Multiple-Criteria Decision Analysis for Electromobility: The Case of European Union Regions

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Abstract

Greening the economy reduces environmental costs through more efficient use of resources, while new eco-friendly technologies and techniques help boost employment, and give new impetus to the economy. Environmental policy can help achieve strategic objectives for smart, sustainable and overall growth. The presented study is part of the subject of resource management in accordance with the assumptions of sustainable development. The study aims to compare the development of the use of electric vehicles in the countries of Europe. Indicating the degree of development and differences between countries can be helpful in developing a strategy in this area, both for individual countries and a single strategy for the region. The study used data from a survey conducted for the purpose of work on a sample of 312 people from the Union European countries. Comparative analysis and tools from the field of multivariate statistical analysis were used in the work. Models based on multi-criteria analysis are implemented to evaluate the effectiveness of the selected subjects. The research has demonstrated the importance of national legislative action to promote this mode of transport. We focused on comparing demographically comparable countries such as Slovakia and Finland. The research has shown that Electromobility is a good choice for reducing passenger transport emissions. It is essential that the weakest countries have to invest in the infrastructure needed to run electric vehicles. This is an important step to achieve greater interest in this alternative power source.

Keywords: multi-criteria; electric car; entropy; TOPSIS; WSA;

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1. Introduction

Climate change is becoming an urgent problem but also a challenge for the development of electric vehicles that can reduce greenhouse gas emissions and the impact of environmental and climate change (Stjepanovic et al., 2022; Jia et al., 2022; Yin et al., 2023). Electromobility reduces negative environmental impacts. Electric cars are energy efficient and do not cause local pollution (Figenbaum et al., 2015a). For households, these are not only environmental, but also new financial solutions (Šubová et al., 2021; Lyu, Liu, 2023; Bednarz et al., 2023).

If electricity is produced from renewable sources, electromobility can contribute to reducing CO_2 emissions. Otherwise, electric vehicles may have more negative environmental impact than vehicles using diesel and gasoline (Zamasz et al., 202; Bazienė, Gargasas, 2023; Naimoğlu & Kavaz, 2023). Electric vehicles are seen as an essential part of addressing Europe's transport challenges, the sustainable use of energy sources, air pollution and noise. Today, the automotive industry is undergoing significant changes and new megatrends. The interest in electric vehicles is increasing dramatically. This is mainly due to emission standards, forcing car manufacturers to produce alternatively powered cars (Zecca, Pronti & Chioatto, 2023). Another reason for dramatic growth is the improving charging infrastructure around the world (Schulz & Rode, 2022).

Electromobility is part of a complex whole and is linked to technological development, innovation, policy, business models, governance and inter-sectoral connectivity (Anton et al., 2021; Balcerzak et al., 2023). Therefore, Electromobility must be understood as a process of socio-technical transformation. Electric vehicles are the future of the development sector and positively affect the political and economic levels of the country.

Electric vehicles have several competitive advantages compared to conventional motor vehicles (Patola & Szpytko, 2021). However, electric vehicles still face many challenges in terms of purchase price, infrastructure, range and durability and battery recycling (Mule et al., 2021).

In December 2019, the European Commission announced the Green Deal to reduce greenhouse gas emissions related to transport by 90 % by 2050 compared to 1990 levels, as part of a broader effort to become a climate-neutral economy (Kowalska & Bieniek, 2022). This work aims to compare the development of Electromobility within European countries, as transport accounts for about a quarter of total greenhouse gas emissions, of which 70 % is road transport (Ritchie et al., 2020).

The Green Deal estimates there will be 13 million zero-emission or low-emission vehicles on European roads by 2025. In its 2020 Sustainable and Smart Mobility Strategy, the Commission set a milestone of 30 million zero-emission vehicles by 2030 and a predominantly zero-emission fleet by 2050, a significant increase from the roughly two million electric vehicles currently registered in the EU (European Court of Auditors, 2021).

