APPLICATION OF MULTI-CRITERIA DECISION MAKING METHODS FOR EVALUATION OF SELECTED PASSENGER ELECTRIC CARS: A CASE STUDY

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Resume

The article deals with the analysis of selected technical and economic aspects that influence decision making process when choosing a car with an electric drive - an electric car. Environmental friendliness is beginning to be one of the key aspects in the context of electric vehicle selection, but its final choice is still affected by the standards offered by internal combustion vehicles. In our case, the relevant standards were defined when using the results of a questionnaire survey, the criteria of scales, which are used to compare selected types of electric passenger cars in the conditions of the Czech Republic. The aim of the article is to select an appropriate electric car by using specific techniques of multi-criteria decision making - the Basic Variant method and the Analytic Hierarchy Process (AHP). The scientific value of the article lies primarily in its applicability to the global environment and the variability possibilities of criteria set and their significance.

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1 Introduction

Electromobility is gradually building its strong position in the transport market Although it is not possible to clearly determine the sense of the emergence of modern electromobility, the environmental aspect is considered to be the most important, influenced in particular by the following regulations:

- The UN Framework Convention on Climate Change was adopted by the 1992 UN Conference on Environment and Development in Rio de Janeiro [1].
- Kyoto Protocol to the United Nations Framework Convention on Climate Change (hereinafter only "the Protocol"), adopted in December 1997 [2].
- Paris Agreement [3].

These regulations impose the protection of the climate system for the benefit not only of the present but also of future generations, on the basis of four basic principles [4]:

- principle of intergenerational justice,
- common but differentiated responsibilities,
- the need to protect in particular those parts of the planet which are more susceptible to the negative effects of climate change,
- preliminary caution.

The development of electric cars in the last two decades is one of the reactions of the automotive industry to the above-mentioned regulations and a manifestation of the effort to maintain the experienced user concept of the passenger car. From this point of view, it is clear that if the current electric car is to replace or even offer better standards than a car with an internal combustion engine, it will be necessary to define and evaluate customer requirements and, based on them, to develop the car and assess its suitability in accordance with the above regulations. If so, it will be possible to adhere this concept, and if not, it will be necessary to look for a different and perhaps completely different concept for this type of transport. The aim of the article is to select an electric vehicle under current conditions using scientific methods and on the basis of defined criteria.

2 Literature review

The topic of electromobility has long been dealt with by scientific teams around the world, not only from a technical point of view. In particular, the environmental, social and economic factors influenced by electromobility and which must be taken into account in its development are examined. The electric vehicle's propulsion unit itself is at a relatively high level in terms of available technology, efficiency and reliability, both the Battery Management System (BMS), which is discussed, for example, by Ayob et al [5], including the subject of recharging, which is addressed, e.g., in [6]. However, regarding the issue of electromobility, the storage of electrical energy in fuel cells remains. These possibilities were investigated in collaboration with Volkswagen AG Groger et al [7] or Mouli et al [8], whose study compares different charging options. The issues of recycling and charging or exchange stations are also presented, the possibilities of which are described by Buzoverov and Zhuk [9] in their extensive study.

Putting electric cars into practice, i.e., to their end users, carries with it multiple partial topics. From the point of view of economics and legislation, it is therefore mainly up to the individual states how they will react to the topic of electromobility, or in what ways they will support it. Territorial differences in relation to the approach to electromobility are addressed, for example, by Zhao, which compares world leaders - Germany and China [10]. This study takes into account specific territorial and political requirements as a basis for the development of batteries or fuel cells. The social aspects of electromobility lie, for example, in the so-called environmental responsibility, i.e., the effort of consumers to reduce their eco-footprint, with the aim of achieving so-called carbon-free urban mobility [11-12]. However, the issue of reducing the eco-footprint leads back to the technology and operation itself, because in the analysis of the life cycle of an electric vehicle, it is necessary to consider its components, their impact on environment and possible recyclability. Helmers in [13] and Wuschke et al in [14] addressed this issue in detail.

As mentioned, the market is an important factor for the further development of passenger electric cars, although its current strength is not comparable to the market for cars with internal combustion engines. It is not known what the climatic conditions and the car market will be in the coming decades. In addition to a series of technological, raw material and economic uncertainties, we often find opinions that electromobility will affect movement in urban areas and change the behavior of the automotive industry, energy and public administration [15].

