bariviera, 2022). Consequently, these financial constraints can create long-term sustainability challenges for SMEs within DE if planning is not carried out carefully, in a detailed and methodical manner at the level of each individual country (Sanga and Aziakpono, 2023).

Research by Brink and Packmohr (2023) has shown that most SMEs lack developed technical support, infrastructure, and digital platforms compared to large business systems, which limits their ability to successfully integrate into DE. In addition, insufficient knowledge and skills in the domains of digitalisation and digital technologies among human resources hinder the adoption and implementation of digital expertise, representing *technical barriers* for SMEs (Santos and Neumeyer, 2023). These technical limitations are not only infrastructural; they also reflect the capability of SMEs to protect DS (Cheenepalli et al., 2025). Addressing these technical barriers requires continuous investment in both human resources and technology to ensure long-term sustainability (Rampaul, 2025). On the other hand, the introduction of advanced technologies into business systems generates uncertainty for SMEs due to their limited capacities and the shortage of skilled personnel (Ingaldi and Ulewicz, 2025). Therefore, medium-sized enterprises, in particular, should seize opportunities to invest in intangible and technical resources to internationalise their operations and achieve global competitiveness (González-Varona et al., 2021). This further implies establishing spin-offs with scientific institutes or collaborations with academic researchers, supported by increased financial investment in the digital upskilling of professional staff (Omowole et al., 2024). Furthermore, *regulatory barriers* may represent the key obstacle to the transformation of digitally advanced SMEs and their integration in DE. The lack of legal procedures, highly complex administrative processes, and insufficient vertical communication across national, municipal, city, or regional policy levels reduce the ability of SMEs to achieve a “global connection” in terms of digital literacy and maturity with other large business systems (Liu, 2023). Uneven legal requirements, information security, and data protection are among the elements that impose significant financial demands, particularly for enterprises with limited access to funding, such as SMEs (de Mattos et al., 2023). Research by Rupeika-Apoga and Petrovska (2022) has shown that SMEs do not receive sufficiently strong state incentives to digitise their business activities, which, in the long term, further widens the gap between SMEs and large enterprises. From the above, it is evident that institutional and regulatory support plays a crucial role in the potential success or even failure of SMEs (Yang, Likai and Ruoyu, 2022).

The proposed integrated DEA-LOGSTA-MARCOS model enriches the entire field of decision-making and efficiency field in such a way that such model can be applied in similar studies with no limitations of areas of action. Also, such a model can be applied on different inputs and outputs. Compared to other available studies that employ similar methodology, this paper brings out the importance of inputs/outputs obtained in an objective way.

2. Methods

This section presents in detail the steps and equations that constitute the applied methodology, which consists of the DEA, LOGSTA, and MARCOS methods.

2.1. DEA

The DEA CCR model (Charnes et al., 1994; Andrejić and Pajić, 2024; Huskanović, Bjelić, and Novarlić, 2024; Pajić, Andrejić and Kilibarda, 2025) is formed for determining vehicle fleet efficiency:

$$\begin{aligned}
&DEA_{input} = \max \sum_{i=1}^{m} w_i x_{i-input} \\
&st: \\
&\sum_{i=1}^{m} w_i x_{ij} - \sum_{i=m+1}^{m+s} w_i y_{ij} \le 0, \quad j = 1,...,n \\
&\sum_{i=m+1}^{m+s} w_i y_{i-output} = 1 \\
&w_i \ge 0, \quad i = 1,...,m+s
\end{aligned} \tag{1}$$

where the Decision-Making Unit (DMU) includes *m* inputs for x_{ij}, while *s* denotes outputs for y_{ij}.

2.2. LOGSTA (LOGarithmic normalisation and STAndard deviation) method

This method, proposed by Stević et al. (2025), refers to the objective determination of the weighting coefficients. It is presented through the following steps:

Step 1: The initial decision matrix *Z* is created for *n* alternatives and *m* criteria.

$$Z = \left[z_{ij} \right]_{n \times m} \tag{2}$$

where z_{ij} marks the value of alternative *i* per criterion *j*.