2. Literature Review

In 2020, the world was affected by the pandemic, which resulted in declining car sales, but still, the sales of electric cars rose by 40 % compared to the previous year. The global market for all types of cars has been affected by the consequences of the pandemic (Mačiulis, 2023). The reason for the increase in sales of electric vehicles were some factors. Electric vehicles are becoming more competitive due to the lower total cost of ownership. Another factor is the provision of financial incentives by national governments. In 2020, 3 million electric cars will be sold. In total, 10 million electric vehicles have been registered worldwide, with Europe surpassing China, which is considered the most significant market. Car companies set high targets for electrification. Manufacturers are expanding the number of electric car models, falling battery costs, and expanding charging infrastructure. The downside is that government incentives for electric vehicles have fallen recently, but it suggests that electric vehicles are becoming increasingly affordable and attractive to consumers (OECD, 2021; Pietrzak & Pietrzak, 2021).

In early 2021, electric vehicle sales worldwide increased by 140 % compared to 2020. For the electric vehicle market to continue to expand, national governments need to step up their support for achieving climate targets. Countries should focus on promoting electric vehicles, tightening measures on CO_2 standards, taxation of petrol and diesel, and differentiated vehicle and fuel taxation (Østli et al., 2021; Plötz et al., 2018). In addition, individual countries need to consider renewable electricity generation, focus on expanding charging infrastructure, promote the integration of electric vehicles with energy systems and, last but not least, ensure sustainable production and recycling of electric vehicle batteries (Karlsson, 2020; Erbaş et al., 2018). Contributing to sustainable development which is sensitively perceived by consumers (Mishchuk et al., 2023; Mukhtarov et al., 2023).

In 2020, the automotive market in Europe contracted by 22 %. Nevertheless, registrations for electric vehicles have doubled, with a total share of 1.4 million electric vehicles. For example, one of the largest markets in Europe is Germany, where 395 thousand electric vehicles were registered, and 185,000 electric vehicles were registered in France. In the UK, registration doubled compared to last year, reaching 176,000 vehicles. The most successful electric car market is Norway, with the share of electric vehicle sales in 2020 accounting for 75 %. Other countries such as Iceland accounted for 50 %, 25 % in the Netherlands and Sweden and reached a 30 % share of sales (Knobloch et al., 2020; Kołtonowski et al., 2021).

The increase in electric vehicles in Europe was due to two main reasons. The first is due to emission standards, and the second is the increased subsidies from the European Union, which are part of the incentive packages to compensate for losses due to the consequences of the pandemic.

The sale of cars, especially alternative drive models, is also linked to the GDP per capita in a given country. In terms of statistics with the highest market share of ECV sales, including their GDP per capita for 2020, the highest ranked were Sweden (32.2 %), the Netherlands (25.0 %), and Finland (18.1 %). It can be assumed that the further expansion of the market for electrically rechargeable vehicles (ECVs) is directly linked to affordability for final consumers. There is a clear difference in the affordability of ECV between Central and Eastern Europe and Western Europe. There is also a significant difference between the north and south, which runs across the continent. 73 % of all electric vehicle sales are concentrated in only four Western European countries. On the other side of the spectrum is that ten EU Member States still have a market share of less than 3 % of the ECV market. In other words, in countries where direct and incentive subsidy support operates, the share of low-emission vehicle sales is high (Anwar et al., 2022).

3. Methods

Multi-criteria analysis methods were used to carry out the research. The multi-criteria analysis deals with mutually exclusive criteria that can be formally linked to management planning (Joshi & Kumar, 2014; Fiala et al., 1994). There are some multi-criteria analysis methods (Mura & Stehliková, 2023). For example, a set of alternatives describes multi-criteria decision-making problems A = {a 1, and 2,.., and p}, in our work consisting of selected countries of Europe and a set of evaluation criteria $F = \{f_1, f_2, ..., ..., f_k\}$in our case consisting of selected indicators directly linked to the development of electromobility in the examined country and their interdependencies through the so-called 'criteria matrix' (Coroničová Hurajová & Hajduová, 2021).

The scoring method is based on the distribution of a certain number of points among the criteria according to their importance. It is essential to know the preferences of the task assigner. The more critical the criterion, the higher the number of points. Subsequently, the values are divided by the total number of points distributed to obtain the standardized weights of the criteria (Brozová et al., 2003).

