Towards Sustainable Transport Assessment Considering Alternative Fuels Based on MCDA Methods

Jarosław Wątróbski, Aleksandra Bączkiewicz
Institute of Management, University of Szczecin
ul. Cukrowa 8, 71-004 Szczecin, Poland
Email: jaroslaw.watrobski@usz.edu.pl, aleksandra.baczkiewicz@phd.usz.edu.pl

Abstract—Sustainable transport can contribute to many beneficial changes, such as reducing greenhouse gas emissions and pollutants into the atmosphere, improving the country's energy security, and enhancing energy efficiency. Therefore, it is essential to provide a framework for reliable measurement of sustainable transport, enabling its evaluation in terms of diversity and the significance of renewable energy sources (RES). This paper presents a methodological framework for a multi-criteria assessment of sustainable transportation. The proposed framework is based on three multi-criteria decision analysis (MCDA) methods: SPOTIS (Stable Preference Ordering Towards Ideal Solution), ARAS (Additive Ratio Assessment), and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). The application of the proposed tool is demonstrated in an illustrative example of the assessment of European countries in terms of the share of alternative fuels in final energy consumption in road transport. The authors used the proposed framework to perform a comparative analysis considering three MCDA methods and two methods for determining the significance of evaluation criteria: equal and entropy weighting methods. The investigation has proven the practical suitability of the proposed tool in the problem of multi-criteria sustainable transport assessment. Furthermore, conducted analysis indicated that Sweden is characterized by the most sustainable transport in terms of significance and share of alternative fuels and RES and their diversification.

I. INTRODUCTION

CURRENT European environmental policy is focused on improving the ecological situation by reducing greenhouse gas (GHG) emissions [1]. The European Union's goals also cover increasing the share of renewable energy sources (RES) in all fields, including road transport [2]. The road transport sector, dominated by petroleum-derived fuels, is the source of about 25% of total GHG emissions in Europe [3]. As a consequence, the use of alternative fuels that cause less atmosphere pollution and at the same time contribute to increased security of supply and optimal energy storage is widely promoted. The investigation presented in the paper [3] found that the increase in electric vehicles, gas-engine vehicles, and biofuel-powered vehicles contributes to more sustainable energy consumption and reduces carbon emissions.

The long-term goals of the European transport economy are to increase the use of alternative fuels. The strategy set by European Commission includes targets covering 60% reduction in carbon dioxide emissions from transport by 2050 compared to 1990 [4], [5], and 70% reduction of final oil consumption

by 2050. The mentioned strategy also covers reduced increase of congestion implied multimodal solutions and innovative technologies in transport improving energy efficiency [6]. This trend is promoted by technological development and targeted investments. This strategy is justified by the harmful effects of the combustion of conventional fuels on the environment, depletion of sources for conventional fuels, and the aim to reduce dependence on oil imports from countries beyond the European Union [7], [8]. Motor fuels consist of a group of liquid fuels, including gasoline, diesel, biofuels, and a group of gaseous fuels, such as liquefied petroleum gases (LPG). Gasoline is produced by the rectification of petroleum. The advantages of gasoline include its high calorific value, low sulfur content, and resistance to low temperatures. However, some of the disadvantages of gasoline include environmental pollution in its combustion process, depletion of petroleum reserves, and high-cost production. Increasing the popularity of alternative fuels regarding conventional fuels such as gasoline and diesel includes the promotion of fuels derived from sources such as natural gas, LPG, biofuels and hydrogen, and electricity [5]. Electric vehicles do not pollute the atmosphere with exhaust fumes. Moreover, when RES power them, they contribute to reducing carbon dioxide emissions and fossil fuel consumption. Electric vehicles are particularly advantageous in urban areas, where travel distances are usually short [2]. The development of electric vehicles contributes to sustainable transportation in urban areas due to limited emissions and noise. In addition, hybrid vehicles with an internal combustion engine and an electric motor are also being developed to help reduce toxins and carbon dioxide emissions in exhaust gases. Fuels that play a significant role in replacing petroleum-based fuels in road transportation are biogas and natural gas. Natural gas is advantageous compared to petroleum because of less environmental impact and lower cost. Natural gas has good potential as an alternative fuel in road transport due to its contribution to supply security and lower environmental impact than conventional fuels [9]. Currently, the market for natural gas vehicles, including compressed natural gas (CNG) and liquefied natural gas (LNG), is expected to grow, expanding the opportunities for various road participants and contributing to fuel market diversification. On the other hand, the long-term benefits of diesel oil, CNG, and LPG are limited

due to their fossil fuel character [2]. Bioethanol and biodiesel are other fuel types that contribute to making transport less dependent on oil. First generation bioethanol and biodiesel are obtained from agricultural crops, the second generation from lignocellulosic biomass and third generation biofuels are produced from algae. The popularity of biofuels is growing, influenced by environmental regulations [2]. In the case of biofuels, the constant development of technology makes it possible to produce them from different sources. In addition, biofuels are also blended with conventional fuels to reduce environmental pollution. Liquefied petroleum gas (LPG) is an alternative fuel derived from oil and natural gas but can also be derived from biomass. In terms of environmental impact, it is more eco-friendly than conventional fuels as it has lower emissions [10].

Indeed, as can be seen, reliable assessment requires the consideration of many different criteria [11], [12], which in the case of the problem analyzed in this paper are the different types of alternative fuels. Various alternative fuels contribute as a whole to the reduction of carbon dioxide and pollutants to the atmosphere and the reduction of dependence on imported petroleum-based fuels [6]. Moreover, the growing popularity of fuels from RES contributes to the realization of an essential principle of sustainable development, which is increasing the share of RES in all sectors of the economy [13], including road transport [14]. The need to simultaneously consider multiple fuels as criteria for the proposed framework for European country evaluation implies the application of multi-criteria decision analysis (MCDA) methods.

MCDA methods are widely used in transport assessment because they allow for building models with multiple criteria necessary to evaluate and consider them simultaneously. For example, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is widely popular among researchers and practitioners due to its wide range of applications in various fields and real-life decision problems [15]. The TOPSIS method was applied for transport assessment concerning energy and environmental efficiency divided into road, rail, and air transport sectors [6]. Multi-criteria evaluation of electric vehicles from the perspective of sustainable transportation priorities often considers comparative analysis involving several MCDA methods. In the framework proposed in [16], the authors used fuzzy extensions of three MCDA methods, including TOPSIS, Simple Additive Weighting (SAW), and Preference Ranking Organization METHod for Enrichment of Evaluation (PROMETHEE), due to the necessity to regard the uncertainty occurring in the considered data on parameters and performance of evaluated vehicles, which is represented as interval or triangular fuzzy number (TFN). The vehicle rating for sustainable public transport presented in paper [17] employs a multi-criteria model built for evaluation using the ELECTRE (ELimination Et Choice Translating REality) TRI method. ELECTRE III was used to benchmark the buses recommended for the public transportation sector [18]. The authors of another work applied Multiattribute Utility Theory Approach (MAUT) method to determine consumer preferences

for alternative fuel vehicles [14]. In another research, the Analytical Hierarchy Process (AHP) was employed to evaluate alternative fuels in the context of sustainable transport [19]. Applying a multi-criteria decision analysis model based on the Additive Ratio Assessment (ARAS) method to assess alternative fuels for public transport was the main contribution of work [20]. The above literature review allows concluding that MCDA methods are widely and successfully used to evaluate sustainable transportation in many aspects. However, most research focuses on evaluating different vehicle technologies and fuels. On the other hand, attempts to rank countries concerning the share of alternative fuels in transport are rather limited. Therefore, it motivated the authors of this research to create a methodological framework based on MCDA methods that could support an information system for sustainable transport assessment, focusing on the share of alternative fuels in road transport.

