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IMPLEMENTATION OF ELECTRIC ROAD TRANSPORT – POLAND IN COMPARISON WITH EUROPEAN COUNTRIES

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Purpose: Electromobility significantly changes the approach to road transport. Therefore, we decided to evaluate the implementation of electric vehicles in road transport in selected countries and compare Poland with the leaders in the transformation taking place in Europe.
Design/methodology/approach: Statistics on electromobility and national energy systems were obtained from Eurostat. We used statistical measures to measure the extent of progress of the introduced electric mobility solutions. We identified leaders in road transport transformation using the TOPSIS method.
Findings: The successful implementation of electromobility solutions in road transport across Europe is limited to a handful of countries that we have identified. Most countries do not have sufficiently developed grid infrastructure and charging stations. Poland compares very unfavourably with the leaders in road transport transformation and occupies roughly the same distant position in the rankings.
Research limitations/implications: The most recent data available are from 2021. In addition, some countries did not provide Eurostat with complete data on road transport and energy policy. It would be worthwhile to re-examine the study with completed data to understand the impact of the disrupted supply chains and the war in Ukraine that occurred in 2022.
Originality/value: This interdisciplinary study combines green logistics, statistical analysis of energy policy and multi-criteria optimisation. We propose a new way of evaluating consumer interest in electric vehicles. In addition, our set of criteria in the TOPSIS method includes an assessment of a country's energy security.

Keywords: electromobility, TOPSIS, energy transformation, energy policy.

Category of the paper: research paper.

1. Introduction

Logistics serves as the circulatory system of the modern economy. One of the key forms of logistics activity is road transport, where the impact of electromobility is increasingly evident. This is part of a "green logistics," aimed at reducing the negative environmental impact of

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logistics (Lee, 2012). This trend is unlikely to change, given the emphasis on implementing sustainable socio-economic development in the European Union (EU).

However, the concept of electromobility does not yet have a universally accepted definition. For instance, the Polish Act from 11th January 2018, on electromobility and alternative fuels does not provide such definition. Most publications also refrain from explicitly defining this term, although a recurring set of concepts and ideas describing electromobility can be identified. Koszowska and Rokicki (2021) noticed this.

We will consider electromobility to encompass issues arising from the use of electric vehicles (EV), including the technologies used in EVs, charging infrastructure, legal frameworks, and the social, economic, and environmental consequences. Electromobility significantly changes the approach to road transport, leading to transformations worthy of investigation (Reid et al., 2011). Therefore, our study has two main objectives:

1. Evaluate the extent of electromobility solutions implementation in road transport across selected European countries, expressed not only by changes in the structure of the existing car fleet but also by the manner it is fuelled.
2. Identify a group of countries leading the transformation of road transport and examine how Poland compares to them to assess the distance separating Poland from these leaders.

The article is structured as follows. The second section describes EU regulations related to reducing CO2 emissions, increasing the use of renewable energy and introducing electromobility affecting road transport. In the third section, we have included a literature review. The fourth section describes the algorithms of the TOPSIS method and the Shannon's entropy method. The fifth section presents the results of our study. The sixth section contains a discussion of the results of section five. The article concludes with a summary.

2. The impact of energy policy on road transport in Europe

Electricity nowadays is the basis for the functioning of virtually every area of life. Most daily-use equipment and machines are powered by it. Prolonged power outages pose a serious problem and threat, destabilising the economy (Schossig T., Schossig W., 2014). Naturally, electricity is exported and imported, but with current consumption we cannot rely solely on imports. In addition, advances in technology and civilisation are increasing the need for it (Samuel, Jan, 2020).

Renewable energy sources (RES) play a crucial role in the energy economy of European countries (Buonocore et al., 2019). The European Union, through European Commission directives, emphasizes the need to increase the share of RES in the energy mix. One of the most important documents is the Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. There, we find a definition of energy from renewable sources: it is energy from non-fossil sources, namely wind energy, solar energy (thermal and photovoltaic), aerothermal, geothermal, and hydrothermal energy, ambient heat, tidal, wave and other ocean energy, hydropower, energy from biomass, gas from landfills, sewage treatment plants and from biological sources (biogas). The EU's energy policy aims to fulfil the 2015 Paris Agreement on climate change by promoting renewable energy sources. This directive establishes a common framework for promoting energy from renewable sources in various sectors. Specifically, it:

- sets a binding EU target for the share of such energy in the energy mix by 2030,
- regulates self-consumption for the first time,
- establishes a common set of rules for the use of renewable energy in the electricity, heating and cooling, and transport sectors in the EU.

Increased use of renewable energy will significantly counteract climate change, support environmental protection, and reduce energy dependence. It will contribute to the EU's technological and industrial leadership, create new jobs, and promote growth, especially in rural and isolated areas. The directive mandates an overarching EU target for 2030 whereby a minimum of 32% of electricity generated in a Member State must originate from RES. From our perspective, the goals set in the transport sector are important, particularly the target of a 14% share of energy from renewable sources (Amin et al., 2020).

The law created by the European Commission compels vehicle manufacturers to implement new technical solutions leading to lower emissions. Regulations are also emerging mandating the recycling of lithium used in battery construction. Legislation is also being developed to mandate the recycling of lithium used in batteries. Therefore, we will commence this chapter with a brief discussion of the legal regulations introduced in the EU and Poland in recent years.

Firstly, we will mention the White Paper on Transport published by the EC in 2011. It outlines a plan for a unified European transport area and establishes several goals of EU transport policy, such as:

- A 60% reduction in GHG emissions from transportation by 2050 compared to 1990 levels. This will primarily require changes in vehicle propulsion and restrictions on the use of conventional vehicles in densely populated areas.
- Reduction of dependence on fossil fuels.
- Introduction of electromobility in transport following the principles of sustainable development (SD).

These goals should be achieved in harmony with maintaining the efficiency of road transport without limiting the mobility of its users. The set of strategies, recommendations, and initiatives from the White Paper continues to influence the transformation of road transport in Europe.

Another notable European legal act is the Directive on the Development of Alternative Fuel Infrastructure from 22th October 2014. It imposes obligations on member countries, including:

- The development of national policy frameworks for alternative fuel markets in the transport sector.
- The development of appropriate infrastructure for the production and supply of alternative fuels along with specified deadlines.
- The assumption that the average number of publicly accessible EVSE (Electric Vehicle Supply Equipment) points in 2020 should be at least one charging point per 10 EVs.

The implementation of this regulation will have an impact on the country's energy demand and security of supply, as electricity will be needed to operate the charging stations.

In 2016, the European Commission published the European Strategy for Low-Emission Mobility. In this document it addressed actions to achieve a reduction of at least 60% in GHG from the transport sector by 2050 compared to 1990 levels, progressively reducing these emissions to zero. The strategy includes actions such as optimising the transport system, promoting multimodality, increasing the use of low-emission alternative energy sources in transport, building infrastructure for alternative fuels, and transitioning to zero-emission transport.

In 2019, the European Green Deal was published, emphasising the commitment to achieve climate neutrality by 2050. It incorporates the "green transformation" into key cross-cutting programs and sectoral policies. The authors of the document identified infrastructure development as one of the strategic elements of the transition to a "clean", safe, and intelligent transport network.

Another document worth mentioning is the Strategy for Sustainable and Intelligent Mobility from 9th December 2020. It includes 82 initiatives in 10 key areas and specific actions to significantly reduce the current dependence on fossil fuels. Priorities include the development of affordable alternative solutions to increase demand for zero-emission vehicles, greater use of digital technologies supporting the functioning of an integrated multimodal transport network, and 'green' financing to increase the resilience of transport infrastructure.

The most recent European document is the Fit for 55% package, which took the form of a communication of the European Commission Communication in 2021. In essence, it is a set of interrelated proposals aimed at collectively ensuring the implementation of the ambitious climate policy of the EU. It is named after the plan to reduce GHG emissions by at least 55% by 2030 compared to 1990 levels. The document aims to achieve climate neutrality by 2050. The plan outlined in the document for the development of alternative fuels and infrastructure is important from a road transport perspective.