An entropy method is used to determine the weighting of criteria when the preferences of those criteria are unknown or difficult to determine (Remeikienė et al., 2022). The process of Entropy can be described in the following steps:

Criteria matrix $Y = (y_{ij})$ created from input data:

$$Y = \begin{pmatrix} y_{11} & y_{12} & \cdots y_{1n} \\ y_{21} & y_{22} & \cdots y_{2n} \\ \vdots & \vdots & \ddots \ \vdots \\ y_{m1} & y_{m2} \cdots & y_{mn} \end{pmatrix} \qquad (1)$$

For each E_j of the criteria considered, Entropy is:

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij}. \qquad (2)$$

The weighting of the criteria is:

$$w_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j}; \ \ j = 1,2, \dots, n. \qquad (3)$$

The second step in analyzing several criteria is determining the order of variants. It is essential to adapt the choice of method to the objective pursued, as well as to know what type of information is being worked with, i.e. whether the input data is of a cardinal or ordinal nature. Two basic information methods have been selected: the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method and the WSA (Weighted Sum Approach) method. These are among the most commonly used methods, which was one of the reasons to apply them in this research (Memari et al., 2019).

The TOPSIS method uses basic information to identify a compromise variant as close as possible to the ideal variant and as far as possible from the basal variant. If there is an ideal variant and it is possible to achieve it, then the ideal and compromise option will match. The ideal variant obtains the best values concerning all specified criteria, and is represented by the vector (h_1, h_2, …, h_n). The base variant obtains the worst possible values in all criteria and is represented by (d_1, d_2, …, d_n) a vector n indicating the number of criteria to be considered in the analysis (Chen, 2019; Behzadian et al., 2012).

Identification of the ideal solution $h = (h_1, h_2, \ldots, h_n)$ and basal parameter $d = (d_1, d_2, \ldots, d_n)$, where:

$$h_j = \max_i z_{ij}\,; j = 1, 2, \ldots, n, \quad (4)$$

$$d_j = \min_i z_{ij}\,; j = 1, 2, \ldots, n. \quad (5)$$

The distance between each alternative and the ideal and the basal variant as follows:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - h_j\right)^2}\,;\ i = 1, 2, \ldots, m, \quad (6)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - d_j\right)^2}\,;\ i = 1, 2, \ldots, m. \quad (7)$$

For each alternative, calculate the relative distance indicator as follows:

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-}\,;\ i = 1, 2, \ldots, m. \quad (8)$$

The weighted sum method, WSA, for the weighted sum method, it is necessary to draw up a matrix of criteria $Y = (y_{ij})$. For each criterion, the best h_j and worst d_j the value shall be identified. Subsequently, $U = (u_{ij})$ the matrix is created as follows (Palczewski & Sałabun, 2019):

$$u_{ij} = \frac{y_{ij} - d_j}{h_j - d_j}\,;\ \ i = 1,2, \ldots, m; j = 1,2, \ldots, n. \quad (9)$$

The value u_{ij} reflects the advantage of the i-th variant with the j-th criterion. In addition, the values of the aggregate utility function u(V_i) for each variant V_i are determined using standardized weights:

$$u(V_i) = \sum_{j=1}^{n} w_j u_{ij}. \quad (10)$$

4. Results

The evaluation and comparison of the development of Electromobility within the European countries were carried out through eight criteria: K1 - Eco-Innovation Index, K2 - GDP per capita in PPS, K3 - EPI, K4 - Recharging points per 100,000 people, K5 - High-Power Public Recharges per 100 Km Highway, K6 - Electric car sales and national income, K7 - Electric cars per thousand inhabitants, K8 - Electric cars per square km.

Multi-criteria analysis methods were used in this research, but the first step after data collection was required to assign weights to the given criteria. To ensure the most objective assessment possible, three weighting methods have been selected for this analysis. Method A is a method of equal weight. In this case, each criterion had a value of 1/8 since the method B was scoring and method C was the entropy method. The equal weight and entropy methods depend only on the input data. The scoring method appears to be subjective. Therefore, the analysis itself was preceded by a survey in the form of a questionnaire, so that this method of scoring could be used without subjective involvement.

The questionnaire consisted of twelve open questions on the development of Electromobility. The questionnaire was completed by 312 respondents aged 21 to 52 between March and May 2022. The age structure of respondents was focused on a group that could use an electric car. As the questionnaire was distributed to the countries of Europe, we can conclude that the highest interest and return of the questionnaire were from countries such as Sweden and Finland. As far as the issues are concerned, their focus was:

- on the financial aspects of Electromobility,
- on the common approach of European countries in this area in the context of the global development of electric vehicles,
- on the success factors of the introduction of this type of means of transport into road transport,
- on the benefits that the owner of electric cars in that country can benefit from.