This paper aims to present a multi-criteria approach, including the developed framework for measuring sustainable transport, particularly for assessing European countries considering sustainable energy consumption focused on alternative fuels in road transport. The objective of the research is to identify the country among the analyzed European countries where the share of alternative fuels is the most significant and diversified, which contributes to the reduction of greenhouse gas emissions and pollutants to the atmosphere and increases the country's independence from petroleum-derived fuels imports. The framework comprises a comparative analysis of results obtained using different MCDA methods to provide a reliable assessment [21], [22]. Another goal of the paper was to investigate the comparability of results obtained using three different MCDA methods based on distance measurement to reference solutions. Thus, the proposed approach involves employing three selected MCDA methods, including SPOTIS (Stable Preference Ordering Towards Ideal Solution), ARAS, and TOPSIS, for the multi-criteria evaluation of European countries regarding the share of alternative fuels in final Energy consumption in road transport. SPOTIS is a newly developed MCDA method that was introduced in 2020 [23]. The advantage of the SPOTIS method is resistance to the ranking reversal effect, which means that there is no ranking reversal when a particular alternative is removed or added from the evaluated set [24]. The mentioned advantage is possible because direct comparisons between alternatives are not required. In the SPOTIS approach, options are compared only with the ideal solution constructed by the decision-maker in the procedure of specification minimum and maximum bounds of each criterion which define multi-criteria problem to be solved. An additional advantage of the SPOTIS method is identifying the whole domain model due to building the ideal solution point defining the considered problem [23]. To confirm the results' reliability, the authors compared the results of the SPOTIS method with the results given by two other benchmark MCDA methods, ARAS and TOPSIS. The authors chose both benchmarking methods regarding a similar principle to the SPOTIS method, namely considering

the ideal solution in evaluating alternatives. The ARAS method evaluates alternatives by determining each option's degree of utility (efficiency) concerning the ideal alternative [25]. The TOPSIS method, on the other hand, takes into account their distance from the ideal and anti-ideal solutions in calculating the utility function values for each alternative [26]. In contrast to ARAS and TOPSIS, the SPOTIS method is more flexible because it allows the decision-maker to define the ideal solution independently instead of solely based on the data in the decision matrix [23]. Mentioned MCDA methods, besides providing a decision matrix containing performance values against the criteria, also require assigning a value of each criterion importance to the decision-maker, i.e., a weight. A strategic approach to fulfilling the long-term needs of all modes of transportation is recommended to be based on a full suite of alternative fuels without preference for particular types [9], [27]. The authors assigned equal weights to the criteria with this fact in mind. However, the authors also included in performed analysis objective weights determined by the Entropy method for a more comprehensive and reliable research procedure.

The rest of the paper is organized as follows. Section II provides basic assumptions and mathematical formulas of methods applied in this research. Next, in section III the practical problem of European countries' assessment regarding the share of alternative fuels in consumption in final energy consumption in road transport. Then, in section IV research results are presented. In section V discussion of obtained results is provided. Finally, in the last section VI the summary and conclusions are given, and future work directions are drawn.

II. METHODOLOGY

This section provides the basics and main assumptions of the particular MCDA methods employed in this research and other supporting techniques as criteria weighting methods and correlation coefficients for determining obtained rankings consistency for benchmarking analysis.

A. The SPOTIS Method

The subsequent stages of the SPOTIS (Stable Preference Ordering Towards Ideal Solution) method are given based on [23].

Step 1. Define the MCDA problem by determining the bounds containing the minimum and maximum performance values included in evaluated decision matrix $S = [s_{ij}]_{m \times n}$ for each criterion. The minimum and maximum bounds For each criterion $C_j (j = 1, 2, \ldots, n)$ is determined respectively by S_j^{min} and S_j^{max}.

Step 2. Determine the Ideal Solution Point (ISP) represented by $S^\star$. When for the criterion C_j larger score value is preferable, then the ISP for criterion C_j is $S_j^\star = S_j^{max}$. From the other side when for the criterion C_j lower score value is favored, then the ISP for criterion C_j is $S_j^\star = S_j^{min}$. The ideal multi-criteria best solution $S^\star$ is denoted by coordinates $(S_1^\star, S_j^\star, \ldots, S_n^\star)$.

Step 3. Determine the normalized distance values d_{ij} based on ISP for each considered alternative A_i according to Equation (1).

$$d_{ij}(A_i, s_j^\star) = \frac{|S_{ij} - S_j^\star|}{|S_j^{max} - S_j^{min}|} \tag{1}$$

Step 4. Calculate of the weighted normalized averaged distance values for each alternative A_i as Equation (2) shows

$$d(A_i, s^\star) = \sum_{j=1}^{n} w_j d_{ij}(A_i, s_j^\star) \tag{2}$$

where w_j represents the weight of jth criterion.

Step 5. Create ranking of evaluated alternatives by sorting $d(A_i, s^\star)$ values in ascending order. Alternative with the lowest $d(A_i, s^\star)$ value is the best scored option.

B. The ARAS Method

The following stages of the ARAS method are presented below, based on [25].

Step 1. Normalize the decision matrix using the Sum normalization method applying Equation (3) for benefit criteria and Equation (4) for cost criteria.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

$$r_{ij} = \frac{\frac{1}{x_{ij}}}{\sum_{i=1}^{m} \frac{1}{x_{ij}}} \tag{4}$$

where $X = [x_{ij}]_{m \times n}$ represents the decision matrix containing performance values of m alternatives in respect to n evaluation criteria.

Step 2. Calculate the weighted normalized decision matrix $D = [d_{ij}]_{m \times n}$ according to Equation (5)

$$d_{ij} = r_{ij} w_j \tag{5}$$

where w_j denotes jth criteria weight values.

Step 3. Compute the optimality function S_i for each ith alternative as Equation 6 presents.

$$S_i = \sum_{j=1}^{n} d_{ij} \tag{6}$$

Step 4. Calculate the utility value U_i for each ith alternative according to Equation (7)

$$U_i = S_i / S_o \tag{7}$$

where S_o denotes the optimality function value for the optimal alternative. U_i values are in the range from 0 to 1. The option which has the highest U_i value is regarded as the best scored alternative. Thus, the ranking of the ARAS method is constructed in descending order according to U_i values.