Laws adopted at the EU level influence regulations in member countries, including Poland. In response to the aforementioned legal acts, the Polish government and the Sejm (Polish Parliament) have developed and implemented a series of plans and regulations. Firstly, we mention the Development Plan for Electromobility in Poland 2016-2025 announced in 2016. It outlines three phases of development: (preparatory phase - 2016-2018, pilot projects phase - 2019-2020, implementation phase - 2020-2025). The plan complements a set of instruments aimed at contributing to the development of the electromobility industry, the modernisation and stabilisation of the power grid, and the creation of demand for electric vehicles. Within the second phase, projects such as e-Bus and e-Car were initiated. ElectroMobility Poland SA, a company created as part of the second project to design a modern electric city car.

A year later, the National Framework for the Development of Alternative Infrastructure was published. Among other things, it contains general and specific goals for the development of charging infrastructure. According to these goals, by the end of 2020, 6000 normal power and 400 high power charging points were to be deployed in 32 selected agglomerations in Poland. The pandemic and subsequent events hindered the implementation of this plan.

A crucial legal act is the Law from 11th January 2018, on Electromobility and Alternative Fuels with subsequent amendments. It defines the principles of development and functioning of the infrastructure necessary for using alternative fuels in transport. It aims to encourage drivers to choose electric vehicles and those powered by alternative fuels. Interestingly, there is no definition of electromobility as such in the Act. Instead, it defines many other concepts, e.g., an electric vehicle is a motor vehicle under road traffic law that uses exclusively electric energy accumulated by connecting to an external power source. The law allows municipalities to create clean transport zones, which are designated and appropriately marked areas where only vehicles meeting specific emission requirements can operate.

3. Literature review

While many publications on energy management focus on technical issues, we will highlight a few that consider the economic aspect. Many authors describe case studies. Dergiades, Martinopoulos, and Tsoulfidis (2013) focused on energy consumption and economic growth in Greece. The conclusion from their research provides valuable information for a more effective energy policy regarding both energy consumption and environmental protection. Energy-related analyses are very often addressed in relation to Asian countries. Rehman et al. (2023) investigated the impact of digitalisation on renewable electricity generation and identified both positive and negative effects of globalisation on renewable energy production in specific South Asian countries.

Aszódi et al. (2023) focused on the future impact of nuclear energy on decarbonisation and continuous electricity supply in the EU. They analysed the energy strategies of 15 European countries and then compared the impact of nuclear power plants on the mix of electricity production, carbon dioxide emissions, natural gas demand, and supply security in 2030 and

2040. Their results indicate that scenarios involving nuclear energy provide the lowest CO2 emissions. Closing such power plants, despite using solar and wind energy, increases CO2 emissions, limits supply, and requires larger energy storage. These findings have significant implications for the EU's energy policy, which advocates for a greater use of RES while simultaneously reducing reliance on nuclear and coal power.

Tansel Tugcu and Menegaki (2023) have a different perspective on the energy situation in Europe. They considered energy security as the most important one and examined the relationship between renewable energy generation and energy security in G7 countries between 1980 and 2018. They used several methods for this purpose. The results show a one-way causal relationship between renewable energy and energy security in the short term, while renewable energy generation significantly reduces the risk that threaten energy security in the long term. Tansel Tugcu and Menegaki suggested that due to the current energy crisis in Europe, there is an urgent need to increase the share of renewable energy generation to mitigate threats to energy security. The presented publications offer different perspectives and potential consequences of increasing the share of RES in the energy mix. There is an increasing interest in literature on the energy economy concerning the potential repercussions and impact of energy policy on technological advancement, predominantly reliant on electricity.

DeRosa et al. (2022) also consider energy security to be important. Their study shows a stable evolution of fuel mix diversification and a relatively low concentration in the European energy market over the period considered. They found that import dependence reduces energy security by about 30% due to the high share of imports from a limited number of countries.

One of the threats to Europe's energy security is the war in Ukraine. Osička and Černoch (2022) analysed this influence. They expect that the main objectives of EU policy will be to reduce energy vulnerability and accelerate decarbonisation, probably at the expense of the further development of the EU's integrated energy market in its current form. They concluded that the EU has the resources, knowledge base, and determination to turn the crisis into an opportunity.

We will discuss publications on electromobility from two points of view: general and multi-criteria optimisation.

Brdulak and Pawlak (2022) point out the challenges associated with the electrification of road transport, with a particular focus on transformations related to urban logistics. Many inaccuracies, terminological confusion and even deliberate marketing manipulation are currently slipping into the discussion on the transformation of car transport. We also noted the problem with terminology. The article also addresses the cost and infrastructure-related conditions associated with the implementation of electromobility in Polish road transport. Similar issues considered Drábik and Krnáčová (2018) in Slovakia, with a strong emphasis on the preferences of potential buyers of electric vehicles. Ehrler and Camilleri (2021) conducted a survey in Germany and France to assess the attractiveness of electric vehicles for users. Igliński (2018) performed a comparative analysis of the level of electromobility development in Poland compared to 10 countries in the region. Kłos et al. (2019) assessed the impact of developing electromobility on the Polish electricity system. They pointed out that the distribution subsector is most exposed to negative interactions with the expanding electric vehicle power grid infrastructure. Tamba et al. (2022) conducted an extensive analysis of the impact of electrification in the EU on road transport. They measured these impacts using a Computable General Equilibrium (CGE) model that combines techno-economic assumptions about electric vehicles with deployment scenarios derived from energy models.

Bednarczyk and Bielski (2021) aimed to determine if electromobility in the supply chain enhances its innovativeness. They identified the lack of a sufficiently developed charging network as a primary obstacle to the transformation of transportation. Cempírek et al. (2019) focused on electric freight transport, drawing on experiences from trolleybus operations. According to them, regardless of the type of power supply considered, the ecological efficiency of electric freight transport depends on the main method of energy generation, which varies between countries. Jedliński and Nürnberg (2022) focused on electric delivery vehicles for courier services, conducting simulations of deliveries for the Szczecin Metropolitan Area. Malladi et al. (2022) addressed a somewhat similar issue. They studied the problem of optimising the size and mix of a mixed fleet of electric and conventional vehicles owned by urban freight companies. Malladi et al. formulated a two-stage stochastic program and proposed a heuristic method based on sample-average approximation for its solution.

Charging infrastructure returns repeatedly in articles. Several publications discuss the selection of charging point locations, including (Szterlik-Grzybek, Kucharski, 2023) - the case of the city of Lodz (Poland), or (Guler, Yomralioglu, 2010) – Istanbul (Turkey). Both articles employed discrete multi-criteria optimisation. In (Philipsen et al., 2015) preferred locations for charging stations are indicated by users who participated in a special survey.

In the second part of the study, we used the TOPSIS method, which belongs to the group of multi-criteria optimization methods. The TOPSIS method is frequently encountered in research related to energy production and consumption, RES, and electromobility. Let's delve into the literature on this topic from the last few years.

To begin with, let us turn our attention to research on the role of various energy sources in sustainable economic development. Many authors opted for a fuzzy version of TOPSIS (FTOPSIS) due to difficulties in linguistically determining the importance of individual criteria. Afsordegan et al. (2016) highlighted the problem of uncertainty in determining precise evaluations of decision variants if the decision-maker uses a descriptive approach. Their study aimed to identify sustainable alternative energy sources that best align with decision-makers' preferences. They utilised their own modification of the TOPSIS, converting verbal descriptions provided by decision-makers into sets of labels. Bilgili et al. (2022) employed fuzzy TOPSIS to assess RES that were expected to ensure the sustainability of Turkey. They proposed the Intuitionistic Fuzzy TOPSIS (IF-TOPSIS), which they believed performs better for problems with numerous criteria and fluctuating decision-maker preferences.

Ervural et al. (2018) also focused on RES in Turkey, integrating multicriteria optimisation with SWOT analysis.

Publications on sustainability and energy transition from countries like Turkey make frequent appearances, which is not unexpected due to their efforts to swiftly catch up with more advanced economies. Şengül et al. (2015) created a ranking of RES available in the Turkey using FTOPSIS. They determined the criterion weights using Shannon’s entropy. Li et al. (2022) analysed a set of criteria for assessing the suitability of land for geothermal energy use in a province of China. They applied not only the classical TOPSIS method but also weights obtained by the entropy method. This approach made it possible to create maps of areas particularly suitable for this type of energy source. Yuan and Luo (2019) used 14 criteria to analyse China's energy security by province. Objective weights were determined by using the Mahalanobis-Taguchi Gram-Schmidt system and were then included in the SPA-TOPSIS (Set Pair Analysis TOPSIS) model.