Of course, the questionnaire also included questions, which of course, also included critical areas. Raw materials and transport access can be critical in car production in a hectic world. For many car owners, charging and range options are important factors when considering an electric car. The question was also raised about the increasing number of electric vehicles and the subsequent higher energy consumption. Just now, Europe is in an exceptional energy situation with the war in Ukraine and less access to natural gas. Each person interviewed was asked to rank the criteria according to importance based on their preferences, and to allocate 100 points among those criteria. The data collected has been used to determine the weights in the scoring method, see ***Table 1***.

Table 1. Criteria weights

Weight of criteria	K1	K2	K3	K4	K5	K6	K7	K8
Method A	0.1250	0.1250	0.1250	0.1250	0.1250	0.1250	0.1250	0.1250
Method B	0.1364	0.1136	0.1061	0.0985	0.1439	0.1212	0.1288	0.1515
Method C	0.0136	0.0212	0.0022	0.2930	0.0994	0.0584	0.1654	0.3469

Source: own processing

Following the determination of the weighting of the individual criteria, the following two methods were used to rank alternatives. The first method to evaluate countries was the TOPSIS method, see ***Table 2***.

Table 2. The TOPSIS method results

TOPSIS	Method A	Rank	Method B	Rank	Method C	Rank
	c_i		c_i		c_i	
Luxembourg	0.953774	1	0.5035002	2	0.983544877	1
Netherlands	0.416110	2	0.5474000	1	0.422980927	2
Ireland	0.091256	3	0.4871270	5	0.007927792	11
Estonia	0.048174	4	0.4911830	4	0.016816310	5
Austria	0.047665	5	0.4990900	3	0.025301767	4
Sweden	0.046598	6	0.4676250	6	0.029869717	3
Denmark	0.042277	7	0.4491630	8	0.009732591	9
Germany	0.035662	8	0.4391400	9	0.009233144	10
Belgium	0.035517	9	0.4548990	7	0.015797240	6
Finland	0.032403	10	0.4301021	10	0.013594636	8
France	0.029199	11	0.4205210	12	0.013641197	7
Malta	0.021042	12	0.4199210	13	0.001866368	16
Italy	0.019179	13	0.4099521	14	0.002013002	15
Czechia	0.018787	14	0.4299100	11	0.002663120	14
Spain	0.017260	15	0.3998721	16	0.001454312	18
Slovenia	0.016362	16	0.4006578	15	0.003802109	12
Cyprus	0.015420	17	0.3865422	18	0.001144940	20
Lithuania	0.012269	18	0.3982570	17	0.001297309	19
Slovakia	0.011952	19	0.3855214	19	0.003192802	13
Portugal	0.011042	20	0.3712547	21	0.001815137	17
Greece	0.009181	21	0.2150021	22	0.000533443	26
Poland	0.007839	22	0.3756112	20	0.000807049	23
Romania	0.007402	23	0.2041200	23	0.000712003	25
Hungary	0.007202	24	0.1956660	25	0.000737977	24
Latvia	0.006308	25	0.1985221	24	0.000890723	21
Croatia	0.004868	26	0.1812350	26	0.000842539	22
Bulgaria	0.000283	27	0.0547016	27	0.000097779	27

Source: own processing

The second method used in this analysis was the WSA method. In this case, the analysis was carried out for all three weight determination cases as it was assessed for TOPSIS, see ***Table 3***.