There is a wide array of electromobility development programs in countries around the world that motivate the purchase of electric cars with varying degrees of success, for instance in [16-18]. Due to these programs, it is possible to observe an increasing share of electric cars in the total number of sold cars, but the same tendency cannot be expected even after their termination. Electromobility is also closely linked to the development of the smart energy networks of the future [19]. In terms of production itself, the electric car needs up to 30% fewer components than vehicles with internal combustion engines, as stated, e.g., in [20-23]. With the greater development of electromobility, this factor can contribute to influencing supply chains and production logistics, but also to the demise of some component manufacturers. In light with the above remarks, it is already clear that even the current concept of electric cars does not guarantee an improvement in the climate, if it is developed for these purposes, even without mentioning the fact regarding the share of passenger car transport in generation of harmful gases, life cycle of electric cars and so forth. However, as discussed in [20, 24], those who are interested in buying an electric car can also be motivated by other factors.

During the research, it was identified that the current requirements imposed by the customer on the electric car are mainly influenced by the standards imposed on cars with internal combustion engines, which was also examined, for example, by Metso et al [25]. From the environmental-technical standpoint, the customer's questions relating to the electric car are mainly focused on the safety of operation, the efficiency of the propulsion system and the service life of its components. It was not identified that the customer was interested in the possible advantages of an electric car over a car with an internal combustion engine in terms of user comfort - such as automatic preparation before driving, including defrosting windows in winter and heating or cooling the cabin from external power supply when connected to the charging network. Such equipment represents an indisputable advantage over a car with an internal combustion engine, especially when it is possible to program it or control it remotely [26].

The multi-criteria evaluation in this article therefore applies to the most frequently asked questions of potential customers to whom weights for the overall evaluation were assigned.

3 Materials and methods

For the purposes of this case study, six types of electric cars of comparable categories in terms of equipment and parameters coming from various manufacturers were objectively selected. By applying the Basic Variant method and the AHP method [27-28], the most appropriate model is then specified. As already mentioned, the most frequently asked customer questions concern the comparability of an electric car and an internal combustion engine car. Six basic factors were selected for the multi-criteria evaluation process. The foundation for the very evaluation was, on the one hand, a questionnaire survey among sellers of Hyundai, Kia and Nissan electric cars. To provide relevant information on this particular issue, data provided by CEZ were also used, which can already be ranked among the largest providers of services in the area of electromobility. The company operates in the operation

Table 1 *Variants of the criteria of the Basic variant method*

Vehicle	Price [CZK]	Mileage [km]	Power [kW]	Energy need [kWh.100km-1]	Max. speed [km.h-1]	Trunk volume [l]
Hyundai IONIQ	899 999	270	100	11.5	165	357
Nissan Leaf	950 000	240	80	15	144	435
VW e-Golf	959 000	180	85	12.7	140	341
BMW i3	954 000	260	125	13.1	150	260
Kia Soul EV	849 950	212	8	14.7	145	281
Renault ZOE	735 000	350	80	13.3	135	338
significance value	0.3	0.25	0.2	0.05	0.06	0.14
criterion	MIN	MAX	MAX	MIN	MAX	MAX

Explanatory note: CZK stands for the Czech crow/koruna and exchange rate of CZK to EUR is 0.04 € (May 30, 2022)

Table 2 *Determination of the base in the Basic Variant method*

Vehicle	Price [CZK]	Mileage [km]	Power [kW]	Energy need [kWh.100km-1]	Max. speed [km.h-1]	Trunk volume [l]
Hyundai IONIQ				1	1	
Nissan Leaf						1
VW e-Golf						
BMW i3			1			
Kia Soul EV						
Renault ZOE	1	1				
Significance value	0.3	0.25	0.2	0.05	0.06	0.14
criterion	MIN	MAX	MAX	MIN	MAX	MAX
B - basis	735 000	350	125	11.5	165	435

of charging infrastructure as well as in the field of sales of electric vehicles themselves. The construction and operation of charging infrastructure is dealt with by the Clean Technology Department branch of the enterprise Ceske energeticke zavody (CEZ CTD), while the sale of electric cars is dealt with by the CEZ Energy Service Company (CEZ ESCO) branch. According to CEZ ESCO's sales department, potential customers and their interest in purchasing an electric vehicle are most influenced by the following factors [20]:

- purchase price of an electric car,
- maximum distance,
- engine power,
- energy need,
- maximal speed,
- luggage compartment volume.

The aim is to select a compromise vehicle with electric drive for purchase. When assessing a significant number of criteria, the following methods are very effective, especially in the case where neither variant is optimal in all respects.