Step 2: Logarithmic normalisation is performed. Eq. (4) is used for benefit (B), while Eq. (5) is used for cost (C) criteria.

$$N = \left[n_{ij} \right]_{n \times m} \tag{3}$$

$$n_{ij} = \left| \frac{\ln z_{ij}}{\ln\left(\prod_{i=1}^{n} z_{ij} \right)} \right|, \quad j \in B \tag{4}$$

$$n_{ij} = \left| \frac{1 - \frac{\ln z_{ij}}{\ln\left(\prod_{i=1}^{n} z_{ij} \right)}}{n-1} \right|, \quad j \in C \tag{5}$$

Step 3: The matrix *G* is calculated as follows:

$$G = \left[g_j \right]_{1 \times m} \tag{6}$$

$$g_j = \sigma_j \times \left(\left| \sum_{i=1}^{n} \left(\ln\left(n_{ij} \right) \right) \right| \right)^{-1} \tag{7}$$

Step 4: The final criterion weights w_j are obtained using Eq. (8):

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{8}$$

2.3. MARCOS method

The MARCOS method belongs to the field of MCDM and is designed to rank potential solutions. The procedure is carried out through the following steps (Stević et al., 2020; Blagojević et al., 2025):

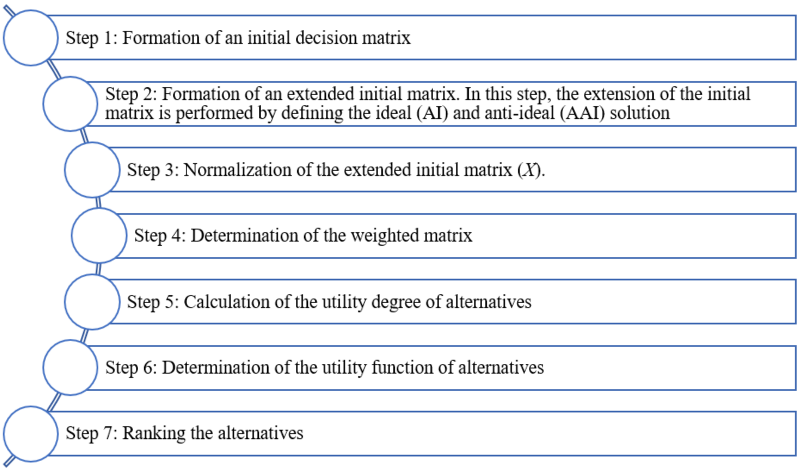

Figure no. 1. MARCOS algorithm

3. Assessment of vehicle fleet efficiency using DEA

In this case study, the vehicle fleet of the utility company Progres JSC from Doboj (B&H) is analysed. The company operates a total of 10 utility vehicles, but only five are included in the detailed analysis. All vehicles are equipped with internal combustion engines (ICE) compliant with the EUR 3 class and are powered by diesel fuel. The analysis includes four garbage trucks manufactured by MAN and one manufactured by IVECO. These vehicles service the entire territory of the city of Doboj (13,530 households and 1,218 business entities) in the process of municipal waste collection and transportation. The vehicles included in the analysis are as follows: 1. MAN M34-J-372 (model year 2004; payload capacity 10,750 kg; 412,710 km travelled); 2. MAN E26-A-502 (model year 2003; payload capacity 11,450 kg; 648,673 km travelled); 3. MAN T32-J-339 (model year 2003; payload capacity 10,425 kg; 267,864 km travelled); 4. IVECO K01-A-552 (model year 2003; payload capacity 10,750 kg; 417,619 km travelled); and 5. MAN 058-T-914 (model year 2009; payload capacity 9,150 kg; 544,713 km travelled). On average, each truck consumes approximately 55 litres of fuel per day. Route length and vehicle activity depend not only on operational requirements and unforeseen circumstances but also on the duplication of transport routes caused by improper waste disposal by irresponsible individuals and groups, as well as insufficient public awareness regarding proper waste disposal. These vehicles are used on a daily basis, while the remaining vehicles are operated only occasionally, which justifies the selection of five vehicles for detailed analysis. In order to determine the efficiency of the company's existing vehicle fleet by years of operation, and to identify opportunities for more cost-effective performance, DEA was applied using two different models, incorporating 5-2 and 3-2 input-output ratios, respectively. The evaluation of efficiency based on a sample of five vehicles is intended to serve as a benchmark analysis for other utility companies in Bosnia and Herzegovina, as this company is recognised as one of the best organised in the sector and demonstrates a clear commitment to adopting sustainable practices within the shortest possible time frame. First, a model was applied with the following five inputs: fuel costs, regular and extraordinary maintenance costs, the number of all minor accidents and damages involving the vehicles, and the number of days the vehicle was out of service. The model includes two outputs: the percentage (%) of cargo capacity utilisation and the vehicle performance rate, which reflects the time utilisation of the vehicles. The model consisting of 3 inputs and 2 outputs differs from the previously described model in that all cost-related variables are aggregated into a single input. DMUs have been defined as combinations of vehicle types and their years of operation to assess individual efficiency, which can be correlated with specific tasks over the observed period. The analysis of the vehicle fleet covers the years 2020-2024. The results of the DEA model are presented in Table 1.