C. The TOPSIS Method

The successive steps of the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method are demonstrated as follows, based on [26].

Step 1. Normalize the decision matrix with performance values by chosen normalization technique, for example, the Minimum-Maximum normalization method, as performed in this research. Another normalization method can also be employed for this aim. In the Minimum-Maximum normalization r_{ij} normalized values of decision matrix are calculated by Equation (8) for benefit criteria and (9) for cost criteria.

$$r_{ij} = \frac{x_{ij} - min_j(x_{ij})}{max_j(x_{ij}) - min_j(x_{ij})} \quad (8)$$

$$r_{ij} = \frac{max_j(x_{ij}) - x_{ij}}{max_j(x_{ij}) - min_j(x_{ij})} \quad (9)$$

where $X = [x_{ij}]_{m \times n}$ represents the decision matrix containing performance values of m alternatives in respect to n evaluation criteria.

Step 2. Calculate the weighted normalized decision matrix as Equation (10) presents.

$$v_{ij} = w_j r_{ij} \quad (10)$$

where w_j denotes jth criteria weight values.

Step 3. Determine the Positive Ideal Solution (PIS) using Equation (11) and Negative Ideal Solution (NIS) by Equation (12). PIS includes the maximum values of the weighted normalized decision matrix, while in NIS, its minimal values are contained. Since the normalization of the decision matrix was applied in the previous step, there is no necessity to separate the criteria into profit and cost types.

$$v_j^+ = \{v_1^+, v_2^+, \ldots, v_n^+\} = \{max_j(v_{ij})\} \quad (11)$$

$$v_j^- = \{v_1^-, v_2^-, \ldots, v_n^-\} = \{min_j(v_{ij})\} \quad (12)$$

Step 4. Calculate the distance from PIS (13) and NIS (14) of each alternative. The default measure for distance determination in TOPSIS method is Euclidean distance.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2} \quad (13)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \quad (14)$$

Step 5. Calculate the utility function value for each evaluated alternative as Equation (15) shows. The C_i value is within the range from 0 to 1, and the alternative with the highest C_i value is the most preferred. Thus, the ranking of the TOPSIS method is constructed by descending ordering of alternatives according to their utility function values.

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (15)$$

D. The Equal Weighting Method

The equal weighting method is the simplest technique for determining criteria significance values. However, for several MCDA problems assigning equal weights to evaluation criteria is appropriate. Equal weights are determined as Equation (16) shows.

$$w_j = 1/n \quad (16)$$

where n represents number of evaluation criteria.

E. The Entropy Weighting Method

The entropy weighting method is an objective weighting technique based on Shannon's entropy theory. Shannon entropy performs an important role in information theory. For example, entropy is used to measure the information included in data, which is contained in a two-dimensional decision matrix in the case of MCDA problems [1]. The following stages of the Entropy weighting method are given as follows, based on [1].

Step 1. Normalize the decision matrix using sum normalization method to obtain normalized decision matrix $P = [p_{ij}]_{m \times n}$ where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$, m represents number of alternatives and n denotes number of evaluation criteria.

Step 2. Calculate the entropy value E_j for each jth criterion as Equation (17) shows.

$$E_j = -\frac{\sum_{i=1}^{m} p_{ij} ln p_{ij}}{ln m} \quad (17)$$

Step 3. Calculate d_j value according to Equation (18).

$$d_j = 1 - E_j \quad (18)$$

Step 4. Calculate the entropy weights for each jth criterion as Equation (19) shows.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (19)$$

F. The Weighted Spearman Rank Correlation Coefficient

The r_w correlation coefficient is determined to compare two rankings x and y according to Equation (20). N denotes a number of rank values x_i and y_i [1].

$$r_w = 1 - \frac{6\sum_{i=1}^{N}(x_i - y_i)^2((N - x_i + 1) + (N - y_i + 1))}{N^4 + N^3 - N^2 - N} \quad (20)$$

G. The Spearman Rank Correlation Coefficient

The Spearman Rank Correlation Coefficient is computed to determine the correlation between two rankings x and y according to Equation (21)

$$r_s = 1 - \frac{6 \cdot \sum_{i=1}^{N}(x_i - y_i)^2}{N \cdot (N^2 - 1)} \quad (21)$$

where N denotes size of vector x and y [28].

III. The practical problem of European countries' assessment regarding alternative fuels in total final energy consumption in road transport

This paper aims to assess 32 selected European countries regarding sustainable energy consumption considering alternative fuels in road transport. For this purpose, the authors developed the framework based on annual data on final energy consumption in road transport provided by Eurostat, considering different alternative fuel types [29] (accessed on 2 May 2022). Furthermore, to analyze the up-to-date situation, the authors gathered the most recent data available in the Eurostat database for 2020. This Eurostat frame excludes off-road use of fuels from road transport (for example, cranes and excavators at construction sites, harvesters, and tractors at fields). However, it is included in the respective consumption sector. Road transport includes passenger and freight transport, domestic and international transport, urban and intercity transport performed on public road networks, and publicly accessible private road network, including both the free and the paid part of the road network systems. The authors assessed sustainable energy consumption in road transport by incorporating the percentage share of each considered alternative fuel type in the annual total final energy consumption in road transport. Table I presents alternative fuel types playing the role of evaluation criteria in the proposed framework. Each criterion has to be maximized because the objective is to increase the share of alternative fuels in total road transport fuel consumption. Due to the recommended lack of preference for particular alternative fuel types, each criterion has the same significance value represented by equal weights. The last two columns of Table I provide the significance values of the criteria of the proposed evaluation framework, i.e., the different types of alternative fuels considered.

TABLE I
EVALUATION CRITERIA INCLUDING SHARE OF ALTERNATIVE FUEL TYPES
IN TOTAL FINAL ENERGY CONSUMPTION IN ROAD TRANSPORT.

C_j	Criterion name	Unit	Aim	Equal Weight	Entropy Weight
C_1	Blended biodiesels	[%]	Max	0.1111	0.0103
C_2	Liquefied petroleum gases	[%]	Max	0.1111	0.0754
C_3	Blended biogasoline	[%]	Max	0.1111	0.0198
C_4	Natural gas	[%]	Max	0.1111	0.0543
C_5	Pure biodiesels	[%]	Max	0.1111	0.1875
C_6	Biogases	[%]	Max	0.1111	0.1370
C_7	Electricity	[%]	Max	0.1111	0.0770
C_8	Pure biogasoline	[%]	Max	0.1111	0.2403
C_9	Other liquid biofuels	[%]	Max	0.1111	0.1985

Data for the mentioned criteria were collected from the Eurostat database available at the link [29] for 32 selected European countries listed in Table II. The value of each criterion is provided in the Eurostat database in the unit called a Thousand tonnes of oil equivalent (TOE). For a representative and reliable countries assessment in terms of sustainable fuel consumption in transport sustainability, the authors calculated the share of each fuel as a percentage of total annual fuel consumption based on the available values. Such an approach allows for an individual approach for each country that adequately considers the needs and capacities of countries resulting from independent aspects such as geography, area, and population size.