3.1 Basic variant method

This technique is based, like the weighted sum method, on maximizing utility. In principle, on the contrary, it is the target method, i.e., with the best values in all criteria. In the case of this method, 2 key equations are given, which are formulated in the manuscript methodology, and which can be partially modified. The modified relation for the yield (maximization) criteria shows Equation (1) [29]:

$$u_{ij} = \frac{original\ value}{base}\ [-], \tag{1}$$

where the benefit of a given variant is denoted as u_{ij}.

A modified relation for cost (minimization) criteria is shown in Equation (2).

$$u_{ij} = \frac{base}{original\ value}\ [-]. \tag{2}$$

The total benefit of the i-th variant is again calculated as a weighted sum of the partial benefits.

Individual selection variants together with criteria are shown in Table 1. The vehicles were selected according to two parameters - a range of more than 150 km and availability on the Czech market. The values of the criteria were determined according to the data provided by the manufacturers. Significance weights were thereafter determined by interviewing 6 experts who specialize in the sale of electric cars at CEZ. These experts defined the input weights of all the criteria independently of the other persons. Then, the sum of the obtained results was counted, and the weights of

Table 3 Calculated values of individual criteria

Vehicle	Price [CZK]	Mileage [km]	Power [kW]	Energy need [kWh.100km-1]	Max. speed [km.h-1]	Trunk volume [l]
Hyundai IONIQ	0.817	0.771	0.800	1	1	0.821
Nissan Leaf	0.774	0.686	0.640	0.767	0.873	1
VW e-Golf	0.766	0.514	0.680	0.906	0.848	0.784
BMW i3	0.770	0.743	1	0.878	0.909	0.598
Kia Soul EV	0.865	0.606	0.648	0.782	0.879	0.646
Renault ZOE	1	1	0.640	0.865	0.818	0.777
Significance value	0.3	0.25	0.2	0.05	0.06	0.14
criterion	MIN	MAX	MAX	MIN	MAX	MAX
B - basis	735 000	350	125	11.5	165	435

Table 4 Scalar product of selected variants

Vehicle	Price [CZK]	Mileage [km]	Power [kW]	Energy need [kWh.100km-1]	Max. speed [km.h-1]	Trunk volume [l]	w
Hyundai IONIQ	0.817	0.771	0.800	1	1	0.821	0.822
Nissan Leaf	0.774	0.686	0.640	0.767	0.873	1	0.762
VW e-Golf	0.766	0.514	0.680	0.906	0.848	0.784	0.700
BMW i3	0.770	0.743	1	0.878	0.909	0.598	0.799
Kia Soul EV	0.865	0.606	0.648	0.782	0.879	0.646	0.723
Renault ZOE	1	1	0.640	0.865	0.818	0.777	0.879
Significance value	0.3	0.25	0.2	0.05	0.06	0.14	
Criterion	MIN	MAX	MAX	MIN	MAX	MAX	
B - basis	735 000	350	125	11.5	165	435	

individual criteria significance were determined using the arithmetic mean.

The first step is to determine the base that represents the optimal value in the column according to the nature of the criterion. It is necessary to distinguish whether these are maximization or minimization criteria.

The following is the designation of the relevant places where the individual most advantageous values of the base are located by the number 1. The determination of the individual bases is shown in Table 2.

Subsequently, the values of the other criteria are calculated using two modified equations for the maximization and minimization criteria given in the introduction of this chapter [30]. The calculation of partial values is shown in Table 3.

After calculating the individual values, a column marked "w" is added to the table, which shows the scalar product between the individual values of the variants and the weights of the individual criteria - Table 4. The compromise variant is then represented by the variant with the highest scalar product.

According to Table 4, the electric vehicle Renault Zoe was chosen by the method of Basic Variant as compromise

3.2 AHP method

The second method used is the Analytic Hierarchy Process method, which was designed by Thomas L. Saaty in 1980. This method seeks to simplify the complex decision-making problems that it presents as a hierarchical structure. By this term is meant a linear structure comprising several levels, each of which contains several elements. The arrangement of individual levels goes from the general to the specific. The principle of this method is to quantify the intensity of interaction of individual elements in the system using Saaty's method of quantitative pairwise comparison, which is used at each level of the hierarchical structure [31].

In the initial stage of the method, it is again necessary to determine the possible variants along with the given criteria. The possible variants, the given criteria and the determined weights are the same as for the method of the Basic Variant mentioned in the previous chapter. The input data are provided in Table 5.