Iqbal et al. (2021) explored Pakistan's challenges in adopting sustainable energy technologies in the industry. They combined two multicriteria optimisation methods: AHP and TOPSIS. A similar methodological approach but for Iran can be found in Sadat (2021). Sadat focused solely on barriers to photovoltaic development. Again, Pakistan is covered in a study by Solangi et al. (2019). They prepared ranking of 13 energy strategies for sustainable electricity supply planning. They also used AHP and SWOT. Rani et al. (2020) proposed an extensive algorithm for selecting RES, incorporating fuzzy TOPSIS and testing it on data from India.

Kay and Kahraman (2011) introduced a modified fuzzy TOPSIS to select among alternative energy sources. They concentrated on depicting technical, economic, environmental, and social aspects of energy production and consumption. Leng and Zhang (2023) conducted a study evaluating the progress of RES in selected countries on several continents. They used the classical TOPSIS method and proposed some ideas to promote the development of RES, including improving the efficiency of energy use, improving the renewable energy distribution system, and optimising the industrial structure.

In our research, we assess European countries using a set of predetermined criteria which outline, among other factors, their energy policies. Vavrek and Chovancová (2019) used seven indicators and the CV-TOPSIS (Coefficient of Variance TOPSIS) method. Their article aimed to provide a quantitative assessment of results of ongoing energy management and environmental measures in EU countries. While this study partially differs from ours, some criteria overlap. Wang et al. (2021) conducted an analysis covering 42 countries from all continents. They used the DEA technique to determine the most effective countries regarding producing renewable energy. They subsequently used fuzzy TOPSIS to highlight three countries with the highest capacity for renewable energy production.

The TOPSIS method also emerges in research on electromobility. Wątróbski et al. (2017) applied multicriteria optimisation to aid the selection of an electric vehicle for urban deliveries. The set of alternatives consisted of vans, and the criteria were divided into four groups, mainly focusing on technical parameters of vehicles. In addition to fuzzy TOPSIS, the authors used the PROMETHEE II method and placed the entire analysis in the context of urban logistics. Urban logistics also interested Wołek et al. (2021). Their analysis concerns the selection of bus lines on which diesel vehicles would be replaced with electric ones. Ziemba (2020) combined PROMETHEE with Monte Carlo simulation to give a tool to support the selection of electric vehicles for SD of local government units and state administration in Poland.

An interesting application of classical TOPSIS can be found in (Yildiz, 2021). Yildiz assessed the performance of batteries used in electric vehicles. Battery performance directly affects vehicle efficiency. The author examined six types of batteries by taking their technical parameters. Zhang et al. (2020) evaluated the quality of public chargers in China. They used TOPSIS and concluded that decision-makers in their country underestimate the importance of charger's availability. Zirganos et al. (2022) focused on promoting electromobility. They developed a methodology to assess a set of good practices based on predefined criteria. Combining expert knowledge and the AHP method, they determined weights for the criteria.

4. The TOPSIS Method

The transition of road transportation to electromobility solutions is a complex process. To describe and assess it correctly, a whole set of criteria should be used. Our goal is to determine the distance that separates Poland from the leaders in the transformation of road transportation. Therefore, we opted for multi-criteria optimisation. We have chosen the TOPSIS method, which in our opinion is best suited to achieving the stated goal.

The TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution) was developed by Hwang and Yoon (Hwang, Yoon, 1981; Cheng, Hwang, 1992). It falls under deterministic methods for multi-criteria optimisation. Its primary concept is to apply the principle of selecting decision variant that is closest to the ideal solution while simultaneously being the farthest from the anti-ideal solution.

Let's assume that the set of decision alternatives $A = \{\mathbf{a}_1, \ldots, \mathbf{a}_n\}$ is evaluated with respect to the set of criteria $F = \{f_1, \ldots, f_m\}$. Each criterion is assigned a weight w_k and $\sum_{k=1}^{n} w_k = 1$. We will now outline the successive steps of the TOPSIS method algorithm.

Step 1. Create the normalised matrix **N**. Calculate its elements using the formula:

$$x_{ik} = \frac{f_k(\mathbf{a}_i)}{\sqrt{\sum_{i=1}^{m} f_k(\mathbf{a}_i)^2}} \tag{1}$$

where: $f_k(\mathbf{a}_i)$ – evaluating variant $\mathbf{a}_i$ by criterion f_k, i = 1, …, m, k = 1, …, n

Step 2. Calculate the elements of the weighted normalised decision matrix:

$$v_{ik} = w_k x_{ik} \tag{2}$$

Step 3. Determine the weighted ideal solution:

$$v_k^+ = \begin{cases} \max\limits_i v_{ik} & k \in K^+ \\ \min\limits_i v_{ik} & k \in K^- \end{cases} \tag{3}$$

and the anti-ideal solution:

$$v_k^- = \begin{cases} \min\limits_i v_{ik} & k \in K^+ \\ \max\limits_i v_{ik} & k \in K^- \end{cases} \tag{4}$$

where K^+ represents the set of stimulant criteria, and K^- the set of destimulant criteria.

Step 4. Calculate the Euclidean distances separating the alternatives from the weighted ideal solution:

$$d_i^+ = \sqrt{\sum_{i=1}^{m} (v_{ik} - v_k^+)^2} \tag{5}$$

and the anti-ideal solution:

$$d_i^- = \sqrt{\sum_{i=1}^{m} (v_{ik} - v_k^-)^2} \tag{6}$$

Step 5. For each $\mathbf{a}_i$ calculate the relative distance from the weighted ideal solution:

$$s_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{7}$$

The s_i belongs to the interval $\langle 0,1 \rangle$. The closer the $\mathbf{a}_i$ is to the ideal solution, the greater the value of s_i becomes. In its final step the algorithm produces a ranking of decision alternatives based on the decreasing values of s_i.

The weights from formula (2) are relevant to the results. The classical approach assumes that ratings of the decision alternatives against criteria and the weights of criteria are known and expressed using real numbers. Experts can provide weights, but in real decision problems, decision-makers have difficulty in determining their preferences and judgments. If reliable weights cannot be determined, objective weights can be used. Abbreviations for technical terms will be explained upon first use. The Shannon's entropy method is one such procedure.

Our study employed this method, and the following description of the calculations is based on (Kacprzak, 2018; Lotfi, Fallahnejad, 2010; Kobryn, 2014).

The algorithm for determining weights in the Shannon's entropy method proceeds in the following steps:

Step 1. Construct matrix **Y**, where all criteria are of the stimulant type:

$$y_{ik} = \begin{cases} f_k(\mathbf{a}_i) & k \in K^+ \\ \dfrac{1}{f_k(\mathbf{a}_i)} & k \in K^- \end{cases} \tag{8}$$

Step 2. Create the normalised matrix **Z** with elements:

$$z_{ik} = \frac{y_{ik}}{\sum_{i=1}^{m} y_{ik}} \tag{9}$$

Step 3. Calculate the entropy vector **e**:

$$e_k = -\frac{1}{\ln m}\sum_{i=1}^{m} z_{ik} \ln z_{ik} \tag{10}$$

In the case where $z_{ik} = 0$ for a certain i, the value of the component $z_{ik} \ln z_{ik}$ equals to zero.

Step 4. Calculate the variability level vector d for each criterion:

$$d_k = 1 - e_k \tag{11}$$

Step 5. Calculate the criteria weight vector:

$$w_k = \frac{d_k}{\sum_{k=1}^{n} d_k} \tag{12}$$

5. Results

5.1. Dynamics of electricity production for chosen European countries

We will start by presenting the analysis of the production dynamics and the balance of electricity export and import in selected European countries. The data is sourced from Eurostat database. Figure 1 depicts the dynamics of electricity production in 2021 compared to 2014. With a different shade of grey we have marked the results for Poland and the EU. Poland performs well in this comparison. We chose 2014 as the base because, in May of that year, the European Commission and the Council published a communication about the EU's strategy for energy security. This was a response to concerns about the EU's energy dependence and disruptions in supply, aiming to ensure stable and ample energy supplies for the citizens and economy of Europe.

