



This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits use, distribution, and reproduction in any medium, provided the original publication is properly cited. No use, distribution or reproduction is permitted which does not comply with these terms.

EMPIRICAL MEASUREMENT OF ELECTROMOBILITY EFFICIENCY IN THE ENVIRONMENT OF THE EUROPEAN UNION

Jozef Kubás ^{1,*}, Michal Ballay ¹, Jozef Ristvej ², Katarína Záborská ¹

¹University Science Park, University of Zilina, Zilina, Slovakia

²Department of Crisis Management, Faculty of Security Engineering, University of Zilina, Zilina, Slovakia

*E-mail of corresponding author: jozef.kubas@uniza.sk

Resume

The article presents an assessment of the use of alternative fuels in Europe with an emphasis on electromobility. In this regard, the impact of political intentions, ambitions and goals are analyzed, in relation to the current situation. Based on the results of empirical measurements, the efficiency of implementation of a European publicly accessible infrastructure for charging electric vehicles was determined. Using the method, the efficiency of electromobility in all the countries of the European Union was investigated. The resulting parameters are comparable in the context of the objectives of the Green Deal and the expected impact of electric cars. Using the results of the DEA model, one can point out the efficiency of countries and suggest ways to improve it.

Article info

Received 20 October 2021

Accepted 21 January 2022

Online 30 May 2022

Keywords:

electromobility

efficiency

DEA model

charging infrastructure

European Union

Available online: <https://doi.org/10.26552/com.C.2022.3.A123-A132>

ISSN 1335-4205 (print version)

ISSN 2585-7878 (online version)

1 Introduction

Transportation in the 19th century was a century of steam, the 20th century was a century of oil and it is more than likely that the 21st century will be a century of alternative propulsion, including electric vehicles. Electromobility is growing every year and has a significant share. However, compared to internal combustion engines, the current market share of electric cars is low. Within electric cars, one can encounter several problems, out of which the main one is relatively low energy efficiency. These vehicles are not a full-fledged alternative to internal combustion vehicles. The age of technology is upon us and we should be able to find a solution for any possible disadvantage. However, with each new technology come new challenges and, in general, electromobility is the future.

Many expert studies estimate the number and overall share of the electric car market in the future. In these cases, one encounters different information, depending on the area in which these studies come from. Some are about the breakdown of their production costs and assumptions about how these components will evolve over time, others are directly related to the environment. At the same time, there are various strategies at national or international level that promote

alternative fuels in relation to the environment. In this article, authors point out the support mechanisms in relation to political ambitions and goals. Is assessed the planned (future) state with the current state in the field of electromobility. The important fact is that electromobility cannot be without the necessary infrastructure, which means that it does not impose the new demands on the road infrastructure, but it does require the construction of a charging network.

2 Ambitions and targets of the European Union in relation to electric vehicles

Popularity of alternative fuel vehicles has been rising in recent years based on effort on maximizing fuel efficiency and minimizing negative environmental impacts. A transport system is gradually being set up, which aims at the efficient use of resources and eliminating oil dependence. In this article, in order to deal with alternative fuels, there must be an appropriate definition, which clearly identifies what these terms represent. Directive 2014/94 / EU of the European Parliament and of the Council of 22 October 2014 defines the concept of alternative fuels. "Alternative fuels" are fuels or energy sources, which serve at least