Figure 1 displays, in the form of a stacked column chart, the percentage of alternative fuels in final Energy consumption in road transport in 2020 for which investigation was performed. The chart analysis allows us to observe the largest share of alternative fuels as a whole in the considered domain for Sweden (SE). Blended biodiesels represent the most significant part of this share (C_1). Apart from that, pure biodiesels (C_5), blended biogasoline (C_3), biogases (C_6), and electricity (C_7) account for a significant share. The chart provided demonstrates the dominance of blended biodiesels (C_1) and LPG (C_2) share among the countries assessed. The countries where energy consumption from electricity in road transport is most noticeable are Norway (NO), Iceland (IS), and Sweden (SE). However, an evaluation based only on the cumulative values of individual fuels is insufficient because it does not allow for simultaneous consideration of the degree of diversification of fuels and decision-makers preferences concerning particular fuels. Therefore, to consider the mentioned aspects, a framework employing MCDA methods is recommended [30].

IV. Results

This section presents the results of each MCDA method individually for the equal and entropy evaluation criteria weights. The results include MCDA utility function values for each alternative, rankings constructed based on them, and analysis of obtained rankings convergence represented by correlation coefficient values.

A. Results for the Equal Weighting Method

Table III contains utility function values and rankings received for evaluated countries concerning equal weights assigned to considered criteria with SPOTIS, ARAS, and TOPSIS methods. For the SPOTIS method, the alternative that received the lowest utility function value is the best-ranked alternative. On the other hand, for the ARAS and TOPSIS methods, the alternative that has the highest utility function value is the best option.

It can be observed that when the criteria are assigned equal weights, all MCDA methods used in this research indicated Sweden (SE) as the country with the most significant share of alternative fuels in final Energy consumption in road transport. Another well-scored country is Norway (NO), ranked second in all rankings. Norway was ranked better than Bulgaria (BG) and Ukraine (UA), although its overall share of alternative fuels is lower. Norway was nevertheless ranked second because it has a more diversified share of alternative fuels than Bulgaria and Ukraine. Therefore, diversification of alternative fuels in final energy consumption in transport is promoted, and MCDA methods enable appropriate reflection of this fact. Norway's share of alternative fuels in road transport consists of a mix covering six different alternative fuel types, namely

TABLE II

Decision matrix with percentage shares of alternative fuels in final energy consumption in road transport in 2020.

| Country	Code	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Austria	AT	4.5648	0.0426	0.7669	0.2713	0.3467	0.0047	0.0162	0	0
Belgium	BE	7.7250	0.6543	1.7500	0.5747	0	0	0.1553	0	0
Bulgaria	BG	4.6534	13.2909	0.8475	2.7555	0	0	0.0998	0	0
Croatia	HR	3.4274	3.1351	0.0402	0.1629	0.0085	0	0.0128	0	0
Cyprus	CY	4.0226	0.0733	0.1059	0	0	0	0	0	0
Czechia	CZ	4.9672	1.2723	1.0810	1.2599	0	0.0193	0.1005	0	0
Denmark	DK	4.6560	0	2.1625	0.2147	0	0	0.2227	0	0
Estonia	EE	4.2500	1.3120	0.8033	2.0164	0	1.0882	0.1604	0	0
Finland	FI	8.2455	0	2.4812	0.3792	0	0.1117	0.2963	0	0
France	FR	5.7580	0.1086	1.5421	0.5374	0	0	0.1014	0	0
Germany	DE	5.2409	0.5146	1.4152	0.2731	0.0093	0.1558	0.0784	0	0.0014
Greece	EL	3.0211	4.2903	1.3879	0.4014	0	0	0.0371	0	0
Hungary	HU	4.5742	0.3356	1.9646	0.1818	0	0	0.1229	0	0
Iceland	IS	4.6093	0	2.3228	0	0	0.5875	0.8353	0	0
Ireland	IE	4.6710	0.0253	0.5853	0	0	0	0.1042	0	0
Italy	IT	4.6143	5.3319	0.0728	2.8625	0	0.0001	0.0607	0	0
Latvia	LV	3.1032	4.3335	1.2623	0.0529	0	0	0.2314	0	0
Lithuania	LT	4.1574	4.7534	0.7719	0.4112	0	0	0.1708	0	0
Luxembourg	LU	7.7657	0.0116	0.8351	0	0	0	0.0896	0	0.0013
Malta	MT	7.0464	0.3755	0	0	0	0	0.0969	0	0
Netherlands	NL	3.3488	1.2979	2.5357	0.6489	0	0	0.6481	0	0
Norway	NO	10.5502	0.1851	1.1836	0.7354	0	0.6206	2.9069	0	0
Poland	PL	3.9713	9.0431	0.8682	0.0925	0.0920	0	0.0304	0	0
Portugal	PT	4.8778	0.6410	0.1336	0.3187	0.0294	0	0.0186	0	0
Romania	RO	5.4875	1.4321	1.4831	0	0.8511	0	0.0576	0	0
Serbia	RS	0	3.5315	0	0.9394	0	0	0	0	0
Slovakia	SK	5.5505	0	1.1137	0	0	0	0.0886	0	0
Slovenia	SI	5.4665	0.5868	0.5157	0.2236	0	0	0.0118	0	0
Spain	ES	5.3262	0.3110	0.3583	1.1540	0.1457	0	0.0725	0.0012	0
Sweden	SE	14.8589	0	1.5113	0.1382	4.6082	1.4162	0.6828	0.0509	0
Ukraine	UA	0	19.8763	0.7555	0.2694	0	0	0	0	0
United Kingdom	UK	3.2833	0.1745	1.0015	0	0	0	0.0817	0	0
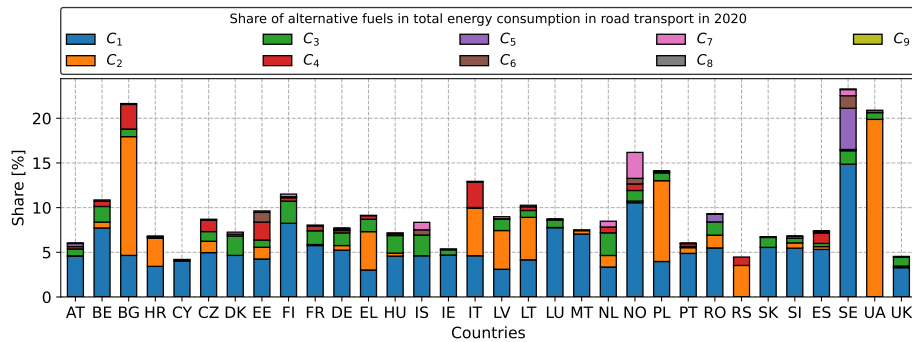
Fig. 1. Shares of alternative fuels in annual final energy consumption of evaluated countries in road transport in 2020.