Table no. 1. Vehicle fleet efficiency based on 5-2 and 3-2 input-output parameter ratios

	I_1	I_2	I_3	O_1	O_2	5-2	3-2
DMU1	69151	3	20	0.82	0.83	0.693	0.531
DMU2	65711	4	12	0.82	0.84	0.834	0.726
DMU3	67782	7	8	0.87	0.83	1.000	0.945
...	...						
DMU7	40092	2	8	0.89	0.72	1.000	1.000
...	...						
DMU15	24048	1	12	0.81	0.85	1.000	1.000
DMU16	44045	6	8	0.81	0.88	1.000	1.000
DMU17	44550	4	14	0.81	0.83	0.907	0.714

	I_1	I_2	I_3	O_1	O_2	5-2	3-2
DMU18	44095	3	9	0.86	0.86	1.000	1.000
DMU19	37195	6	7	0.88	0.77	1.000	1.000
DMU25	24048	1	15	0.75	0.85	1.000	1.000

Source: Author's calculation

The obtained results indicate the efficiency of vehicles used for the collection and transport of municipal waste, analysed by years of service. A total of 14 DMUs received a value of 1.00, implying efficiency in task performance and economic benefit to the company. However, a more detailed analysis is necessary to obtain more precise values and to enable the formulation of future strategies regarding the development of a hybrid fleet and the reduction of negative environmental impact. For this reason, a re-modelling with three inputs and two outputs was performed, with the results presented in the last column showing the efficiency of the fleet by years of service for only six DMUs.

2.5. Integrated LOGSTA-MARCOS model for evaluating six efficient DMUs

The initial matrix, which serves as the basis for determining criterion weights using the LOGSTA method, is presented in Table 2.

Table no. 2. Initial matrix

	C1	C2	C3	C4	C5
DMU7	40092	2	8	0.89	0.72
DMU15	24048	1	12	0.81	0.85
DMU16	44045	6	8	0.81	0.88
DMU18	44095	3	9	0.86	0.86
DMU19	37195	6	7	0.88	0.77
DMU25	24048	1	15	0.75	0.85

Source: Author's calculation

It is important to note that, in this model, the criteria correspond to the inputs and outputs previously described in the 3-2 ratio. Furthermore, the first three criteria belong to the group that should be minimised, while the fourth and fifth criteria tend to and prefer maximum values. By applying the LOGSTA method, the values of the weighting coefficients were determined as follows: C1 = 0.060, C2 = 0.193, C3 = 0.028, C4 = 0.365 and C5 = 0.409, resulting in the ranking order C5>C4>C2>C3>C1. The complete MARCOS algorithm was then applied to obtain the final results, which are presented in Table 3.

Table no. 3. Evaluation of the most efficient DMUs using the MARCOS method

	Si	Ki-	Ki+	fK-	fK+	fKi	Rank
AAI	0.691						
DMU7	0.825	1.193	0.825	0.409	0.591	0.643	4
DMU15	0.941	1.362	0.941	0.409	0.591	0.734	1
DMU16	0.801	1.160	0.801	0.409	0.591	0.625	5
DMU18	0.841	1.218	0.841	0.409	0.591	0.656	3
DMU19	0.784	1.135	0.784	0.409	0.591	0.611	6
DMU25	0.916	1.326	0.916	0.409	0.591	0.714	2
AI	1.000						