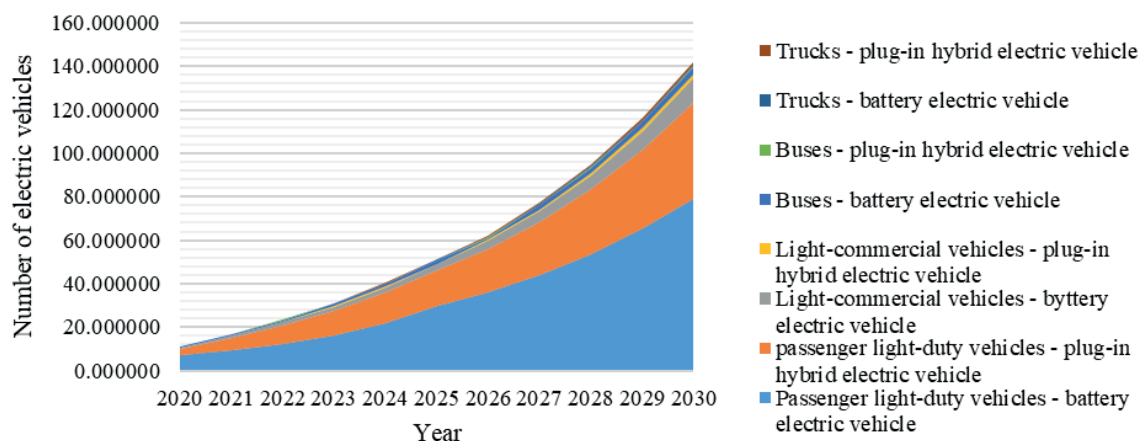


Figure 1 Global electric vehicles stock by mode in the Stated Policies Scenario, 2020-2030 [6]

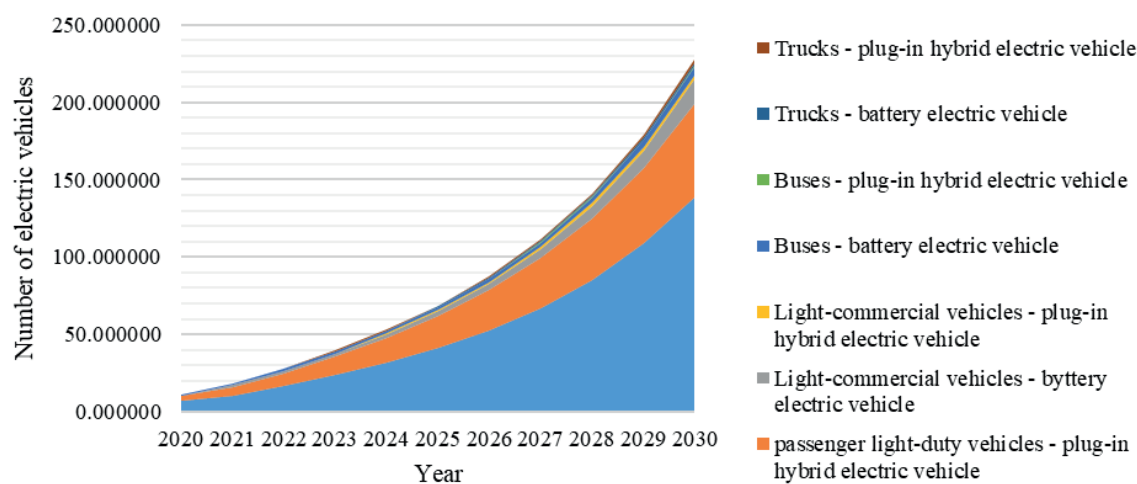


Figure 2 Global electric vehicles stock by mode in the Sustainable Development Scenario, 2020-2030 [7]

in part to replace fossil oil sources in the supply of energy to transport and which have the potential to contribute to its decarbonisation and to improve the environmental performance of the transport sector. Defined alternative fuels include the following: natural gas, including biomethane in gaseous form (compressed natural gas) and liquefied gas (liquefied natural gas), biofuels, electricity, liquefied petroleum gas, hydrogen and synthetic/paraffin fuels [1-2].

Road transport is an important part of all social processes. Nowadays, it is significantly affected by technological advances and societal change. Besides that, due to the growing demand for mobility, there is an overload. Road infrastructure in some cases is not able to provide sufficient traffic flow throughput and not fast enough to increase traffic. Additional expansion of road infrastructure is not possible, especially in urban areas and the construction of new infrastructure is very demanding. In this respect, it is therefore necessary to look for new, progressive tools, which, when applied, will make the transport system safer and more efficient [3].

At the same time, it must be emphasized that there is a constant increase in means of transport. The current trend in road transport is electric mobility, which also reflects existing policy frameworks and intentions, based on the developed strategies, whose main goal is to meet the global climate goals and achieve significant reductions in air pollutant emissions. By 2070, net-zero emissions should be achieved. These ambitions and goals contribute to a significant increase in the number of electric vehicles. This is largely due to growing enlargement in China. Worldwide, the number of electric vehicles for all the vehicle categories in the world will increase from 11 million in the current year to 145 million by 2030. The average annual growth is almost 30% (Figure 1).

The main goal stated in the Sustainable Development Scenario, 2020-2030, is reduction of carbon intensity of electricity generation and utilization of public transport. This represents a significant increase in the number of electric cars, which should reach the level of 230 million vehicles (Figure 2) [4-5].