C_1, C_2, C_3, C_4, C_6, and C_7. A particularly favorable result is implicated by the highest percentage of energy consumption of C_7 by Norway. For Bulgaria (BG), the share of four alternative fuel types (C_1, C_2, C_3, and C_4) and the trace share of C_7 are noticeable. In the case of Ukraine (UA), the contribution of only three types of alternative fuels covering C_2, C_3, and C_4 is evident. Bulgaria (BG) was ranked third in SPOTIS and TOPSIS, while it was ranked sixth in the ARAS ranking. Bulgaria (BG) was thus rated better than Ukraine (UA), supported by a more diversified alternative fuel mix. The worst-rated country by all MCDA methods applied in the presented research was Cyprus (CY), which has a low share of only three alternative fuels comprising C_1, C_2, and C_3, with the most significant share of C_1. Besides the two top places and the last place in the obtained rankings of the evaluated countries, some divergences are noticeable depending on the MCDA method used. The divergences occurring in each ranking are visualized in the column chart in Figure 2. Due to the observed differences in rankings, objective measures of convergence of compared rankings were applied to establish the degree of divergence of particular rankings, which are two ranking correlation coefficients: the Weighted Spearman Rank
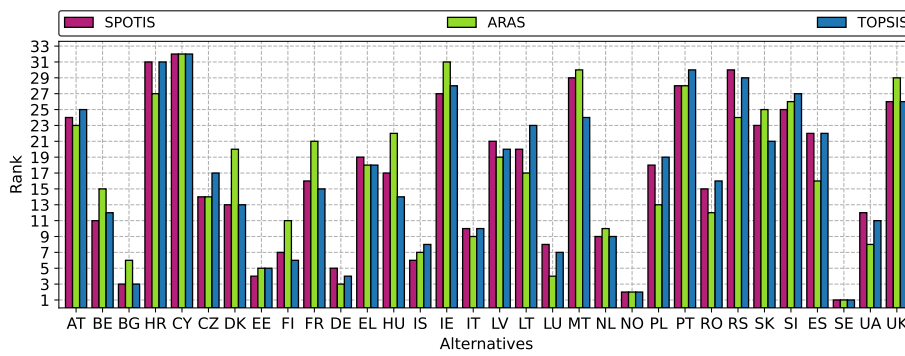
Fig. 2. Comparison of rankings obtained using three different MCDA methods for Equal criteria weights.

Correlation Coefficient r_w and the Spearman Rank Correlation Coefficient r_s.

TABLE III
RESULTS OF MCDA METHODS FOR EQUAL CRITERIA WEIGHTS.

Country	Utility function value			Rank		
	SPOTIS	ARAS	TOPSIS	SPOTIS	ARAS	TOPSIS
AT	0.9121	0.0415	0.1396	24	23	25
BE	0.8336	0.0617	0.2544	11	15	12
BG	0.7430	0.1457	0.3402	3	6	3
HR	0.9481	0.0273	0.0910	31	27	31
CY	0.9649	0.0114	0.0862	32	32	32
CZ	0.8541	0.0641	0.2113	14	14	17
DK	0.8536	0.0511	0.2542	13	20	13
EE	0.7559	0.1638	0.3178	4	5	5
FI	0.7948	0.0793	0.3073	7	11	6
FR	0.8640	0.0489	0.2186	16	21	15
DE	0.7588	0.2011	0.3281	5	3	4
EL	0.8756	0.0535	0.1925	19	18	18
HU	0.8661	0.0452	0.2367	17	22	14
IS	0.7857	0.1205	0.3024	6	7	8
IE	0.9353	0.0228	0.1217	27	31	28
IT	0.8191	0.1014	0.2915	10	9	10
LV	0.8864	0.0528	0.1787	21	19	20
LT	0.8860	0.0567	0.1577	20	17	23
LU	0.7963	0.1723	0.3059	8	4	7
MT	0.9415	0.0228	0.1427	29	30	24
NL	0.8066	0.0854	0.2939	9	10	9
NO	0.6799	0.2265	0.3812	2	2	2
PL	0.8747	0.0676	0.1908	18	13	19
PT	0.9403	0.0253	0.1104	28	28	30
RO	0.8632	0.0744	0.2132	15	12	16
RS	0.9438	0.0365	0.1157	30	24	29
SK	0.9063	0.0305	0.1727	23	25	21
SI	0.9241	0.0275	0.1329	25	26	27
ES	0.8891	0.0579	0.1715	22	16	22
SE	0.4579	0.5999	0.5236	1	1	1
UA	0.8453	0.1040	0.2792	12	8	11
UK	0.9275	0.0241	0.1389	26	29	26

High values of these coefficients close to 1 indicate high convergence of the compared rankings. Figure 3 displays the r_w and r_s coefficient values calculated for the pairwise comparisons of the obtained rankings. The correlation coefficient r_w calculated for the compared SPOTIS and TOPSIS rankings has the highest value, equal to 0.9887. Furthermore, the correlation coefficient r_w between SPOTIS and ARAS

rankings is also high, 0.9417. The lowest correlation of 0.9254 was observed for comparing ARAS and TOPSIS rankings. The values of the second correlation coefficient r_s are similar. High correlation values for comparisons of SPOTIS ranking with rankings provided by benchmarking methods TOPSIS and ARAS confirm the results' reliability.
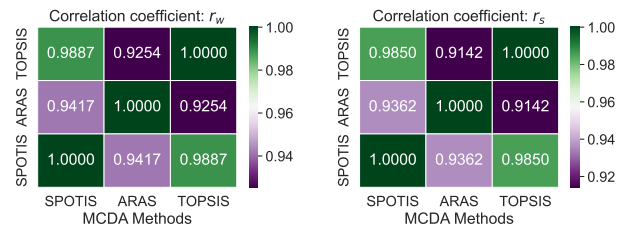

Fig. 3. Correlation between rankings for Equal criteria weights.