Source: Author's calculation

The results obtained with the hybrid DEA-MCDM model yielded the following ranking of DMUs: DMU15>DMU25>DMU18>DMU7>DMU16>DMU19. The best individual performance was achieved by the vehicle MAN T32-J-339 in 2020, which recorded only one minor incident during daily operations and was out of service for just 12 days. The period of high vehicle efficiency coincided with the COVID-19 pandemic, when the majority of the population stayed outside the city of Doboj (due to movement restrictions). Consequently, waste disposal at the regional landfill decreased, which contributed to a more efficient work process. The analysis further demonstrates that the aforementioned vehicle outperformed all other vehicles included in the study, highlighting its critical importance in the future DE implementation. Therefore, the utility company's limited financial resources, combined with the absence of external co-financing, prevent the replacement of the entire vehicle fleet in the short term. Currently, the company will retain the vehicles demonstrating the highest performance, characterised by superior operational efficiency, optimal cargo capacity utilisation, and manoeuvrability during daily waste collection and transportation operations. In addition to the previously mentioned vehicle, this includes MAN 058-T-914 and IVECO K01-A-552, which are also technically reliable for continued operation in the near future. Hence, it is recommended that the management of the utility company replace the remaining two vehicles with optimal electric alternatives when the opportunity arises. A comprehensive feasibility study, including precise specifications of the new electric vehicles to be procured, should be conducted by company management as the next step. Electric vehicles, in turn, contribute to long-term sustainability when combined with timely digital integration. Technological sustainability involves digital coordination aimed at transforming the business model and achieving system efficiency. Accordingly, factors such as battery life under real operating conditions, the availability of charging infrastructure within the local community, and the manoeuvrability of vehicles along transport routes (with gradients of up to 10% at certain waste collection points in the city of Doboj) are critical for ensuring both operational and environmental sustainability. Electric trucks not only reduce CO_2 emissions and noise levels (given that waste collection and transportation services in the city of Doboj operate daily from 7 p.m. to 7 a.m.), but also help decrease local pollution and increase energy efficiency.

2.6. Verification tests

In this section of the paper, verification tests were conducted to assess the validity of the results. The initial decision matrix was modelled as an input parameter in a comparative analysis with six other MCDM methods (Figure no. 1). In order to predict future actions and define strategies in the uncertain environment in which nearly all companies operate, it is necessary to analyse changes in the significance of influencing factors, whose exceptional value has been confirmed through numerous studies (Ristić et al., 2024; Baydaș et al. 2025; Bhowmik et al., 2025).

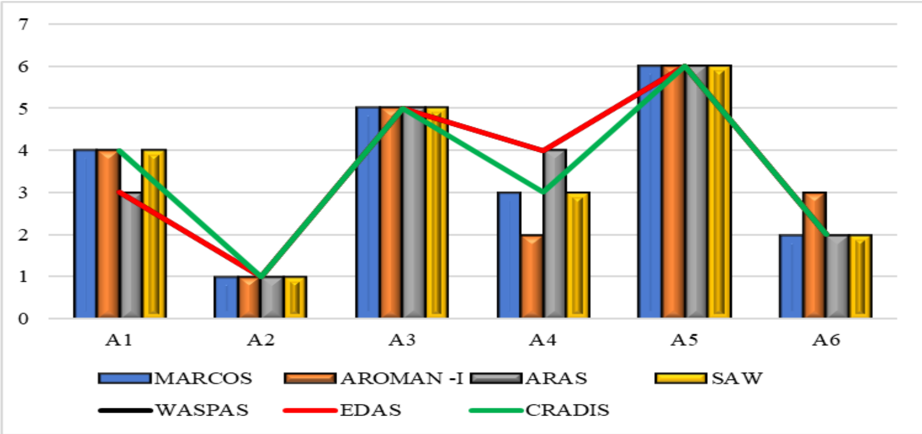

Figure no. 1. Display of original results and results obtained using other MCDM methods

Due to the nature of the algorithms of different methods, it is normal that the rankings of evaluated potential solutions may differ in certain situations. However, for the model to be considered stable, the changes need to remain within the allowed boundaries. However, in light of the observed changes, statistical correlation tests (SCC and WS) were performed to unambiguously determine the stability of the obtained results. The calculated correlation coefficients show an exceptionally high degree of correlation between the DEA-LOGSTA-MARCOS model and the other applied methods, with the lowest value being WS = 0.896, while the remaining values for both WS and SCC tend to be fully correlated. In this way, the original results were verified from the perspective of comparative analysis.

Figure 2a shows 30 scenarios in which new environmental conditions were simulated by assuming changes in the significance of the criteria. In these 30 scenarios, the significance of the criteria was reduced within the range of 15-90%, and the models were re-run with the input parameters.