All electric vehicles related targets and ambitions

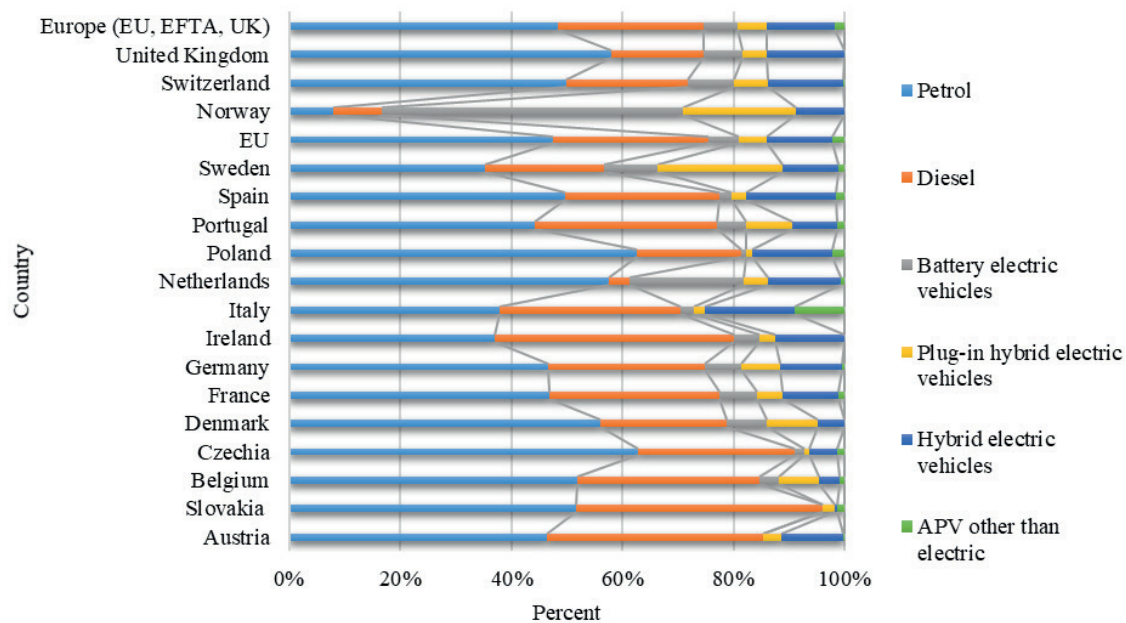


Figure 3 Passenger car sales in selected European countries in 2020, by fuel type [8]