The subsequent procedure consists in creating as many tables as there are specified criteria. In this case it

Table 5 *criteria of the AHP method*

Vehicle	Price [CZK]	Mileage [km]	Power [kW]	Energy need [kWh.100km-1]	Max. speed [km.h-1]	Trunk volume [l]
Hyundai IONIQ	899 999	270	100	11.5	165	357
Nissan Leaf	950 000	240	80	15	144	435
VW e-Golf	959 000	180	85	12.7	140	34
BMW i3	954 000	260	125	13.1	150	260
Kia Soul EV	849 950	212	81	14.7	145	281
Renault ZOE	735 000	350	80	13.3	135	338
Significance value	0.3	0.25	0.2	0.05	0.06	0.14
criterion	MIN	MAX	MAX	MIN	MAX	MAX

Table 6 *Saaty scale*

1	variants are equally important both compared	both variants compared have the same property
3	the variant is slightly more important than the other variant	the first variant is slightly more significant than the other
5	the variant is much more important than the other variant	the first variant is strongly more significant than the other
7	the variant is significantly more important than the other variant	the first variant is very strongly more important than the other
9	extreme significance of one variant over another	the first variant is even more than strongly significant than the other

Table 7 *Cost criterion - complete table*

Price	Hyundai IONIQ	Nissan Leaf	VW e-Golf	BMW i3	Kia Soul EV	Renault ZOE	geom. mean	N weight	x weight
Hyundai IONIQ	1	3	5	7	0.2	0.142	1.172	0.110	0.033
Nissan Leaf	0.333	1	3	1	0.111	0.111	0.48	0.045	0.014
VW e-Golf	0.2	0.333	1	0.333	0.111	0.111	0.254	0.024	0.007
BMW i3	0.143	1	3	1	0.143	0.111	0.435	0.041	0.012
Kia Soul EV	5	9	9	7	1	0.2	2.876	0.270	0.081
Renault ZOE	7	9	9	9	5	1	5.425	0.510	0.153

is about 6 criteria = 6 tables. Each table will contain, in addition to the variants being compared, the geometric mean, the standard weight and the final weight.

The AHP method is based on the Saaty method, which is partially modified here. It will be based on the Saaty scale of preferences, which is shown in the following Table 6.

The value of 1 is the main diagonal in the tables, as it represents the equivalence of the same variants. Subsequently, 2 variants are always compared against one criterion. Preferences are determined according to the Saaty scale in Table 6. For illustration, Table 7 below compares the purchase price criterion with respect to all specified variants. The method of calculation is the same for all 5 remaining criteria (mileage, engine power, energy need, max. speed and luggage compartment volume = trunk volume).

Subsequently, the values are calculated into the geometric mean column.

After calculating the individual geometric means, it is necessary to standardize the given weights. Normalization of values is performed by dividing the individual geometric means by their sum for the given column. Subsequently, it is only necessary to multiply the individual standardized weights by the weights of the individual criteria and add them to the last column. Entire this process is presented, for instance, in [32]. Table 8 shows the calculated values of the geometric mean, the standard weight and the multiplication by the respective weight for the purchase price criterion.

Table 8 *The resulting values of the AHP method*

Vehicle	Price [CZK]	Mileage [km]	Power [kW]	Energy need [kWh.100 km-3]	Max. speed [km.h-1]	Trunk volume [l]	Sum
Hyundai IONIQ	0.033	0.043	0.048	0.021	0.028	0.029	0.202
Nissan Leaf	0.014	0.023	0.01	0.002	0.006	0.073	0.128
VW e-Golf	0.007	0.005	0.02	0.012	0.004	0.015	0.063
BMW i3	0.012	0.045	0.102	0.007	0.013	0.004	0.183
Kia Soul EV	0.081	0.011	0.012	0.002	0.007	0.006	0.119
Renault ZOE	0.153	0.122	0.008	0.006	0.002	0.014	0.305