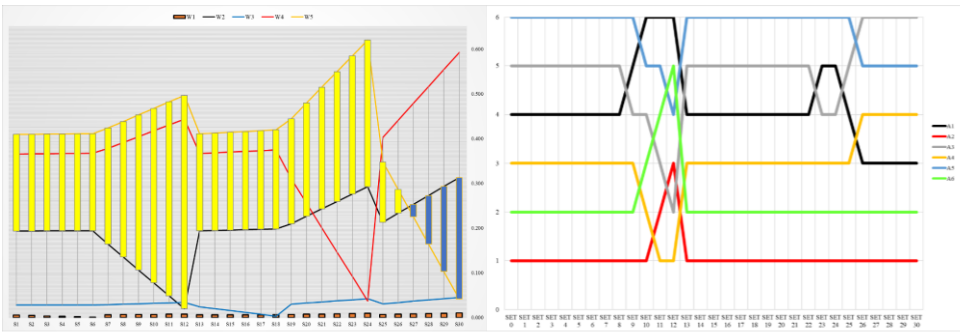

Figure no. 2. a) Simulation of criterion weights across 30 scenarios, b) Sensitivity analysis results

As shown in the figure, in the sixth scenario, the value of the first criterion approaches zero, representing one extreme, while in the 24th scenario, the value of the fifth criterion reaches 0.620, indicating its dominance over the other criteria. After applying the MARCOS method to the criterion weight structure across all 30 scenarios, new results were obtained and are presented in Figure 2b. As can be seen, different values of criteria and the reduction in the importance of certain criteria play a crucial role in determining the final results of the model. In this way, it is possible to take future changes in the environment into account and act promptly to prevent potential errors and define appropriate steps toward achieving minimal costs and reducing negative impacts in the environment, on the one hand, while increasing user satisfaction on the other. As part of the analysis of changes in the significance of the criteria across 19 scenarios, the statistical correlation tests yielded a value of 1.00, indicating a full correlation, i.e., no changes compared to the initial results. Therefore, in 63% of the cases, the results are identical due to the full correlation, while in 27% of the cases the correlation is very high; in one scenario it is moderately low and in another it is very low.

3. Discussion

The aim of this paper is to analyse the fleet of a medium-sized utility company, whose waste collection and transport vehicles are 15 years old or older, and to propose measures for an efficient transition from a conventional to an innovative business model based on artificial intelligence and DS. Similarly, Restrepo-Morales et al. (2024) have confirmed that limited access to technological modernisation and digitalisation, extremely high operational costs, and inefficient resource utilisation, in the long term, reduce the business sustainability and competitiveness of SMEs, particularly in the municipal sector, where enterprises are primarily constrained by their current operational liquidity. A utility company represents a low-accumulative sector of the economy, particularly a company engaged in the collection and transport of municipal waste, where operating costs are exceptionally high and the revenue from the provided service is at an exceptionally low level. This further means that the utility company is constantly faced with the challenge of deciding whether, and to what extent, to allocate its revenue toward fleet renewal and the digitalisation of its operations.

Research by Bühler et al. (2023) has confirmed that technical barriers reduce the ability of SMEs to make timely data-driven decisions. This further demonstrates that these barriers diminish the company's digital capability to optimise costs, as it continues to rely on manual rather than digital, modern, and efficient records of its business activities (Mick et al., 2024). Digital barriers reduce the ability of SMEs to optimise processes and provide services, especially when transforming from a conventional to a digital business model. Moreover, the technical inefficiency of SMEs leads to an even greater gap between performing daily business tasks and engaging in DE (Kahveci, 2025). The lack of information technology infrastructure, digital tools for data management, and the absence of human competencies in performing DP-based tasks represent a fundamental barrier to the potential success of SMEs in the context of DE (Nambisan, Wright and Feldman, 2019). Unlike developed countries, which provide support to the SME sector in the fields of innovation and business digitalisation, transitional countries, such as Bosnia and Herzegovina, are deprived of direct material assistance, resulting in inefficiencies in the technical and financial activities in the SME sector (Sengupta et al., 2021). Consequently, the state and its institutions must provide stronger support to small and medium-sized enterprises throughout the process of digital transformation, as key drivers of global economic trends and pillars of competitiveness, with the aim of achieving long-term sustainability.