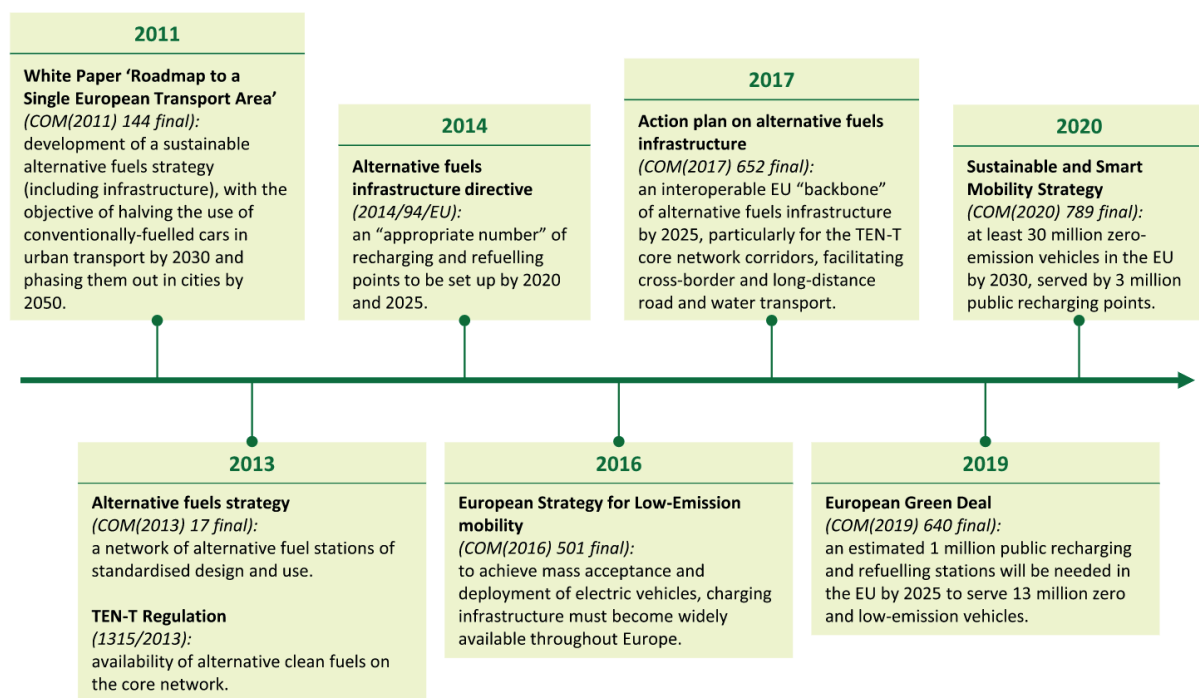


Figure 4 EU policy documents on alternative fuel infrastructure [9]

are met, even if the current policy measures are not deemed sufficient to stimulate such adoption rates. Number of electric vehicles in Europe is still small and largely dependent on support policies. Most electric road vehicles are concentrated in a few northern and western Member States, although the southern and eastern ones have recently recorded the biggest sales growth.

Each Member State is responsible for developing

and implementing its own alternative fuels policy within the framework set by EU legislation. Countries that offer generous incentives and have developed a good charging infrastructure have a higher share of electric road vehicles on transport routes.

There are measures at European Union level that support:

- assistance in the development and standardization of charging infrastructure,

- the use of renewable electricity and intelligent charging
- the battery research [9].

In relation to alternative fuels, several strategies have been developed at European Union level since 2011 and directives issued, which are gradually leading to the ambitious goal of becoming a climate-neutral continent.

The Green Deal, which is the latest in a series of EU policy documents on development of the alternative fuels infrastructure, should also contribute to this goal (Figure 3). Alternative fuels are very important in this regard, as transport in Europe produces almost a quarter of greenhouse gas emissions. At the same time, we are facing a major challenge in the field of alternative fuels infrastructure. In this regard, it is important to adopt the common standards to ensure interoperability, coordinate and support Member States' deployment of electrical charging infrastructure [9-11]. Figure 4 shows the timeline of EU policy documents on alternative fuel infrastructure.

The 2014 directive on alternative fuels infrastructure is the key policy tool within the overall EU strategy to develop publicly accessible electrical charging infrastructure. It aims to overcome a market failure best described as the “chicken-and-egg” problem: on one hand, vehicle uptake will be constrained until charging infrastructure is available, while on the other hand, investments in infrastructure require more certainty of vehicle uptake levels [9, 11].

3 Electric vehicles charging infrastructure

Electric vehicles require access to charging points, which are not the sole choice of their owners. For

this reason, electric car infrastructure plays a very important role, especially with regard to urbanism, energy companies and technological change. The number of charging stations is affected by the location, distribution and types of electric vehicles. Charging infrastructure for electric vehicles can be considered from the three perspectives:

- Home charging - is the most readily available, with charging options technically at level 1 (portable charger) and level 2 (more powerful unit).
- Workplaces - the availability of charging stations depends on regional or national policies.
- Publicly available chargers - needed where charging from home and in the workplace is not available or not enough to meet needs (for example, when traveling long distances).

The number of charging stations is increasing every year. The largest increase and share was recorded by private charging points (domestic charging). Slow charging is prevalent worldwide and this is mainly due to the fact that fast charging stations make up the smallest share. On average, the expansion of charging stations (infrastructure) increases by 30% every year. The distribution between the fast and slow charging points is determined by various factors. These are interconnected and dynamic, such as charging behavior, population density, battery capacity, housing and local government policy. Sustainable and Smart Mobility Strategy identifies infrastructure expansion forecast for electric vehicles (Figure 5).