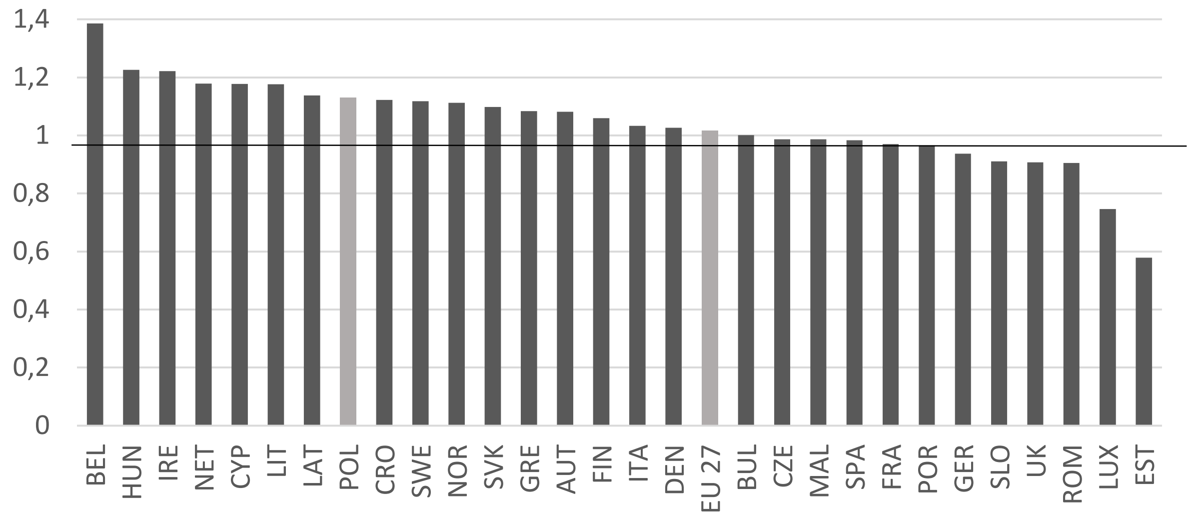

Figure 1. Dynamics of electricity production 2021/2014.

Source: own calculations.

Overall, the EU recorded a modest (2%) increase in electricity production, which is positive. However, current technology development significantly increases electricity consumption. The actions of Priority Axis I of the Operational Programme Infrastructure and Environment in Poland for the years 2014-2020 aimed to improve energy efficiency and increase the share of energy from RES. Hence, the 13% increase in electricity production in Poland.

Table 1.
Balance (Export - Import) of Electricity (GWh)

	2018	2019	2020	2021		2018	2019	2020	2021
AUT	-8946.8	-3128.6	-2195.8	-7543.2	**IRE**	27.73	-644.54	151.9	-1587.6
BEL	-17327.5	1854.6	332.9	7876.5	**ITA**	-43898.8	-38141.2	-32200.4	-42789.8
BUL	7807.3	5810.2	3408.1	8778.3	**LAT**	-908.9	-1118.08	-1625.6	-1772.6
CRO	-5387.6	-6133	-4639.3	-3961	**LIT**	-9632.5	-9343.6	-7908.5	-9043.7
CZE	13907.1	13096.6	10152.9	11075.3	**NET**	-7969.9	-855.235	2659.5	-252.9
DEN	-5224.3	-5810.9	-6882.6	-4868.8	**NOR**	10149.2	-44	20472.1	17583.8
EST	1897	-2157	-3644	-2629	**POL**	-5694.5	-10623	-13267	-887.8
EU 27	-8850.5	-2944.7	-13962.3	-7317.4	**POR**	2657	-3399.17	-1456.3	-4753
FIN	-19936	-20042	-15104	-17768	**ROM**	2544.4	-1518.02	-2792.3	-2199
FRA	62966.7	57667.1	45039.2	44892.3	**SLO**	502.2	318.556	2003.1	270.4
GER	48736	32667	19029	18575	**SPA**	-11102	-6862.3	-3279.6	-852.4
GRE	-6278	-9944	-8864	-3684	**SVK**	-3682	-1700	-319	-774
HUN	-14348	-12584	-11677	-12754	**SWE**	17223	26161	24997	25568

Source: own calculations.

Belgium leads this ranking with a growth of 39%, attributed to the maintenance of nuclear power plants and the construction of modern offshore wind farms (located at sea). Additionally, Belgium gradually increased the use of gas in its energy mix. Estonia closes the ranking. Its low electricity production dynamics (below 60%) is related to the closure of four oil shale energy blocks. The country has thus reduced its greenhouse gas emissions (GHG).

In Table 1, we present the electricity balance (in GWh) for selected European countries for the period 2018-2021. It is the difference between electricity exports and imports. Countries with a positive annual electricity balance produce more electricity than their demand.

Countries with a favourable geographical location, such as the Scandinavian countries, take advantage of the natural conditions to produce larger amounts of electricity. They are thus becoming the leading suppliers in Europe. Countries utilising nuclear energy also exhibit a positive balance in the examined years. An example is France, which has the most nuclear reactors in Europe with a total capacity of more than 63,000 megawatts. Nuclear power plants alone make it possible to meet about 75% of French electricity demand. There have been fluctuations in Poland's balance value, however, it has consistently remained negative. Despite Poland possessing natural coal deposits, the EU climate policy is pushing the country to abandon this fuel.

5.2. Status of electromobility road transport implementation in Europe

To assess and compare the degree of implementation of electromobility solutions in selected European countries, we calculated an index giving the number of electric vehicles per 1000 internal combustion engine vehicles. We present this index separately for passenger cars, buses and coaches, and trucks for the period 2018-2021. Our index measures consumer interest in electric vehicles. A higher value indicates a greater significance of electromobility in the transportation sector of a given country.

In Table 2, we presented the number of passenger electric cars per 1000 of their combustion engines counterparts. We have not taken hybrids or plug-in hybrids into account. The denominator includes cars powered exclusively by petrol and diesel engines.

Table 2.
Number of electric cars per 1,000 equivalent internal combustion engine vehicles

Country	2018	2019	2020	2021	Country	2018	2019	2020	2021
AUT	4.24	5.96	8.98	15.57	**LAT**	0.67	0.97	1.74	2.95
BEL	1.62	2.68	4.24	7.33	**LIT**	0.74	1.02	1.74	3.32
CRO	0.29	0.44	0.78	1.74	**NET**	5.57	13.08	21.36	30.66
DEN	3.89	5.90	11.98	25.20	**NOR**	82.54	112.69	148.51	211.04
EST	1.70	1.77	2.24	3.07	**POL**	0.15	0.25	0.46	0.84
FIN	0.73	1.40	2.88	6.89	**POR**	1.93	3.42	5.00	8.02
FRA	2.84	3.77	6.58	10.94	**ROM**	0.17	0.41	0.81	1.66
GER	1.80	2.93	6.65	13.49	**SLO**	1.16	1.74	3.20	4.67
HUN	1.07	1.77	2.90	4.88	**SPA**	1.10	1.64	2.36	2.74
IRE	2.16	3.94	5.79	9.88	**SWE**	3.74	6.85	12.77	26.01
ITA	0.34	0.64	1.50	3.38					

Source: own calculations.

Norway has the highest ratio values in all years. It ranges from around 83 to more than 200 electric cars per thousand combustion cars. Norway surpasses other European countries in this regard. Only in 2021 do some countries, such as the Netherlands or Sweden, reach a level of EV saturation that deems electromobility significant. However, this is still around 25-30 electric cars per 1000 combustion cars. At the other end of the scale is Poland, which performs the worst of all the countries. It loses even to countries with theoretically weaker economies.

In all countries, the ratio of the number of electric to combustion cars is increasing over time. These changes range from tens to over a hundred percent year-on-year. Italy, for instance, recorded growth of 86%, 135%, and 116%, respectively. On the other hand, the growth rate slowed down in 2021 for almost all countries, which may be related to the prevailing COVID-19 pandemic at that time.

Diesel buses, vans, etc. (see Table 3) had only diesel engines due to the lack of data on petrol engines for this category. The number of countries slightly decreased due to the unavailability of data from Estonia and Ireland.

The values shown in Table 3 are not as straightforward as those for passenger cars. One reason is that a higher number of countries have electric buses compared to diesel ones, mainly because local authorities regulate public transport and can more readily introduce electromobility solutions. The EU's Strategy for Sustainable and Smart Mobility has backed the adoption of these greener buses which have replaced their older counterparts.