B. Results for the Entropy Weighting Method

This section presents the second part of the research for the evaluation criteria weights determined by the objective Entropy method. This part of the analysis was conducted to objectify the research results. Objective criterion weighting techniques are used to determine criterion weights based on the outcomes of mathematical models. Objective weighting techniques are useful when determining reliable subjective weights by the decision-maker is not possible, for example, due to the lack of experts with the necessary knowledge of the multi-criteria problem to be solved. Figure 4 displays a chart comparing SPOTIS, ARAS, and TOPSIS rankings for entropy weights visually. Table IV contains the utility function values and rankings of applied MCDA methods obtained for evaluated countries. The leader of all rankings is Sweden (SE), as it was noticed for the use of equal criteria weights. Germany (DE) took second place in all rankings employing Entropy criteria weights, which is different from equal criteria weights. Germany was ranked fifth for equal weights by the SPOTIS method, fourth by the TOPSIS method, and third by the ARAS method.
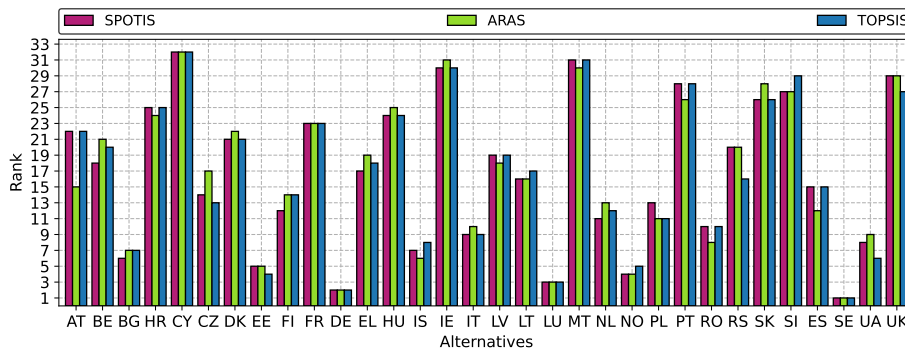
Fig. 4. Comparison of rankings obtained using three different MCDA methods for Entropy criteria weights.

TABLE IV
RESULTS OF MCDA METHODS FOR ENTROPY CRITERIA WEIGHTS.

Country	Utility function value			Rank		
	SPOTIS	ARAS	TOPSIS	SPOTIS	ARAS	TOPSIS
AT	0.9706	0.0222	0.0396	22	15	22
BE	0.9635	0.0133	0.0447	18	21	20
BG	0.8848	0.0555	0.1555	6	7	7
HR	0.9816	0.0096	0.0300	25	24	25
CY	0.9961	0.0010	0.0071	32	32	32
CZ	0.9548	0.0188	0.0612	14	17	13
DK	0.9699	0.0105	0.0439	21	22	21
EE	0.8380	0.1028	0.2285	5	5	4
FI	0.9491	0.0225	0.0592	12	14	14
FR	0.9707	0.0100	0.0391	23	23	23
DE	0.7622	0.2123	0.3643	2	2	2
EL	0.9622	0.0162	0.0498	17	19	18
HU	0.9735	0.0086	0.0389	24	25	24
IS	0.8997	0.0644	0.1411	7	6	8
IE	0.9893	0.0039	0.0151	30	31	30
IT	0.9201	0.0366	0.1267	9	10	9
LV	0.9644	0.0174	0.0479	19	18	19
LT	0.9607	0.0193	0.0501	16	16	17
LU	0.7971	0.1874	0.3471	3	3	3
MT	0.9911	0.0040	0.0138	31	30	31
NL	0.9435	0.0261	0.0683	11	13	12
NO	0.8318	0.1157	0.2065	4	4	5
PL	0.9499	0.0281	0.0811	13	11	11
PT	0.9854	0.0068	0.0182	28	26	28
RO	0.9430	0.0503	0.0867	10	8	10
RS	0.9688	0.0153	0.0524	20	20	16
SK	0.9851	0.0045	0.0235	26	28	26
SI	0.9854	0.0050	0.0177	27	27	29
ES	0.9570	0.0280	0.0567	15	12	15
SE	0.3925	0.6935	0.5966	1	1	1
UA	0.9136	0.0476	0.1595	8	9	6
UK	0.9871	0.0042	0.0204	29	29	27

Third place in all rankings was achieved by Luxembourg (LU), which in the case of applying equal weights ranked fourth in ARAS, seventh in TOPSIS, and eighth in SPOTIS. The better performance of Germany and Luxembourg is reflected in the fact that they are the only of the evaluated countries that have a C_9 share in final energy consumption in road transport. In the case of entropy weights, this is the second most important evaluation criterion. The results show that the determined criterion weights are critical for the MCDA evaluation results. For the weights determined by the

entropy method in the problem analyzed in this paper, the highest weight was assigned to criterion C_8. It is reflected in Spain's better performance (ES) for entropy weights than equal weights. Spain is the only country besides Sweden with a C_8 share in final energy consumption in road transport. Cyprus (CY) was ranked last for entropy criteria weights, as was the case with assigning equal importance to the evaluation criteria.

It can be observed that the convergence of obtained rankings is higher for entropy weights than for equal weights. The high convergence of the rankings is confirmed in Figure 5, displaying the values of correlation coefficients r_w and r_s.
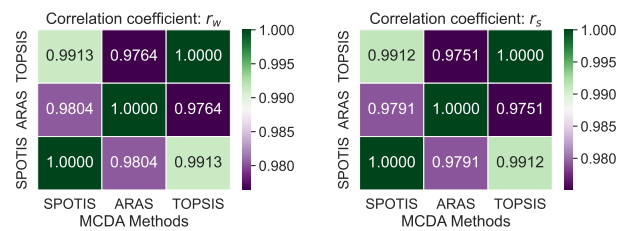

Fig. 5. Correlation between rankings for Entropy criteria weights.

The calculated correlation coefficients are the highest for comparing SPOTIS and TOPSIS rankings (r_w equal to 0.9913 and r_s equal to 0.9912). However, there was also a strong correlation between the SPOTIS and ARAS rankings (r_w equal to 0.9804 and r_s equal to 0.9791). The lowest correlation was observed between the ARAS and TOPSIS rankings. Conducted research showed that the strength of correlation between the determined country rankings for entropy weights is analogous to equal weights. The highest similarity is noticed in the case of SPOTIS and TOPSIS rankings.

The performed investigation proved that Sweden has the most significant and diversified share of alternative fuels in final energy consumption in road transport among 32 European countries evaluated in this research. Furthermore, the high score obtained by this country was confirmed by all MCDA methods, applying both criteria weighting methods.

V. Discussion

It is difficult to compare various alternative fuels because different conflicting goals characterize them. For example, the popularization of electric vehicles contributes to reducing greenhouse gas emissions and may also increase water consumption. Therefore, the sustainability framework recommends evaluating technologies or alternatives by considering multiple dimensions to promote sustainability in each dimension [31], [32], [33]. Many countries intend to replace fossil fuel vehicles with electric vehicles soon. For example, among these countries is Norway, which ranked a high second in this study for equal criteria weights in SPOTIS, ARAS, and TOPSIS and has the largest share of electricity in final energy consumption in road transport [34]. Although the transition to electric vehicles seems promising for sustainable transportation, there are some difficulties such as high purchasing costs, exploitation problems, limited range and long charging times for vehicles, and limited availability of necessary charging infrastructure. Due to the mentioned aspects, it is essential to consider different types of alternative fuels in the sustainable development of transportation. Sweden is a representative example of a country characterized by a high diversification of types of alternative fuels in road transport, identified as the leader of the rankings in this research.