Sustainable and Smart Mobility Strategy identified the need to expand charging stations for 3 million public charging points by 2030. Uncertainty prevails with this prediction, to reach the set targets. If the deployment of infrastructure continues to follow the 2014-2020

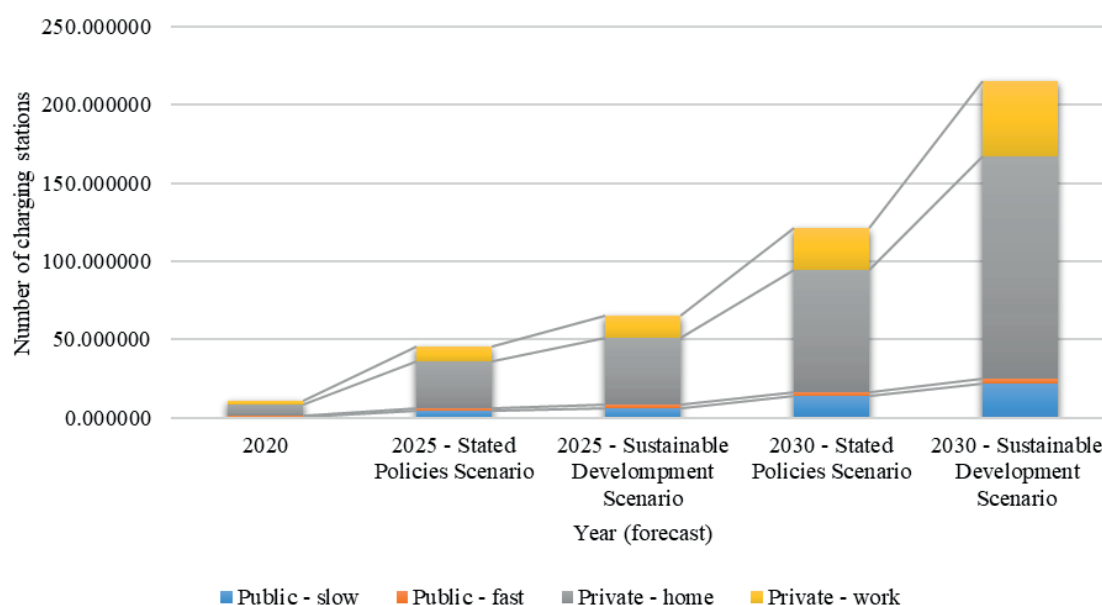


Figure 5 Number of electric LDV chargers by scenario, 2020-2030 [13]

trend, there will be a significant risk that the target of 1 million public charging points by 2025 will be unfulfilled [4, 11-12].

4 Evaluation of the efficiency of electromobility in EU countries with regard to charging infrastructure

One major problem that slows down the electric car is the impression that they cannot travel the required distance without the need to recharge. The cause may be a lack of charging infrastructure or insufficient awareness of its existence. Although the charging infrastructure for electric cars is increasing at different speeds across the EU, as is the use of electric vehicles, in some Member States there is still a lack of differences between countries. The very loss of supplied energy is also a problem with electromobility. Despite the documentation of the cars, which states the technical parameters such as power and range, irregularities may occur. In some cases, the incomplete use of energy does not allow the necessary range and it is necessary to recharge the car more often [14]. That is why it is necessary to examine how the infrastructure is available in individual states. These states need to be compared to each other and the efficiency of electricity infrastructure examined with regard to possibilities of individual states. Various methods can be used to measure efficiency. The popular and frequently used methods are as follows:

- DEA (Data Envelopment Analysis) method - is a non-parametric-deterministic method of estimating efficiency, which has recently become more and more popular in the banking environment. This approach was proposed by Farrell [15] who seeks to find better ways to assess productivity. Thanks to Charnes, Cooper and Rhodes [16], Farrell's concept was later refined into a practical research tool used in various areas of economic research.
- SFA (Stochastic Frontier Analysis) method - This method is one of the best known parametric-stochastic methods used to estimate the efficiency of financial institutions. It was independently developed by several authors [17-18] and subsequently introduced into the banking environment in 1990. The basic approach is a direct estimate of the production function using the profit and cost function. Recently, the multiproduction logarithmic transformation of the costs/profit function has been widely used. Cost and profit efficiency are important economic goals - minimizing costs and maximizing profits. Some authors have also used this method to measure energy efficiency [19].
- Ordinary Least Squares (OLS) method - The main task of this method is that the sum of the error squares they try to minimize is considered as a criterion for the accuracy of the problem.