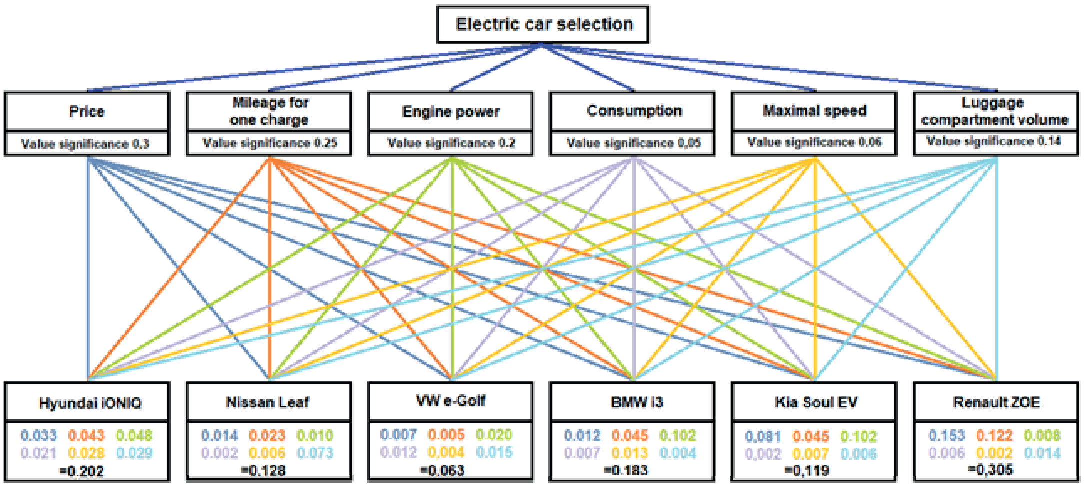

Figure 1 *Graphic representation of the AHP method*

The calculation for the remaining 5 criteria (mileage, engine power, energy need, max. speed and luggage compartment volume) is the same. The final step is to enter the individual values from the "x weight" columns to the individual variants. The values are then summed for each variant. The variant that reaches the highest value is again selected from the given values. The highest value was obtained by Renault ZOE, which, according to the AHP method, represents a compromise variant.

The AHP method also includes a graphical representation of the decision-making process in Figure 1.

Figure 1 graphically shows the dependence of the weights of individual criteria and their effect on the overall result. It is also clear from the figure that when calculating with the AHP method, it is possible to easily apply other criteria or adjust the value of the weights.

4 Results and discussion

The article is focused on the evaluation of economic and technical aspects relevant to the selection of a passenger electric car in the conditions of the Czech Republic. Questionnaire methods, discussions with experts and studies of scientific literature [7-11] were used to select aspects, on the basis of which relevant vehicle parameters influencing their selection were defined by comparative methods. Furthermore, the two most suitable scientific methods of evaluation were selected and the weights of criteria for individual parameters were determined. After performing and evaluating two exact methods [30-32], it was found that according to the Basic Variant method, the compromise variant is Renault ZOE.

The AHP method also reached the same result. The chosen electric car achieves very favorable results regarding the purchase price, mileage and the volume of the luggage compartment. According to the weights of these criteria, the purchase price and mileage are among the most important, which is why the vehicle achieved the best results. On the contrary, it reaches low values in terms of maximum speed and power of the electric engine. A possible alternative to the Renault ZOE electric car is the Hyundai IONIQ electric car. This electric car was placed according to the method of the Basic Variant in second place with a very small difference in values. The vehicle also took second place according to the AHP method.

Comparing the best Renault ZOE and the second Hyundai IONIQ, it can be stated that the Renault ZOE dominates in the two most important criteria, namely the purchase price and mileage. The difference in purchase prices is CZK 164,999 [33]. In terms of mileage, the Renault ZOE dominates by a considerable 80 kilometers.

On the other hand, the Hyundai IONIQ has a 20 kW more powerful electric motor, which allows it to reach speeds of up to 165 km / h, while its need is 1.8 kWh / 100 km lower. The difference in luggage compartment volumes is 19 liters in favor of Hyundai IONIQ. Here, it would depend on the specific customer whether to choose a cheaper vehicle with a higher mileage, or to opt for a vehicle with a more powerful electric motor and lower energy need, which at the same time allows a higher maximum speed to be achieved. If the vehicle were purchased by a family, a luggage compartment almost 20 liters larger could also play a large role [34]. Hence, in the conditions of the Czech Republic, the applied methods and performed procedures in connection with electric cars confirmed to be very useful and adequate.

The proportion of newly registered electric vehicles is only 0.3% of the total number of newly registered vehicles [35]. Nevertheless, sales in Western European countries reach tens of percent. For this reason, the methods are presented and outline the possibility of how a potential car applicant can compare the current offer of electric vehicles and choose the best compromise variant according to his preferences. Completely different criteria can be set, or the same can be used. Each buyer achieves a different result, as it depends very much on the criteria that affect the buyer, as well as on the weight he attributes to each criterion [36].