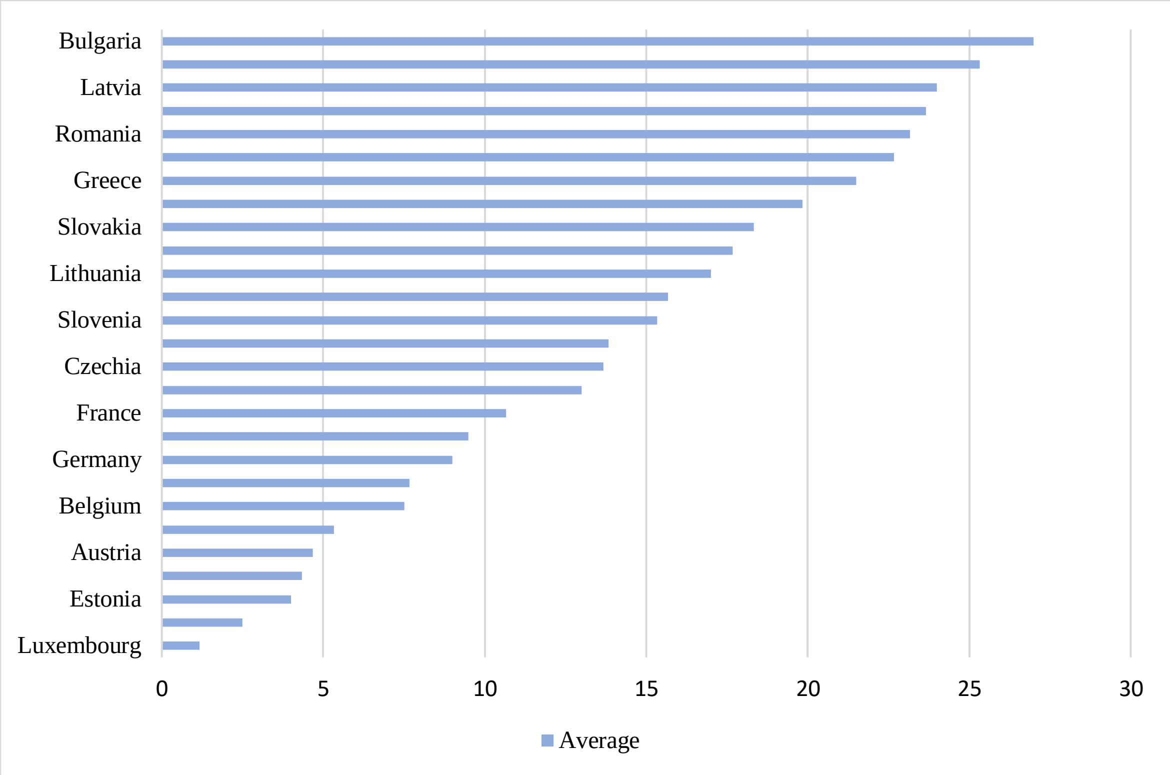
Table 3. The WSA method results

WSA	Method A	Rank	Method B	Rank	Method C	Rank
	u_i		u_i		u_i	
Luxembourg	0.993699	1	0.591452	1	0.998752	1
Netherlands	0.901327	2	0.588542	3	0.990010	5
Ireland	0.872892	3	0.589810	2	0.997210	2
Denmark	0.749678	4	0.552470	4	0.995214	3
Sweden	0.744639	5	0.532714	5	0.988745	6
Austria	0.708044	6	0.512470	7	0.991201	4
Germany	0.643780	7	0.507463	8	0.985466	7
Finland	0.641245	8	0.489731	10	0.979658	9
Belgium	0.607174	9	0.521899	6	0.980081	8
France	0.544889	10	0.500332	9	0.978514	10
Malta	0.457178	11	0.473541	12	0.965660	11
Italy	0.390791	12	0.465229	13	0.922100	12
Estonia	0.377034	13	0.475891	11	0.657737	17
Czechia	0.374130	14	0.437465	15	0.870320	14
Spain	0.372535	15	0.412899	17	0.89242	13
Slovenia	0.350394	16	0.409851	18	0.829113	15
Portugal	0.323245	17	0.428955	16	0.608892	18
Cyprus	0.260168	18	0.458261	14	0.740168	16
Slovakia	0.237226	19	0.400589	19	0.491339	21
Lithuania	0.230141	20	0.378410	21	0.519075	20
Greece	0.215426	21	0.395414	20	0.545384	19
Latvia	0.173590	22	0.175246	25	0.372399	24
Romania	0.170491	23	0.198541	23	0.433907	22
Poland	0.161150	24	0.205812	22	0.425449	23
Hungary	0.143309	25	0.185478	24	0.343105	25
Croatia	0.140699	26	0.115632	26	0.297657	26
Bulgaria	0.009929	27	0.087214	27	0.000014	27

Source: own processing

Based on the results obtained, the final ranking of countries concerning the development of Electromobility was determined as the arithmetic means of all six results obtained by both TOPSIS and WSA methods, see ***Figure 1***.