Numerical and analytical approaches can be used using the method. In particular, the numerical least squares implementation method involves the largest possible dimension of an unknown random variable. In addition, the more calculations, the more the solution itself. Additional sets of predicted solutions are obtained from the set of calculations (initial data), from which the best were selected. If the solution file is parameterized, the least squares method decreases to achieve the optimal parameter value [20].

According to several authors, the DEA method is the most suitable of all the methods for measuring efficiency [21-22]. Ilyasu et al. summarized the possibilities of available software suitable for use in the academic environment [23]. The DEA method chosen by authors in this research is one of the nonparametric methods and it represents a model of linear programming. The DEA method used to analyse the relative efficiency of a production unit in a selected group of production units that use identical aggregated inputs and produce aggregated outputs. Arranged units (DMUs- Decision-making unit's) maximize their efficiency for each DMU_i , $i \in \{1, \dots, n\}$. The optimized unit is called DMU_o , $o \in \{1, \dots, n\}$. The vector of inputs is recorded, as well as of the organizational unit as $x_i = (x_{i1}, \dots, x_{im})^T$ and the vector of outputs $y_i = (y_{i1}, \dots, y_{is})^T$. Every single input and output has some evaluation, i.e. values that are denoted by vectors $u = (u_1, \dots, u_m)^T$ for inputs and $v = (v_1, \dots, v_s)^T$ for outputs. In this case, u_i ($i = 1, \dots, m$) is the value of the i -th input and v_k ($k = 1, \dots, s$) is a certain value of the k -th output [24-26]. For DMU_o , the efficiency measure $E_o(u, v)$ is determined based on the following equation:

$$E_o(u, v) = \frac{\sum_{k=1}^s v_k y_{ok}}{\sum_{j=1}^m u_j x_{oj}} = \frac{v^T y_o}{u^T x_o} \quad (1)$$

In order for the DMU to be effective, there is the so-called optimal solution in the form (u^*, v^*) in the problem, where $E^*(u^*, v^*) = v^* T y_o = 1$ and $u^* > 0$, $v^* > 0$. If a different case occurred, the DMU would be inefficient. The CRR model was chosen for the work, in which it is necessary to enter individual inputs (CCR-I) and individual outputs (CCR-O). Some authors also point out the suitability of using this model [27-28]. Authors in this research have focused on the CCR output model, as it is easier to change the outputs in the parameters that were chosen.

When selecting indicators used to measure efficiency, the focus was primarily on inputs and outputs that need to be determined before entering into the calculation method. This method was used to determine the efficiency of the electrical infrastructure with respect to charging stations. The principle of this method is that the calculation will show which of the compared countries works most effectively (i.e. which would achieve 100% efficiency) and based on the results,

other countries were then compared to it. Under the name of DMU are the organizational units, i.e. states whose goal is to maximize their efficiency. For each organizational unit (DMU), it is important to determine the inputs and outputs, which should neither be zero nor negative.

In the case of the DEA analysis, it is important to determine the input (CCR-I) and output (CCR-O) data. Gross domestic product (GDP) per capita in Purchasing Power Standards (PPS) was chosen as the input data. It is the spending of funds needed to create improvement issues with regard to development and security in transport [29]. Among the output data, the Recharging points for 100,000 people and High-Power Public Recharges for 100km Highway were chosen. Those data for the European Union states (DMU) are shown in Table 1; all the data are from year 2020.

The data from Table 1 are then entered into the DEA model with a focus on the CCR output model. Therefore, it was necessary to correctly determine the inputs and outputs. The correct designation made it

possible to evaluate the efficiency of states with regard to electromobility and charging infrastructure. The results are shown in Figure 6. The number 1 means 100% efficiency. The DMUs are fully (100%) effective based on the available data for other units if and only if their performance does not indicate that some of the inputs or outputs of a given DMU could be improved without compromising the level of other inputs or outputs [32].

Figure 6 shows the efficiency of the European Union countries. Efficiency was evaluated based on selected inputs and outputs. Of the countries compared, only the two countries were 100% efficient, namely the Netherlands and Estonia. Greece and subsequently Malta had the least efficiency in terms of charging infrastructure. If the focus is on efficiency of Slovakia, it can be seen that it was in 5th place with an efficiency rate of 52%. The efficiency of all compared countries is shown in Table 2.