In Sweden, an important goal is the decarbonization process involving increasing the share of alternative fuels in road transport [35]. Therefore, there is considerable interest in exploiting alternative fuels in road transport in Sweden. Biogas is recognized as an alternative fuel in Sweden with significant environmental and social advantages. The technological maturity of biogas is noticeable in the area of biomethane buses. Positive aspects of biogas that public organizations appreciate in Sweden are energy security, nutrient recovery, and reduced environmental pollution. In addition, the Swedish regional transport government contributes to popularizing renewable fuels in the bus fleet [36]. Many public organizations in Sweden focused on bus transportation tendering processes want to contribute to sustainability improvements, including a transformation to reduce fossil fuels and increase renewables in bus transportation. Buses are dominant in public transport in Sweden. Bus fuels in public transport have seen a noticeable transformation over the past two decades. At the beginning of the 21st century, the bus fleet used fossil fuels almost entirely, while in 2017, more than 60% of buses used fuels produced from RES. In Sweden, the transformation towards more alternative fuels for road transport is mainly taking place on a regional level and includes bioethanol, biomethane, biodiesel, HVO (Hydrotreated Vegetable Oil), and most recently, electric buses. Electric buses are very popular, and their role is expected to increase in the future, especially in city centers [37]. The results confirm that diversification and development of alternative fuels at multiple levels contribute to a good evaluation of a country using an evaluation framework that includes different MCDA methods and criteria weighting techniques, as illustrated by an example of Sweden.

VI. Conclusions

The aim of this paper was to present a methodological framework that can be useful in supporting an information system for measurement and assessment of sustainable transport focused on the share of alternative fuels in final energy consumption in road transport. The application of the proposed framework was demonstrated in the illustrative example of the assessment of 32 selected European countries regarding the importance of the share and diversification of alternative fuels in road transport. The research results proved the usefulness of the presented approach in the analyzed problem of sustainable transport assessment. The applied approach indicated Sweden as the best-evaluated country concerning the criteria in the demonstrated evaluation framework. The obtained results showed that the MCDA-based approach has an advantage over simple aggregation methods. It allows a multidimensional assessment with simultaneous consideration of multiple criteria. Such an approach is compatible with the principle of diversification of alternative fuels in sustainable transport. Moreover, models based on MCDA methods enable prioritization of individual fuel types by assigning them significance values that may be equal or determined by objective or subjective weighting methods.

The results encourage the follow-up of research work in the scope of multi-criteria evaluation of sustainable transport considering different fuel types. Further work includes research on the influence of other methods of prioritizing assessment criteria on the results and exploring other MCDA methods, such as PROMETHEE II, which provides different preference functions [38]. Another interesting research direction is the temporal assessment of sustainable transport, considering the dynamics of performance changes in the analyzed time interval. Further work directions also include consideration of the economic aspects of alternative fuels and the level of self-sufficiency in the context of alternative fuel supply.

References

[1] A. Bączkiewicz, B. Kizielewicz, A. Shekhovtsov, M. Yelmikheiev, V. Kozlov, and W. Sałabun, "Comparative analysis of solar panels with determination of local significance levels of criteria using the MCDM methods resistant to the rank reversal phenomenon," *Energies*, vol. 14, no. 18, p. 5727, 2021. doi: https://doi.org/10.3390/en14185727

[2] K. G. Tsita and P. A. Pilavachi, "Decarbonizing the Greek road transport sector using alternative technologies and fuels," *Thermal Science and Engineering Progress*, vol. 1, pp. 15–24, 2017. doi: https://doi.org/10.1016/j.tsep.2017.02.003

[3] J. L. Osorio-Tejada, E. Llera-Sastresa, and S. Scarpellini, "Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?" *Renewable and Sustainable Energy Reviews*, vol. 71, pp. 785–795, 2017. doi: https://doi.org/10.1016/j.rser.2016.12.104

[4] J. Krause, C. Thiel, D. Tsokolis, Z. Samaras, C. Rota, A. Ward, P. Prenninger, T. Coosemans, S. Neugebauer, and W. Verhoeve, "EU road vehicle energy consumption and CO2 emissions by 2050–Expert-based scenarios," *Energy Policy*, vol. 138, p. 111224, 2020. doi: https://doi.org/10.1016/j.enpol.2019.111224

[5] C. Fernández-Dacosta, L. Shen, W. Schakel, A. Ramirez, and G. J. Kramer, "Potential and challenges of low-carbon energy options: Comparative assessment of alternative fuels for the transport sector," *Applied energy*, vol. 236, pp. 590–606, 2019. doi: https://doi.org/10.1016/j.apenergy.2018.11.055

[6] B. Djordjević and E. Krmac, "Evaluation of energy-environment efficiency of european transport sectors: non-radial DEA and TOPSIS approach," *Energies*, vol. 12, no. 15, p. 2907, 2019. doi: https://doi.org/10.3390/en12152907

[7] A. Safari, N. Das, O. Langhelle, J. Roy, and M. Assadi, "Natural gas: A transition fuel for sustainable energy system transformation?" *Energy Science & Engineering*, vol. 7, no. 4, pp. 1075–1094, 2019. doi: https://doi.org/10.1002/ese3.380

[8] D. Chiaramonti and K. Maniatis, "Security of supply, strategic storage and Covid19: Which lessons learnt for renewable and recycled carbon fuels, and their future role in decarbonizing transport?" *Applied Energy*, vol. 271, p. 115216, 2020. doi: https://doi.org/10.1016/j.apenergy.2020.115216

[9] S. Pfoser, O. Schauer, and Y. Costa, "Acceptance of LNG as an alternative fuel: Determinants and policy implications," *Energy Policy*, vol. 120, pp. 259–267, 2018. doi: https://doi.org/10.1016/j.enpol.2018.05.046

[10] Z. Navas-Anguita, D. García-Gusano, and D. Iribarren, "A review of techno-economic data for road transportation fuels," *Renewable and Sustainable Energy Reviews*, vol. 112, pp. 11–26, 2019. doi: https://doi.org/10.1016/j.rser.2019.05.041

[11] J. Wątróbski, A. Bączkiewicz, E. Ziemba, and W. Sałabun, "Sustainable cities and communities assessment using the DARIA-TOPSIS method," *Sustainable Cities and Society*, p. 103926, 2022. doi: https://doi.org/10.1016/j.scs.2022.103926

[12] J. Wątróbski, A. Bączkiewicz, and W. Sałabun, "pyrepo-mcda-Reference objects based MCDA software package," *SoftwareX*, vol. 19, p. 101107, 2022. doi: https://doi.org/10.1016/j.softx.2022.101107

[13] Y. A. Solangi, C. Longsheng, and S. A. A. Shah, "Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach," *Renewable Energy*, vol. 173, pp. 209–222, 2021. doi: https://doi.org/10.1016/j.renene.2021.03.141

[14] G. D. Oliveira and L. C. Dias, "The potential learning effect of a MCDA approach on consumer preferences for alternative fuel vehicles," *Annals of Operations Research*, vol. 293, no. 2, pp. 767–787, 2020. doi: https://doi.org/10.1007/s10479-020-03584-x