Table 3.
Number of electric buses per 1,000 equivalent internal combustion engine vehicles

Country	2018	2019	2020	2021	Country	2018	2019	2020	2021
AUT	16.01	16.50	17.93	18.06	**LIT**	61.06	71.16	62.18	60.46
BEL	1.22	2.85	4.51	6.03	**NET**	45.75	91.53	164.95	208.56
CRO	0.52	0.51	0.59	1.19	**NOR**	2.92	13.78	31.32	39.21
DEN	0.56	6.94	7.86	28.04	**POL**	5.35	3.47	5.47	7.56
FIN	1.31	3.40	4.80	14.79	**POR**	2.54	4.44	6.66	8.74
FRA	5.16	8.07	9.64	17.53	**ROM**	0.27	1.29	2.97	4.74
GER	2.91	4.89	10.17	17.32	**SLO**	1.46	2.17	2.71	2.38
HUN	1.29	1.16	2.60	5.34	**SPA**	4.20	6.72	7.87	5.50
ITA	5.15	5.72	5.47	7.95	**SWE**	9.95	26.19	57.71	81.21
LAT	56.15	59.25	70.34	81.29					

Source: own calculations.

The Netherlands performed exceptionally well in Table 3, surpassing even Norway, the leader in Table 2. It has the most favourable ratio of electric to combustion vehicles. Croatia achieved the weakest results. Poland ranked in the second ten, surpassing Belgium but lagging behind Portugal.

The dynamics of the indicator also proved to be much more diverse. Over the first three years, we mainly observe increases in the number of electric buses per 1000 combustion equivalents. However, in 2021, some countries experienced a decrease. This was the case in Spain (30% drop) or Slovenia (12% decrease). In other countries, the indicator continued to grow compared to 2020 but much less.

Table 4 presents the number of electric heavy-duty vehicles per 1000 combustion equivalents. It includes the fewest number of countries, as only a few have published relevant data. This is partly due to the importance of the transport sector in their economies and partly due to the practice of collecting statistical data.

Table 4.
Number of electric heavy-duty vehicles per 1000 equivalent internal combustion engine vehicles

Country	**2018**	**2019**	**2020**	**2021**	**Country**	**2018**	**2019**	**2020**	**2021**
AUT	4.56	5.34	6.59	10.50	**NET**	3.36	4.57	6.14	9.12
FIN	0.54	0.62	0.83	1.35	**NOR**	9.69	13.19	17.58	17.73
FRA	6.25	7.19	8.19	9.46	**POL**	0.58	0.74	0.57	0.76
GER	5.67	7.57	9.63	12.62	**POR**	0.46	0.69	0.92	1.22
HUN	0.79	0.98	1.36	2.03	**SPA**	1.16	1.49	1.84	2.17
ITA	1.40	1.30	1.46	2.24	**SWE**	4.25	6.20	9.11	12.94

Source: own calculations.

Once again, Norway stands out the most, although its advantage over countries like Sweden or Germany is not as significant. Poland performs the weakest in 2020 and 2021, although even before its index was low. As a country located at the crossroads of trade routes, Poland has a transport sector that is significant for Europe. However, it is highly fragmented, with small companies responsible for most transportation. Until now, they have invested in car fleets powered by combustion engines. Due to frozen capital in these vehicles, leasing agreements, etc., they cannot quickly switch to electric vehicles. Limited charging infrastructure, especially along international and national roads, is also an important factor.

Polish companies often undertake long-distance cargo transport, so combustion engines still lack competition. Nevertheless, over four years, the indicator increased in all surveyed countries each year. Even in 2021, these increases reached tens of percent, except for Norway, where it was only 1%.

5.3. Multi-criteria ranking of countries using the TOPSIS method

Fuzzy methods require each decision option to be described by a certain set of numbers (e.g., three for triangular fuzzy numbers) instead of one. This approach is employed when decision-makers may struggle to unambiguously determine the value of available options. We chose the classical TOPSIS method because our study relied on annual macro data, sourced from reliable government institutions. The greater challenge was the selection of criteria themselves due to data gaps than the values available for decision variants, i.e., countries. Below, we present our set of criteria:

1. Share of electricity import (C1).
2. Share of renewable electricity in total energy consumption in the transport sector (C2).
3. Newly registered electric passenger cars [units] (C3a).
4. Newly registered electric commercial vehicles [units] (C3b).
5. Final electricity consumption in the road transport sector [kt of oil equivalent] (C4).

We divided the study into two parts according to criterion C3. One set of rankings was based on criteria C1, C2, C3a, and C4, while the other used C1, C2, C3b, and C4. This enabled us to analyse the implementation of electromobility regarding both personal passenger transport (private cars) and heavy road transport, independently. Trucks in the study are the sum of vehicles up to 3.5 tons and those above. The first study covered 19 European countries (not only from EU) for the years 2014-2021. In the second, we included data from 16 countries for the years 2017-2021. There are two reasons behind this: to separate commercial road transport from private passenger transport and to address the lack of data, as some countries did not publish data on commercial transport required for our study. We therefore had to limit the time horizon to ensure the highest possible number of decision variants.

The study focused solely on electric vehicles, which must be charged. This creates an additional demand for electricity. Hence, we added the final electricity consumption in the road transport sector (criterion C4). We also expect that the more popular electromobility is in a country, the more electricity comes from renewable sources. This is due, among other things, to the regulations introduced within the EU. This is why we introduced criterion C2, i.e., the share of renewable electricity in total energy consumption in the transport sector. Finally, the demand for electricity generated by the transport sector influences a country's energy security. Criterion C1, i.e., the share of electricity import, aims to introduce the security aspect into the study. Incidentally, it is the only destimulant among all criteria.

Table 5.
Weights determined for criteria, divided into passenger and commercial vehicles

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Criteria	**Passenger cars**							
K1	0.3276	0.1146	0.3084	0.3227	0.3382	0.3242	0.293	0.2967
K2	0.309	0.4312	0.3268	0.3201	0.3358	0.3271	0.3596	0.3567
K3a	0.118	0.1653	0.1513	0.1653	0.152	0.1608	0.1474	0.1404
K4	0.2454	0.2889	0.2134	0.1919	0.174	0.188	0.2	0.2063
	Heavy-Duty Trucks							
K1				0.3724	0.3683	0.34	0.2853	0.2834
K2				0.3777	0.3706	0.3475	0.3712	0.3576
K3b				0.0598	0.1001	0.1288	0.1534	0.1794
K4				0.1901	0.1611	0.1837	0.1901	0.1795

Source: own calculations.

Table 5 shows the weights determined by the Shannon's entropy method. We determined a separate set of weights for each year and the two study options. For criteria C3a and C3b, weights took the lowest values, while the highest occurred for criteria C1 and C2.

Table 6 shows the first part of results from the TOPSIS method. These rankings indicate the performance of each country based on the criteria adopted, with 1 being the best performing option. The dark grey colour cells indicate the top five countries in each year. Bold numerical values highlight the three worst countries in each ranking. We chose to highlight the top five positions in the rankings, as the first two places belong, throughout the entire study period, to Norway and Sweden. Their dominance is particularly evident towards the end of the sample. On the other hand, greater variability is observed in positions 3 to 5, where countries such as Germany and the Netherlands appear and have been trying hard to develop electromobility in recent years.

Table 6.
TOPSIS rankings for passenger cars

Country	2014	2015	2016	2017	2018	2019	2020	2021
AUT	7	7	6	7	7	7	12	12
BEL	14	15	11	12	10	10	8	9
CRO	**19**	**17**	**19**	**19**	**19**	**17**	**18**	14
DEN	13	11	9	13	11	14	13	7
EST	**17**	**19**	**17**	**18**	**18**	15	7	8
FIN	1	2	7	4	6	6	6	4
FRA	3	4	3	3	5	5	5	6
GER	6	6	5	5	4	4	3	3
HUN	11	8	8	8	9	11	9	**17**
IRE	15	12	14	10	12	9	14	**19**
LAT	8	14	16	16	16	**18**	**17**	15
LIT	10	13	15	15	**17**	**19**	**19**	16
NET	5	5	4	6	3	3	4	5
NOR	2	1	1	1	1	1	1	2
POL	12	10	13	11	14	16	16	**18**
ROM	9	9	10	14	13	12	15	13
SLO	**18**	**18**	**18**	**17**	15	13	11	11
SPA	16	16	12	9	8	8	10	10
SWE	4	3	2	2	2	2	2	1

Source: own calculations.

The bottom positions in the rankings, i.e., the weakest results based on the adopted criteria, are occupied by smaller countries with less developed economies such as Croatia or the Baltic countries (Lithuania, Latvia, and Estonia).