5 Conclusion

In the article, a compromise variant of the vehicle recommended for purchase was selected using two exact methods used in operational research. Six objectively selected vehicles with similar values of individual parameters were available. The comparison was made using six criteria and weights, which were determined following a questionnaire survey, discussions with car dealers and experts. As a compromise variant, the Renault ZOE was used using the methods. The result is influenced by the set criteria and their assigned weights as an example for use. Customer requirements that motivate the purchase of an electric car are mainly in the provision of comparable standards, such as a car with an internal combustion engine.

However, this comparison can only be considered temporary, until electric cars offer a better standard than cars with internal combustion engines. The criteria and their weights as well as the electric car model can be changed, in which case completely different results can be obtained. The current trend for changing the significance of individual criteria or their change may also be influenced by the latest knowledge and environmental and social trends. Manufacturers of electric cars, as well as the public administration and the customers themselves, thus having the opportunity to use decision-making methods to influence the vehicle market and the demand for them.

As for a crucial advantage, this study proved that various techniques of multi-criteria decision making in order to evaluate and choose passenger electric cars can be applied. On the other hand, as far as the major disadvantage is concerned, it is very difficult to determine the proper set of criteria taken into consideration as well as appropriate evaluated variants (i.e., passenger electric cars in our case).

In regard to the future research steps, these types of approaches can be successfully introduced to other transport-related issues to a greater or lesser extent and should be examined even more comprehensively. Therefore, further research can focus in particular on the following issues. Various telematics applications or other information technologies should be taken into account when addressing the analogous topics. Moreover, a negative impact of such solutions on environment needs to be investigated as well. And last but not least, it also would be reasonable to deal with the economic aspects of these proposals and approaches in more detail, such as time return on individual investments, overall profitability of the planned project and so forth.

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References

[1] United Nations framework convention [online] [accessed 2021-12-02]. 1992. Available from: https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change

[2] Kyoto protocol to the United Nations framework convention on climate change - Ministry of the Environment of the Czech Republic [online] [accessed 2021-12-02]. 2019. Available from: https://www.mzp.cz/cz/ramcova_umluva_osn_zmena_klimatu

[3] Paris agreement on climate change - Council of the European Union. [online] [accessed 2022-01-30]. 2018. Available from: http://www.consilium.europa.eu/cs/policies/climate-change/timeline

[4] LIU, K, KANG, L., AND PENG, Q. A brief review on key technologies in the battery management system of electric vehicles. *Frontiers of Mechanical Engineering* [online]. 2019, **14**(1), p. 47-64. ISSN 2095-0233, eISSN 2095-0241. Available from: https://doi.org/10.1007/s11465-018-0516-8