Figure 1. Average values of countries' performance ranking



Source: own calculations

The topic of Electromobility and its development is very topical at this time. Therefore, many scientific studies regularly focus on this topic and examine various aspects of the impact on the global economy and climate change (Coffman et al., 2017; Kos et al., 2021). The authors of these studies focus on identifying the benefits of putting electric cars into practice, but on the other hand, they also highlight their shortcomings (Figenbaum et al., 2015b).

When analyzing the results achieved, it should be noted that with the development of Electromobility, infrastructure development has to be implemented as well. This development must go hand in hand with the sale of electric cars. Despite solid pressure on infrastructure deployment for the ECV since 2014, an increase of up to 700 % is around 225 000 recharging points across the EU. Furthermore, the rationale for the research results is that 30 % of charging points are located in the Netherlands, representing 66,665 places.

In addition to purchasing power, it is also essential to create conditions, i.e. support for new low-emission technologies by the state. The form and amount of support vary from one Member State to another. The support concerns preferential legislative conditions, such as taxes, various fees, depreciation, and the advantage of purchasing low-emission vehicles through direct subsidies. This support is available in 18 of the 27 EU countries.

One example is Finland because it is comparable in the demographic parameters of the Slovak Republic. Finland ranked ninth in our list of 27 countries. To achieve the desired target and level of electric vehicles, the Finnish government has introduced higher taxes on high-emission vehicles. On the other hand, lower taxes and subsidies for the purchase of electric vehicles are introduced for electric vehicles. Finland also supports many investment projects to support electric vehicle infrastructure.

In cooperation with the automotive industry, the Finnish government provides direct subsidies for purchasing electric cars. Subsidies for the purchase of electric vehicles were launched in 2018 and ended in 2021.

When buying a new electric car or renting an electric car for a long time, it was possible to receive a subsidy of EUR 2 000. Finland's Ministry of Communication and Transport has published an operational programmed for carbon-free transport by 2045. Almost one hundred thousand new cars were sold in Finland in 2021. Electric vehicles increased to 10.3 % of total car sales, even 24 % in December, or 1,579 electric vehicles. Compared to 2020, electric cars in Finland accounted for only 4.4 % of the total number of new cars, a doubling in 2021.

There is a so-called environmental tax in Finland. Electric cars are usually a cheaper option compared to gasoline cars. The advantage of electric cars is also due to the sharp rises in diesel and gasoline prices. Finland also provides many incentives, for example, a subsidy. Private individuals will receive a subsidy of EUR 2 000 when purchasing a new electric car, provided that the amount of the electric vehicle does not exceed EUR 50,000.

When comparing these conditions with the Slovak Republic, which ranked 18th in the ranking, it follows that the development of Electromobility in the Slovak Republic has great potential. The Slovak Republic provided subsidies for purchases in two rounds. The first round of subsidies lasted from 2016 to 2018 with a budget of 5.2 million euros, which could not be used up. The Slovak Republic is also lagging behind in the development and construction of charging infrastructure. In 2020, only 820 charging stations were registered in Slovakia. Slovakia does not benefit from the promotion of sales of clean vehicles that reduce the CO_2 burden by taxing based on CO_2 emissions.

5. Conclusion

It is clear from the above-mentioned partial facts of this extensive research that has been carried out that an essential role in creating favourable conditions for the development of Electromobility lies with the authorities of the state, including the interconnection of municipalities as well as the car companies themselves. The development of this segment is not only based on the number of electric vehicles sold. This issue needs to be looked at from a global perspective; it must be with the systematic development of the entire ecosystem, creating meaningful conditions, supporting infrastructure and continuous improvement. Including state administration bodies, research, innovation, and education are necessary.

For all countries surveyed in Europe, Norway should be, where exactly logically set steps, this country is successfully implementing the transition to low-emission mobility. This work presents extensive research and individual conditions for the development of Electromobility in the European countries surveyed.

The application of multi-criterial analysis of individual key parameters has created a ranking of individual countries concerning the development of Electromobility in a given country. In the discussion, we discussed in more detail the comparison of two comparable countries, but with another aspect of the development of Electromobility. Despite the problematic social and economic situation, it can be said that Electromobility has a growing character and a rattling trend. At the moment, this mode of transport appears to be the most advantageous way to reduce CO_2.

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