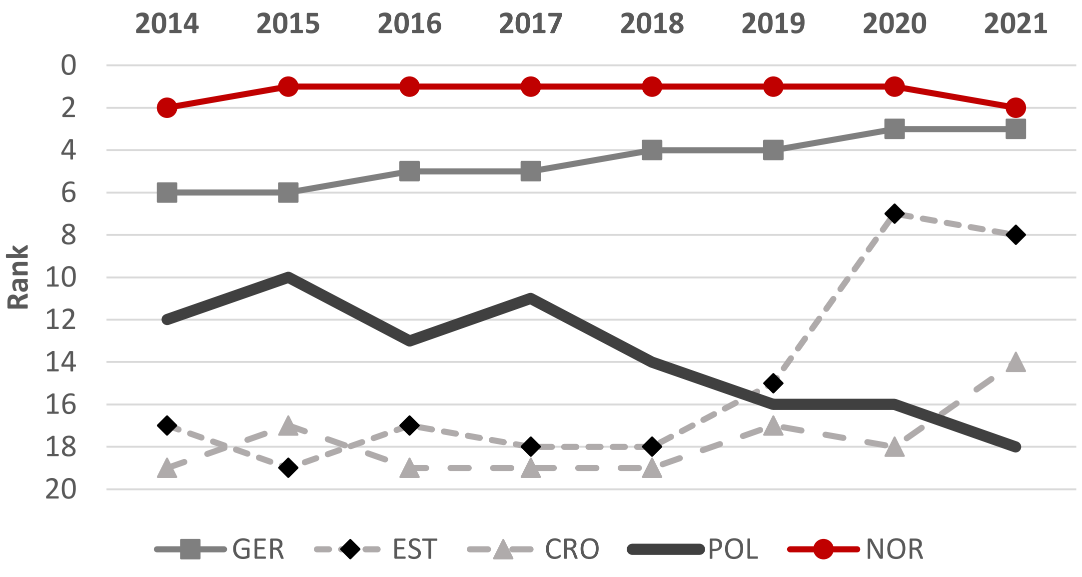

Figure 2. Changes in rankings over time for passenger cars.
Source: own calculations.

Table 7.
TOPSIS rankings for heavy-duty trucks

Country	2017	2018	2019	2020	2021
AUT	7	7	7	10	9
CRO	**16**	**16**	**14**	**15**	11
EST	**15**	**15**	12	7	8
FIN	3	4	6	6	4
FRA	4	3	4	4	5
GER	6	6	5	3	3
HUN	9	10	11	9	**14**
IRE	10	11	10	11	**16**
LAT	**14**	13	**15**	**14**	12
LIT	12	**14**	**16**	**16**	13
NET	5	5	3	5	6
NOR	1	1	1	1	2
POL	13	12	13	13	**15**
POR	8	8	9	12	10
SPA	11	9	8	8	7
SWE	2	2	2	2	1

Source: own calculations.

Figure 2 illustrates the changes in rankings over time for a few selected countries. Over an eight-year period, Norway has typically ranked first, outclassing the other countries. This is due to both its energy policy (Norway exports large amounts of electricity) and its measures to promote electromobility. However, noteworthy are Germany's methodical ascent in the rankings and Estonia's substantial improvement since 2019. Estonia is the only one of the Baltic states to have seen such a big improvement. The bold line without markers corresponds to Poland. Since 2015, it has gradually declined in the rankings. 2015 saw the seizure of power by the Law and Justice party, which maintained its rule until the end of the surveyed sample. The party advocates for a strong reliance on coal in the energy sector for several more decades. Additionally, Polish government efforts to increase the share of RES in the energy mix and promote electromobility proved to be largely ineffective. Consequently, the large gap between Poland and leaders like Norway or Germany has grown over time.

Table 7 presents another summery of TOPSIS rankings, this time for heavy-duty trucks. Like in the previous table, dark grey shading indicates the five highest ranks, while bold formatting highlights the three lowest values. Once again, the results in Table 7 are dominated by Norway and Sweden. France, which has a large transport sector, also performed well. The bottom positions in the rankings still belonged to Croatia and the Baltic countries.

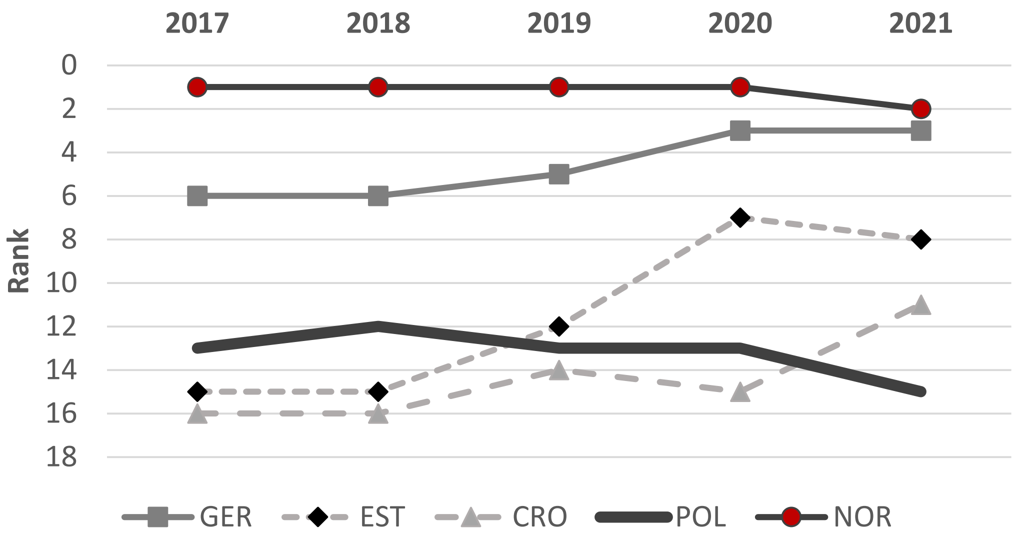

Figure 3. Changes in rankings over time for heavy-duty trucks.

Source: own calculations.

In Figure 3, we present a graph of the change in rankings over time for the same countries as before. This figure concerns electric trucks. Germany again showed an improvement in rankings. Estonia, as was the case for passenger vehicles, has started to climb very strongly in 2019. Poland's situation is only slightly better when it comes to heavy-duty trucks. The declining trend has clearly weakened, yet the distance from the ranking leaders remains substantial.

6. Discussion

The electricity economy and electromobility are closely intertwined. A well-functioning power grid fosters innovation and increased interest in electric vehicles. In countries facing an energy crisis, consumer and business interest in electrically powered equipment and machinery declines. Moreover, European countries are witnessing a rising share of RES in the energy mix resulting from the EU's climate and emissions reduction policies. These factors are influencing the development of electromobility on the continent. Part two of the article showed how much the development of road transport is affected by the regulations introduced by the EU and the parliaments of the Member States. EC directives and Polish laws regularly emphasise the importance of developing infrastructure for the operation and charging of electric vehicles. After all, the lack of infrastructure is seen as the biggest obstacle to the development of electromobility.

Electricity production is one component of the European energy economy. The other is its export and import. An extensive energy network connecting individual countries minimises network overloads and transfers energy between states according to demand. This not only stabilises the network but also minimises energy losses. In addition, energy storage facilities are being developed to store surplus production, but this is not an ideal solution. Governments, energy distributors, and leading energy storage component companies recognise the following problem: modern energy storage methods are neither efficient enough nor cost-effective.

The balance between electricity exports and imports is important for the country's energy security. Based on the results in subsection 5.1 (see Table 1), we find that only a few countries have a surplus of energy that they can export. Poland is not in this group.

As our first objective, we aimed to evaluate the extent to which electromobility solutions have been implemented in road transport. The data utilised in this study allows for the following conclusions to be drawn:

1. There are very large differences in the popularity of electromobility among European countries. Only in a few countries has this process yielded significant results. In most of them, the transportation sector is just beginning the electric transformation, with public bus transport performing best in this regard.
2. All countries experience a year-on-year increase in the number of electric vehicles compared to their combustion counterparts. The aforementioned transformation is therefore taking place across Europe even if the pace varies from country to country.