[5] AYOB, A., WAN MOHD, F., AZAH, M., MOHD, I. Review on electric vehicle, battery charger, charging station and standards. *Research Journal of Applied Sciences, Engineering and Technology* [online]. 2014, **7**(2), p. 364-373. ISSN 2040-7459, eISSN 2040-7467. Available from: https://doi.org/10.19026/rjaset.7.263
[6] MAHESWARI, S., SHARAN, V., SHALINI, V., SOWNDARABARANI, D., DINESH KUMAR, S. Improved battery management system for hybrid electric vehicle using supercapacitor. *AIP Conference Proceedings* [online]. 2021, **2387**, 120005. ISSN 0094-243X, eISSN 1551-7616. Available from: https://doi.org/10.1063/5.0068644
[7] GROGER, O., HUBERT A., GASTEIGER, J. AND SUCHSLAND, H. Review electromobility: batteries or fuel cells? *Journal of The Electrochemical Society* [online]. 2015, **162**(14), p. A2605-A2622. ISSN 0013-4651, eISSN 1945-7111. Available from: https://doi.org/10.1149/2.0211514jes
[8] MOULI, G., KAPTEIN, Z., BAUER, P., ZEMAN, M. Implementation of dynamic charging and V2G using Chademo and CCS/Combo DC charging standard. In: 2016 IEEE Transportation Electrification Conference and Expo (ITEC): proceedings [online]. 2016. p. 1-6. Available from: https://doi.org/10.1109/ITEC.2016.7520271
[9] BUZOVEROV, E., ZHUK, A. Comparative economic analysis for different types of electric vehicles. *International Journal of Sustainable Energy Planning and Management* [online]. 2020, **29**, p. 57-68. ISSN 2246-2929. Available from: https://doi.org/10.5278/ijsepm.3831
[10] ZHAO, Q. Electromobility research in Germany and China: structural differences. *Scientometrics* [online]. 2018, **117**, p. 473-493 ISSN 0138-9130, eISSN 1588-2861. Available from: https://doi.org/10.1007/s11192-018-2873-9
[11] SECHILARIU, M., MOLINES, N., RICHARD, G., MARTELL-FLORES, H., LOCMENT, F., BAERT, J. Electromobility framework study: infrastructure and urban planning for EV charging station empowered by PV-based microgrid. *IET Electrical Systems in Transportation* [online]. 2019, **9**(4), p. 176-185. eISSN 2042-9746. Available from: https://doi.org/10.1049/iet-est.2019.0032
[12] MACIEL FUENTES, D. A.; GONZALEZ, E. G. Technoeconomic analysis and environmental impact of electric vehicle introduction in taxis: a case study of Mexico City. *World Electric Vehicle Journal* [online]. 2021, 12, 93. eISSN 2032-6653. Available from: https://doi.org/10.3390/WEVJ12030093
[13] HELMERS, E. Electric car life cycle assessment based on real-world mileage and the electric conversion scenario. *The International Journal of Life Cycle Assessment*. [online]. 2015, **22**(1), p. 15-30. ISSN 0948-3349, eISSN 1614-7502. Available from: https://doi.org/10.1007/s11367-015-0934-3
[14] WUSCHKE, L., JACKEL, H. G., LEISSNER, T., PEUKER, U. A. Crushing of large li-ion battery cells. *Waste Management* [online]. 2019, **85**, p. 317-326. ISSN 0956-053X. Available from: https://doi.org/10.1016/j.wasman.2018.12.042
[15] ATIAS, D. *The automobile revolution: towards a new electro-mobility paradigm* [online]. Cham Switzerland: Springer, 2017. ISBN 978-3-319-45838-0. Available from: https://books.google.cz/books?id=AgYtDQAAQBAJ&printsec=frontcover&hl=cs&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false
[16] SCHMOCH, U., BECKERT, B., SCHAPER-RINKEL, P. Impact assessment of a support programme of science-based emerging technologies. *Scientometrics* [online]. 2019, **118**, p. 1141-1161. ISSN 0138-9130, eISSN 1588-2861. Available from: https://doi.org/10.1007/s11192-018-03002-x
[17] KIRSANOVS, V., BARISA, A., SAFRONOVA, A. Cost-benefit assessment of electric vehicle vs internal combustion engine in Latvia. In: IEEE 61st Annual International Scientific Conference on Power and Electrical Engineering of Riga Technical University RTUCON: proceedings [online]. IEEE. 2020. Art. no. 9316610. Available from: https://doi.org/10.1109/RTUCON51174.2020.9316610
[18] LUSZCZYK, M., SULICH, A., SIUTA-TOKARSKA, B., ZEMA, T., THIER, A. The development of electromobility in the European Union: evidence from Poland and cross-country comparisons. *Energies* [online]. 2021, **14**(24), 8247. eISSN 1996-1073. Available from: https://doi.org/10.3390/en14248247
[19] VADIRAJ, A. Infrastructure development and its management for future sustainable mobility. *SAE Technical Papers* [online]. 2016, **28**, 0252. ISSN 0148-7191, eISSN 2688-3627. Available from: https://doi.org/10.4271/2016-28-0252
[20] DIZO, J., BLATNICKY, M., SEMENOV, S., MIKHAILOV, E., KOSTRZEWSKI, M., DROZDZIEL, P., STASTNIAK, P. Electric and plug-in hybrid vehicles and their infrastructure in a particular European region. *Transportation Research Procedia* [online]. 2021, **55**, p. 629-636. ISSN 2352-1465. Available from: https://doi.org/10.1016/j.trpro.2021.07.029
[21] STOMA, M., DUDZIAK, A., CABAN, J., DROZDZIEL, P. The future of autonomous vehicles in the opinion of automotive market users. *Energies* [online]. 2021, **14**(16), 4777. eISSN 1996-1073. Available from: https://doi.org/10.3390/en14164777
[22] SETTEY, T., GNAP, J., SYNAK, F., SKRUCANY, T., DOCKALIK, M. Research into the impacts of driving cycles and load weight on the operation of a light commercial electric vehicle. *Sustainability* [online]. 2021, **13**(24), 13872. eISSN 2071-1050. Available from: https://doi.org/10.3390/su132413872