[15] W. Chmielarz and M. Zborowski, "On the Assessment of e-Banking Websites Supporting Sustainable Development Goals," *Energies*, vol. 15, no. 1, p. 378, 2022. doi: https://doi.org/10.3390/en15010378

[16] P. Ziemba, "Selection of Electric Vehicles for the Needs of Sustainable Transport under Conditions of Uncertainty—A Comparative Study on Fuzzy MCDA Methods," *Energies*, vol. 14, no. 22, p. 7786, 2021. doi: https://doi.org/10.3390/en14227786

[17] A. Romero-Ania, L. Rivero Gutiérrez, and M. A. De Vicente Oliva, "Multiple criteria decision analysis of sustainable urban public transport systems," *Mathematics*, vol. 9, no. 16, p. 1844, 2021. doi: https://doi.org/10.3390/math9161844

[18] L. Rivero Gutiérrez, M. A. De Vicente Oliva, and A. Romero-Ania, "Economic, Ecological and Social Analysis Based on DEA and MCDA for the Management of the Madrid Urban Public Transportation System," *Mathematics*, vol. 10, no. 2, p. 172, 2022. doi: https://doi.org/10.3390/math10020172

[19] J. L. Osorio-Tejada, E. Llera-Sastresa, and S. Scarpellini, "A multi-criteria sustainability assessment for biodiesel and liquefied natural gas as alternative fuels in transport systems," *Journal of Natural Gas Science and Engineering*, vol. 42, pp. 169–186, 2017. doi: https://doi.org/10.1016/j.jngse.2017.02.046

[20] M. A. Hatefi, "A Multi-Criteria Decision Analysis Model on the Fuels for Public Transport, with the Use of Hybrid ROC-ARAS Method," *Petroleum Business Review*, vol. 2, no. 1, pp. 45–55, 2018. doi: https://dx.doi.org/10.22050/pbr.2018.77848

[21] J. Wątróbski, J. Jankowski, and Z. Piotrowski, "The selection of multicriteria method based on unstructured decision problem description," in *International Conference on Computational Collective Intelligence.*

[22] J. Jankowski, K. Kolomvatsos, P. Kazienko, and J. Wątróbski, "Fuzzy modeling of user behaviors and virtual goods purchases in social networking platforms," *Journal of Universal Computer Science*, vol. 22, no. 3, pp. 416–437, 2016. doi: http://dx.doi.org/10.3217/jucs-022-03-0416

[23] J. Dezert, A. Tchamova, D. Han, and J.-M. Tacnet, "The spotis rank reversal free method for multi-criteria decision-making support," in *2020 IEEE 23rd International Conference on Information Fusion (FUSION)*. IEEE, 2020. doi: https://doi.org/10.23919/FUSION45008.2020.9190347 pp. 1–8.

[24] J. Jankowski, W. Sałabun, and J. Wątróbski, "Identification of a multicriteria assessment model of relation between editorial and commercial content in web systems," in *Multimedia and Network Information Systems*. Springer, 2017, pp. 295–305.

[25] S. Goswami and S. Mitra, "Selecting the best mobile model by applying AHP-COPRAS and AHP-ARAS decision making methodology," *International Journal of Data and Network Science*, vol. 4, no. 1, pp. 27–42, 2020. doi: http://dx.doi.org/10.5267/j.ijdns.2019.8.004

[26] B. Bera, P. K. Shit, N. Sengupta, S. Saha, and S. Bhattacharjee, "Susceptibility of deforestation hotspots in Terai-Dooars belt of Himalayan Foothills: A comparative analysis of VIKOR and TOPSIS models," *Journal of King Saud University-Computer and Information Sciences*, 2021. doi: https://doi.org/10.1016/j.jksuci.2021.10.005

[27] J. Martins and F. Brito, "Alternative fuels for internal combustion engines," *Energies*, vol. 13, no. 16, p. 4086, 2020. doi: https://doi.org/10.3390/en13164086

[28] M. Sajjad, W. Sałabun, S. Faizi, M. Ismail, and J. Wątróbski, "Statistical and analytical approach of multi-criteria group decision-making based on the correlation coefficient under intuitionistic 2-tuple fuzzy linguistic environment," *Expert Systems with Applications*, vol. 193, p. 116341, 2022. doi: https://doi.org/10.1016/j.eswa.2021.116341

[29] Eurostat, *Final energy consumption in road transport by type of fuel*, 2022. [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/ten00127/default/table?lang=en

[30] J. Wątróbski, J. Jankowski, P. Ziemba, A. Karczmarczyk, and M. Zioło, "Generalised framework for multi-criteria method selection," *Omega*, vol. 86, pp. 107–124, 2019. doi: https://doi.org/10.1016/j.omega.2018.07.004

[31] E. Ziemba, "The contribution of ICT adoption to sustainability: Households' perspective," *Information Technology & People*, vol. 32, no. 3, pp. 731–753, 2019. doi: https://doi.org/10.1108/ITP-02-2018-0090

[32] A. Bączkiewicz, B. Kizielewicz, A. Shekhovtsov, J. Wątróbski, and W. Sałabun, "Methodical Aspects of MCDM Based E-Commerce Recommender System," *Journal of Theoretical and Applied Electronic Commerce Research*, vol. 16, no. 6, pp. 2192–2229, 2021. doi: https://doi.org/10.3390/jtaer16060122

[33] E. Ziemba, "The contribution of ICT adoption to the sustainable information society," *Journal of Computer Information Systems*, vol. 59, no. 2, pp. 116–126, 2019. doi: https://doi.org/10.1080/08874417.2017.1312635

[34] N. C. Onat, "How to compare sustainability impacts of alternative fuel Vehicles?" *Transportation Research Part D: Transport and Environment*, vol. 102, p. 103129, 2022. doi: https://doi.org/10.1016/j.trd.2021.103129

[35] A. Lindfors, R. Feiz, M. Eklund, and J. Ammenberg, "Assessing the potential, performance and feasibility of urban solutions: methodological considerations and learnings from biogas solutions," *Sustainability*, vol. 11, no. 14, p. 3756, 2019. doi: https://doi.org/10.3390/su11143756

[36] S. Dahlgren and J. Ammenberg, "Sustainability Assessment of Public Transport, Part II—Applying a Multi-Criteria Assessment Method to Compare Different Bus Technologies," *Sustainability*, vol. 13, no. 3, p. 1273, 2021. doi: https://doi.org/10.3390/su13031273

[37] J. Ammenberg and S. Dahlgren, "Sustainability Assessment of Public Transport, Part I—A Multi-Criteria Assessment Method to Compare Different Bus Technologies," *Sustainability*, vol. 13, no. 2, p. 825, 2021. doi: https://doi.org/10.3390/su13020825

[38] W. Chmielarz and M. Zborowski, "Towards sustainability in E-banking website assessment methods," *Sustainability*, vol. 12, no. 17, p. 7000, 2020. doi: https://doi.org/10.3390/su12177000

Springer, 2014. doi: https://doi.org/10.1007/978-3-319-11289-3_46 pp. 454–465.