In subsection 5.2 we opted for the number of newly registered vehicles instead of the total number. The greater diversity in the former better reflects changes in transitioning to electromobility over time and differences between countries. Additionally, interest in purchasing EVs is strongly linked to technical solutions used. The gradual development of batteries increases a vehicle's range, which is important for potential buyers who may still choose a combustion engine vehicle. The study therefore needed a variable to somehow represent the technical progress being made with electric cars, and in our opinion, it is the number of newly registered vehicles that describes this process well.

The criteria used in TOPSIS take into account the popularity of electromobility, energy security and the relationship between road transport and RES. Both parts of the analysis (cars and trucks) in subsection 5.3 were dominated by Norway and Sweden. These countries had a surplus of electricity exports over imports. However, this is not the only reason for their dominance as other countries with a surplus perform much less well, e.g. Slovenia. It is the size of the export surplus and the related strength of the economy that is decisive. We have pointed this out when describing the rankings in Tables 6 and 7.

7. Conclusions

We have met both goals stated in the introduction. The implementation of electromobility solutions in road transport across Europe is limited to only a handful of countries, namely Norway, Sweden, the Netherlands, and Germany. However, this implementation aligns with the European Commission's plans outlined in a series of documents. Public bus transportation performs particularly well in this regard. Most countries do not have sufficiently developed grid infrastructure and charging stations. On the other hand, we have observed a clear upward trend in the number of electric vehicles compared to their combustion counterparts. This trend applies to the entire EU, although there are differences among member states.

Poland compares very poorly with the leaders in road transport transformation and occupies roughly the same distant position in the rankings. In the case of passenger cars, it has been steadily declining since 2015. Government actions have not yielded sufficient results, and Poland can compare itself with other Central and Eastern European countries rather than with Western Europe.

We have demonstrated that the use of RES and electromobility in transportation is undergoing dynamic changes. EU authorities are aware of the reasons that hindered their ambitious plans. They will certainly take remedial actions. It is therefore worth monitoring these processes and continuing research in the future.

References

1. Act from 11th January 2018 on electromobility and alternative fuels, Journal of Laws 2018, item 317 (2018).
2. Afsordegan, A., Sánchez, M., Agell, N., Zahedi, S., Cremades, L.V. (2016). Decision making under uncertainty using a qualitative TOPSIS method for selecting sustainable energy alternatives. *International Journal of Environmental Science and Technology, 13,* pp. 1419-1432, doi: 10.1007/s13762-016-0982-7
3. Amin, A., Altinoz, B., Dogan, E. (2020). Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. *Clean Techn Environ Policy, 22,* pp. 1725-1734, doi: https://doi.org/10.1007/s10098-020-01910-2
4. Aszódi, A., Biró, B., Adorján, L., Csaba Dobos, A., Illés, G., Krisztián Tóth, N., Zagyi, D., Tas Zsiborás, Z. (2023). The effect of the future of nuclear energy on the decarbonization pathways and continuous supply of electricity in the European Union. *Nuclear Engineering and Design, Vol. 415,* doi: 10.1016/j.nucengdes.2023.112688.

5. Bednarczyk, M., Bielski, B. (2021). Is Electromobility In The Supply Network A Good Way To Increase Innovation? *Acta Universitatis Nicolai Copernici. Zarządzanie, 48(1).* pp. 17-28, doi: 10.12775/AUNC_ZARZ.2021.01.002.
6. Bilgili, F., Zarali, F., Ilgün, M.F., Dumrul, C., Dumrul, Y. (2022). The evaluation of renewable energy alternatives for sustainable development in Turkey using intuitionistic fuzzy-TOPSIS method. *Renewable Energy, 189*, pp. 1443-1458, doi: 10.1016/j.renene. 2022.03.058.
7. Brdulak, J., Pawlak, P. (2022). Międzynarodowe aspekty jakościowych zmian transportu samochodowego związane z elektromobilnością. *Kwartalnik Nauk o Przedsiębiorstwie, 66(4)*, pp. 5-16, doi: 10.33119/KNoP.2022.66.4.1.
8. Buonocore, J.J., Choma, E., Villavicencio, A.H. et al. (2019), Metrics for the sustainable development goals: renewable energy and transportation, *Palgrave Commun 5, no. 136*, doi: https://doi.org/10.1057/s41599-019-0336-4
9. Cempírek, V., Rybicka, I., Ljubaj, I. (2019). Development of Electromobility in Terms of Freight Transport. *LOGI – Scientific Journal on Transport and Logistics, vol. 10, no. 2*, pp. 23-32, doi: 10.2478/logi-2019-0012
10. Chen, S.J., Hwang, C.L. (1992). *Fuzzy Multiple Attribute Decision Making: Methods and Applications.* Berlin: Springer.
11. Communication from the Commission to the European Parliament and the Council. "European Energy Security Strategy" COM(2014)330 (2014).
12. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, "European Strategy for Low-Emission Mobility," COM/2016/0501 final (2016).
13. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, "The European Green Deal," COM/2019/640 final (2019).
14. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, "Sustainable and Smart Mobility Strategy – European Transport on the Road to the Future", COM/2020/789 final (2020).
15. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, "'Fit for 55': Achieving the EU's 2030 climate target on the way to climate neutrality", COM/2021/550 final (2021).
16. De Rosa, M., Gainsford, K., Pallonetto, F., Finn, D. (2022). Diversification, concentration and renewability of the energy supply in the European Union. *Energy, Vol. 253*, p. 124097, doi: 10.1016/j.energy.2022.124097.

17. Dergiades, T., Martinopoulos, G., Tsoulfidis, L. (2013). Energy consumption and economic growth: Parametric and non-parametric causality testing for the case of Greece. *Energy Economics, Vol. 36*, pp. 686-697, doi: 10.1016/j.eneco.2012.11.017.
18. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11th December 2018 (2018).
19. Directive 2014/94/EU of the European Parliament and of the Council of 22th October 2014 on the development of alternative fuels infrastructure Text with EEA relevance (2014).
20. Drábik, P., Krnáčová, P. (2018). Socio-economic barriers and development opportunities of electromobility as key technological innovation of transportation. *International Journal of Multidisciplinarity in Business and Science, Vol. 4, No. 5,* pp. 91-98.
21. Ehrler, V., Camilleri, P. (2021). Optimising the acceptance of electric vehicles for urban logistics with evidence from France and Germany. *RTS. Recherche, Transports, security, Logistics practices and freight transport challenges: a French-German comparison*.
22. *Electromobility development plan in Poland "Energy for the future".* Ministry of Energy. Retrieved from: https://www.gov.pl/attachment/75d21d4a-fd28-400e-b480-a3bbc3f7db5e, 31.10.2023.
23. Ervural, B.C., Zaim, S., Demirel, O.F., Aydin, Z., Delen, D. (2018). An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning. *Renewable and Sustainable Energy Reviews, 82*, pp. 1538-1550, doi: 10.1016/j.rser.2017.06.095.
24. European Commission, Directorate-General for Mobility and Transport, White Paper on Transport: Roadmap to a Single European Transport Area - Towards a competitive and resource-efficient transport system (2011), doi: 10.2832/34321
25. Guler, D., Yomralioglu, T. (2020). Suitable location selection for the electric vehicle fast charging station with AHP and fuzzy AHP methods using GIS. *Annals of GIS, 26, 2*, pp. 169-189, doi: 10.1080/19475683.2020.1737226.
26. Hwang, C.L., Yoon, K. (1981). *Multiple Atribute Decision Making Methods and Applications: A State-of-the-Art Survey.* New York: Springer-Verlag.
27. Iqbal, M., Ma, J., Ahmad, N., Ullah, Z., Ahmed, R.I. (2021). Uptake and Adoption of Sustainable Energy Technologies: Prioritizing Strategies to Overcome Barriers in the Construction Industry by Using an Integrated AHP-TOPSIS Approach. *Advanced Sustainable Systems, 5*, pp. 1-21, doi: 10.1002/adsu.202100026
28. Jedliński, M., Nürnberg, M. (2022). Application of the Experimental Method in the Assessment of the Electromobility Paradigm for Courier Shipments in an Urban Agglomeration. *Energies, MDPI, vol. 15(24)*, pp. 1-17, doi: 10.3390/en15249573
29. Kacprzak, D. (2018). Metoda SAW z przedziałowymi danymi i wagami uzyskanymi za pomocą przedziałowej entropii Shannona. *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach, nr 348*, pp. 144-155.