[23] MARCZAK, H., DROZDZIEL, P. Analysis of pollutants emission into the air at the stage of an electric vehicle operation. *Journal of Ecological Engineering* [online]. 2021, **22**(8), p. 182-188. ISSN 2299-8993. Available from: https://doi.org/10.12911/22998993/140256

[24] THILINA, D., GUNAWARDANE, N. The effect of perceived risk on the purchase intention of electric vehicles: an extension to the technology acceptance model. *International Journal of Electric and Hybrid Vehicles* [online]. 2019, **11**(1), p. 73-84. ISSN 1751-4088, eISSN 1751-4096. Available from: https://doi.org/10.1504/ijehv.2019.098717

[25] METSO, L., HAPPONEN, A., RISSANEN, M., EFVENGREN, K., OJANEN, V., KARRI, T. Data openness based data sharing concept for future electric car maintenance services [online]. In: *Smart Innovation, Systems and Technologies*. BALL, A., GELMAN, L., RAO, B. (Eds.). Vol. 166. Cham: Springer, 2020. ISBN 978-3-030-57744-5, eISBN 978-3-030-57745-2, p. 429-436. Available from: https://doi.org/10.1007/978-3-030-57745-2_36

[26] JIN, L. Q, SONG, C. X, WANG, Q. N. Evaluation of influence of motorized wheels on contact force and comfort for electric vehicle. *Journal of Computers* [online]. 2011, **6**(3), p. 497-505. ISSN 1796-203X. Available from: https://doi.org/10.4304/jcp.6.3.497-505

[27] EJEM, E. A., UKA, C. M., DIKE, D. N., IKEOGU, C. C., IGBOANUSI, C. C., CHUKWU, O. E. Evaluation and selection of Nigerian third-party logistics service providers using multi-criteria decision models. *LOGI - Scientific Journal on Transport and Logistics* [online]. 2021, **12**(1), p. 135-146. eISSN 2336-3037. Available from: https://doi.org/10.2478/logi-2021-0013

[28] KAYA, O., ALEMDAR, K. D., ATALAY, A., CODUR, M. Y., TORTUM, A. Electric car sharing stations site selection from the perspective of sustainability: A GIS-based multi-criteria decision making approach. *Sustainable Energy Technologies and Assessments* [online]., 2022, **52**(A), 102026. ISSN 2213-1388. Available from: https://doi.org/10.1016/j.seta.2022.102026

[29] WANG, X., ZHANG, H., ZHANG, S., WU, L. Impacts of joint operation of wind power with electric vehicles and demand response in electricity market. *Electric Power Systems Research* [online]. 2021, **201**, 107513. ISSN 0378-7796. Available from: https://doi.org/10.1016/j.epsr.2021.107513

[30] FIALA, P., MANAS, M. *Multicriterial decisions*. Prague: VSE, 1994. ISBN 80-707-9748-7.

[31] FOTR, J., DEDINA, J., HRUZOVA, H. *Managerial decisions*. 3. ed. Prague: Ekopress, 2003. ISBN 80-861-1969-6.

[32] CARNY, S., SPERKA, A., ZITRICKY, V. Multi-criteria evaluation of railway transport using evaluation method. *LOGI - Scientific Journal on Transport and Logistics* [online]. 2020, **11**(2), p. 88-99. eISSN 2336-3037. Available from: https://doi.org/10.2478/logi-2020-0018

[33] ZMESKAL, Z. Application of decomposition multi-attribute methods AHP and ANP in financial decision-making. In: International Scientific Conference Managing and Modelling of Financial Risks: proceedings [online]. Vol. 6. 2012. p. 689-699.

[34] Electrical vehicles specification [online] [accessed 2022-01-21]. Available from: https://www.renault.cz/elektricke-vozy/zoe.html

[35] LINA, X, ZEJUN, K. driving style recognition model based on nev high-frequency big data and joint distribution feature parameters. *World Electric Vehicle Journal* [online]. 2021, 12(3), 142. eISSN 2032-6653. Available from: https://doi.org/10.3390/wevj12030142

[36] GLOSER-CHAHOUD, S., HUSTER, S., ROSENBERG, S., BAAZOUZI, S., KIEMEL, S., SINGH, S., SCHNEIDER C., WEEBER M., MIEHE R., SCHULTMANN, F. Industrial disassembling as a key enabler of circular economy solutions for obsolete electric vehicle battery systems. *Resources, Conservation and Recycling* [online]. 2021, **174**, 105735. ISSN 0921-3449. Available from: https://doi.org/10.1016/j.resconrec.2021.105735