4. Managerial implications

The results indicate that efficiency is not only a measure of the technical performance of vehicles but also reflects organisational and managerial parameters. The highly depreciated vehicle fleet of the observed utility company requires urgent restructuring. Existing trucks are technically unsuitable for the installation of digital solutions that would enable efficient management of transport routes and the digital recording of all deviations during daily operations. They lack the capability to integrate sensors for real-time vehicle monitoring and data collection, as well as to transmit data via the internet to managers or authorised personnel, who could track all changes through an application. Consequently, it is not possible to accurately assess the actual state of collected waste at any given moment, nor to predict waste patterns in the near future. The management of the utility company must evaluate its strategic position and market standing based on the empirical analysis presented in this paper, considering total costs, operational efficiency, and sustainable indicators. Therefore, a phased implementation is recommended, starting with a detailed analysis of existing performance, followed by digital process optimisation, and concluding with the gradual replacement of inefficient vehicles. It has been confirmed that electric vehicles yield better outcomes for the utility company over a period of four to seven years after implementation, compared to their internal combustion engine counterparts. Over their lifecycle, electric trucks produce 30-60% lower CO_2 emissions, reduce energy costs by up to 70% relative to internal combustion vehicles, and decrease maintenance costs by up to 40%, depending on the operational cycle (Piepenbrink, Flämig and Menger, 2025). The company's management should focus its market leadership in Bosnia and Herzegovina on the financial restructuring of its vehicle fleet toward electrification, accompanied by a clear projection of cash flows, considering personal or credit contributions, grants, or other forms of support from the state and donors. This approach would provide clear guidelines for the gradual electrification of other enterprises in the country, in line with the EU's carbon neutrality paradigm by 2050.

Conclusions

This paper analyses the potential opportunities for improving the existing vehicle fleet, i.e., its transition from a conventional to an advanced digital format, in a medium-sized utility company in Bosnia and Herzegovina. The goal is the DE of the existing utility company, with a focus on advanced technological solutions and long-term business sustainability through cost optimisation. The research results, based on the DEA-MARCOS-LOGSTA method, indicate certain limitations for the medium-sized utility company, whose fleet is over 15 years old, particularly in terms of increased operational costs and more frequent vehicle breakdowns while operating on defined transport routes in the city of Doboj. Therefore, the results confirm that conventional, long-term exploited vehicles reduce the business performance of the observed utility company. This is evidenced not only by the age of the vehicles, but also by their limited potential for digitalisation, i.e., the limitations in introducing modern technologies into the existing fleet, whose digital data would facilitate the integration into a functional and successful DE. The results further confirm that companies in transition face the greatest barriers to DE due to financial, regulatory, and technical factors. Therefore, the optimal strategy lies in the coordinated fleet renewal through digital solutions, supported proactively by the government. Increasing investment in the digital transformation of SMEs, particularly those in the waste collection and transport sector, contributes to a sustainable digital ecosystem, with a specific emphasis on environmental protection and public health. Importantly, the financial framework should not be viewed merely as an expenditure for transforming from conventional systems to digital ecosystems, but rather as a strategic investment in long-term sustainability.

The developed hybrid DEA-MCDM model can be applied for efficiency analysis, the selection of electric vehicles using individual MCDM models, the assessment of the suitability of digital technologies, the evaluation of policy options for increasing efficiency, and similar tasks across all types of enterprises, including both public and private organisations. Moreover, this model can be applied regardless of enterprise size, the number of inputs or outputs, or the nature of company activities. The contribution of this study is twofold: methodological and professional. The methodological contribution lies in the development of a unique model for this research and its potential applicability in future studies. The professional contribution lies in the ability to create concise strategies and plan future activities based on the obtained results.

The limitations of this research could be addressed by including a larger number of companies from Bosnia and Herzegovina and by expanding the range of inputs considered, with the aim of maximising outputs and optimising the sustainable transformation strategy of DE in the SME sector. Consequently, the research presented in this paper was conducted in a single city in Bosnia and Herzegovina and may be relevant only to a limited geographical area. Nevertheless, its framework can serve as a benchmark for other developing countries, as well as for developed countries, enabling comparison with similar studies. Future research should include a comprehensive analysis of the vehicle lifecycle and total CO_2 emissions, thereby further highlighting the objectives of the 2050 Green Agenda and climate neutrality, particularly from the perspective of developing countries that lack strict policies and clearly defined green transition goals. Accordingly, it is necessary to expand this research to cover all countries in the Western Balkans to enable comparison of the various factors influencing the adoption of electric municipal vehicles in different contexts, with particular emphasis on economic, infrastructural, environmental, and institutional factors.

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