30. Kaya, T., Kahraman, C. (2011). Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications, 38*, pp. 6577-6585, doi: 10.1016/j.eswa.2010.11.081.
31. Kłos, M., Marchel, P., Paska, J., Bielas, R., Bartecka, M., Michalski, Ł., Wróblewski, K., Zagrajek, K. (2019). Forecast and impact of electromobility development on the Polish Electric Power System. *E3S Web of Conferences, 84, 01005*. doi: 10.1051/e3sconf/20198401005.
32. Kobryń, A. (2014). *Wielokryterialne wspomaganie decyzji w gospodarowaniu przestrzenią*. Warszawa: Difin.
33. Koszowska, N., Rokicki, T. (2021). Development of electromobility in Poland through the use of electric road transport. *Economics and Organization of Logistics, 6(3)*, pp. 33-40, doi: 10.22630/EIOL.2021.6.3.20
34. Lee, A., Zinaman, O., Logan, J. (2012). *Opportunities for Synergy Between Natural Gas and Renewable Energy in the Electric Power and Transportation Sectors, technical report*. United States, doi: https://doi.org/10.2172/1060601
35. Leng, Y.-J., Zhang, H. (2023). Comprehensive evaluation of renewable energy development level based on game theory and TOPSIS. *Computers & Industrial, 175*, 108873, doi: 10.1016/j.cie.2022.108873.
36. Li, Z., Luo, Z., Wang, Y., Fan, G., Zhang, J. (2022). Suitability evaluation system for the shallow geothermal energy implementation in region by Entropy Weight Method and TOPSIS method. *Renewable Energy, 184*, pp. 564-576, doi: 10.1016/j.renene.2021.11.112.
37. Lotfi, F.H., Fallahnejad, R. (2010). Imprecise Shannon's Entropy and Multi Attribute Decision Making. *Entropy, 12*, pp. 53-62, doi: 10.3390/e12010053
38. Malladi, S.S., Christensen, J.M., Ramirez, D., Larsen, A., Pacino, D. (2022). Stochastic fleet mix optimization: Evaluating electromobility in urban logistics. *Transportation Research Part E: Logistics and Transportation Review, vol. 158*, 102554, doi: 10.1016/j.tre.2021.102554.
39. *National policy framework for the development of alternative infrastructure* (2017). Council of Ministers. Journal of Laws 2023, item 875.
40. Osička, J., Černoch, F. (2022). European energy politics after Ukraine: The road ahead, *Energy Research & Social Science, vol. 91*, p. 102757, doi: 10.1016/j.erss.2022.102757.
41. Philipsen, R., Schmidt, T., Ziefle, M. (2015). A Charging Place to Be - Users' Evaluation Criteria for the Positioning of Fast-charging Infrastructure for Electro Mobility. *Procedia Manufacturing, 3*, pp. 2792-2799, doi: 10.1016/j.promfg.2015.07.742.
42. Rani, P., Mishra, A.R., Mardani, A., Cavallaro, F., Alrasheedi, M., Alrashidi, A. (2020). A novel approach to extended fuzzy TOPSIS based on new divergence measures for renewable energy sources selection. *Journal of Cleaner Production, 257*, 120352, doi: 10.1016/j.jclepro.2020.120352.

43. Rehman, F., Islam, M., Ullah, M., Khan, R., Rehman, R. (2023). Information digitalization and renewable electricity generation: Evidence from South Asian countries. *Energy Reports, Vol. 9*, pp. 4721-4733, doi: 10.1016/j.egyr.2023.03.112.
44. Reid, A., Lonza, L., Rose, K.D., Maas, H., Hass, H. (2011). *EU renewable energy targets in 2020: Analysis of scenarios for transport.* doi: 10.2788/749 4810.2788/74948.
45. Sadat, S.A., Fini, M.V., Hashemi-Dezaki, H., Nazififard, M. (2021). Barrier analysis of solar PV energy development in the context of Iran using fuzzy AHP-TOPSIS method. *Sustainable Energy Technologies and Assessments, 47*, 101549, doi: 10.1016/j.seta.2021.101549.
46. Samuel, T., Jan, R. (2020). Drivers of increasing energy consumption in Europe and policy implications, *Energy Policy, Vol. 137(9), 111108*, doi: https://doi.org/10.1016/j.enpol.2019.111108
47. Schossig, T., Schossig, W. (2014). *Disturbances and blackouts — Lessons learned to master the Energy Turnaround.* 12th IET International Conference on Developments in Power System Protection (DPSP 2014), Copenhagen, pp. 1-6, doi: 10.1049/cp.2014.0003
48. Şengül, Ü., Eren, M., Shiraz, S.E., Gezder, V., Şengül, A.B. (2015). Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renewable Energy, 75*, pp. 617-625, doi: 10.1016/j.renene.2014.10.045.
49. Solangi, Y.A., Tan, Q., Mirjat, N.H., Ali, S. (2019). Evaluating the strategies for sustainable energy planning in Pakistan: An integrated SWOT-AHP and Fuzzy-TOPSIS approach. *Journal of Cleaner Production, 236, 117655*, doi: 10.1016/j.jclepro.2019.117655.
50. Szterlik-Grzybek, P., Kucharski, A. (2023). Assessment of the possibility of locating electric car charging stations using Fuzzy AHP and GIS – the case of Łódź, Poland. *Economics and Environment, 84(1)*, pp. 134-148. doi: 10.34659/eis.2023.84.1.540
51. Tamba, M., Krause, J., Weitzel, M., Ioan, R., Duboz, L., Grosso, M., Vandyck, T. (2022). Economy-wide impacts of road transport electrification in the EU. *Technological Forecasting and Social Change, Vol. 182*, p. 121803, doi: 10.1016/j.techfore.2022.121803.
52. Tansel Tugcu, C., Menegaki, A.N. (2024). The impact of renewable energy generation on energy security: Evidence from the G7 countries. *Gondwana Research, Vol. 125*, pp. 253-265. Retrieved from: https://avesis.akdeniz.edu.tr/yayin/74310a60-344e-4229-827e-1f65f6709426/the-impact-of-renewable-energy-generation-on-energy-security-evidence-from-the-g7-countries, 7.09.2023.
53. Vavrek, R., Chovancová, J. (2019). Assessment of economic and environmental energy performance of EU countries using CV-TOPSIS technique. *Ecological Indicators, 106*, 105519, doi: 10.1016/j.ecolind.2019.105519.
54. Wang, C.-N., Dang, T.-T., Tibo, H., Duong, D.-H. (2021). Assessing Renewable Energy Production Capabilities Using DEA Window and Fuzzy TOPSIS Model. *Symmetry, 13*, 334, doi: 10.3390/sym13020334

55. Wątróbski, J., Małecki, K., Kijewska, K., Iwan, S., Karczmarczyk, A., Thompson, R. (2017). Multi-Criteria Analysis of Electric Vans for City Logistics. *Sustainability, 9, 1453*, doi: 10.3390/su9081453
56. Wołek, M., Jagiełło, A., Wolański, M. (2021). Multi-Criteria Analysis in the Decision-Making Process on the Electrification of Public Transport in Cities in Poland: A Case Study Analysis. *Energies, 14*, 6391, doi: doi.org/10.3390/en14196391
57. Yildiz, A. (2021). Evaluation of the performance of batteries used in electric vehicles using TOPSIS method. *Journal of Engineering Research and Applied Science, 10*, pp. 1848-1855,
58. Yuan, J., Luo, X. (2019). Regional energy security performance evaluation in China using MTGS and SPA-TOPSIS. *Science of The Total Environment, 696*, 133817, doi: 10.1016/j.scitotenv.2019.133817.
59. Zhang, L., Zhao, Z., Yang, M., Li, S. (2020). A multi-criteria decision method for performance evaluation of public charging service quality. *Energy, 195*, 116958, doi: 10.1016/j.energy.2020.116958.
60. Ziemba, P. (2020). Multi-Criteria Stochastic Selection of Electric Vehicles for the Sustainable Development of Local Government and State Administration Units in Poland. *Energies, 13*, 6299, doi: 10.3390/en13236299
61. Zirganos, A., Orfanou, F., Vlahogianni, E.I., Yannis, G. (2022). Evaluating good practices for the promotion of electromobility using multi criteria analysis methods. *Case Studies on Transport Policy, 10*, pp. 1602-1610, doi: 10.1016/j.cstp.2022.05.018.