Table 2 shows the efficiency of all the European countries, compared to each other. The advantage of

Table 1 Input and output data to the DEA method [30-31]

State - DMU	(CCR-I) GDP per capita in PPS	(CCR-O) Recharging points per 100.000 people	(CCR-O) High-Power Public Recharges per 100 KM Highway
Netherlands	128	383.1	79
France	106	68.4	35
Germany	120	53.7	57
Italy	96	22.4	18
Sweden	119	100.8	75
Belgium	118	73.6	27
Austria	126	92.5	77
Spain	91	17.3	14
Finland	111	67.5	54
Denmark	130	55.9	42
Portugal	79	24	16
Poland	73	4.4	25
Hungary	73	13	15
Czechia	93	11	49
Ireland	193	22.2	32
Luxembourg	260	589	7
Slovakia	70	16.9	56
Slovenia	89	35.6	17
Croatia	65	16.5	14
Romania	70	2.6	24
Estonia	84	32	131
Greece	73	4.4	4
Latvia	69	16.5	14
Bulgaria	53	2.8	10
Lithuania	84	6.4	31
Malta	100	19.6	0
Cyprus	90	7.9	9

the calculation is that it can point out to the necessary changes so that the efficiency of other states is 100%. In the considered case, the focus was on the output-oriented CCR model, as the outputs can change under certain conditions while maintaining the same inputs. If the focus is, for example on Slovakia, which was on

fifth place, it is possible to see in the table exactly how the outputs could change so that its efficiency becomes 100%. Recharging points per 100000 people would have to change from 16.9 to 32.33. The High-Power Public Recharges per 100km Highway would have to change from the original 56 to 107.12.

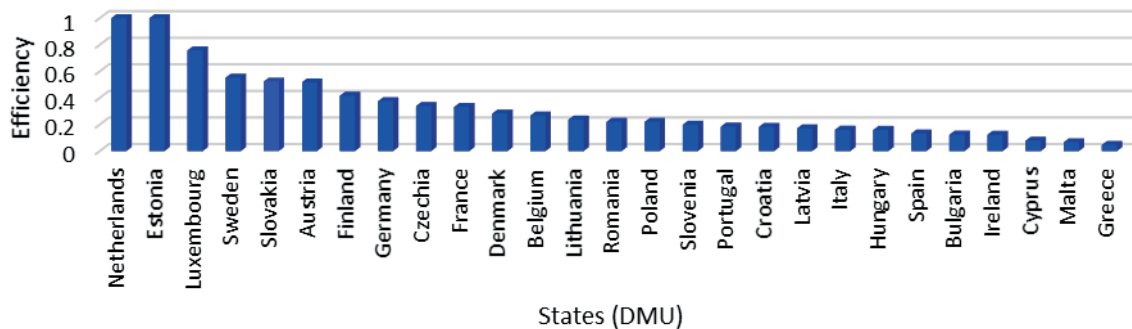


Figure 6 Efficiency of the states of the European Union with regard to charging infrastructure

Table 2 Results of the DEA - CCR output model method

Ranking of state	DMU	Efficiency	Inputs	outputs		Effective pattern (inputs)	Effective pattern (outputs)	
1.	Netherlands	1	128	383.1	79	128	383.1	79
1.	Estonia	1	84	32	131	84	32	131
3.	Luxembourg	0.76	260	589	7	260	778.17	160.47
4.	Sweden	0.55	119	100.8	75	119	182.78	136
5.	Slovakia	0.52	70	16.9	56	70	32.33	107.12
6.	Austria	0.52	126	92.5	77	126	179.2	149.17
7.	Finland	0.42	111	67.5	54	111	162.27	129.82
8.	Germany	0.38	120	53.7	57	120	143.18	151.98
9.	Czechia	0.34	93	11	49	93	35.43	145.04
10.	France	0.33	106	68.4	35	106	206.17	105.5
11.	Denmark	0.28	130	55.9	42	130	198.37	149.04
12.	Belgium	0.27	118	73.6	27	118	275.2	100.96
13.	Lithuania	0.24	84	6.4	31	84	32	131
14.	Romania	0.22	70	2.6	24	70	26.67	109.17
15.	Poland	0.22	73	4.4	25	73	27.81	113.85
16.	Slovenia	0.2	89	35.6	17	89	180.16	86.03
17.	Portugal	0.18	79	24	16	79	130.48	86.99
18.	Croatia	0.18	65	16.5	14	65	91.22	77.39
19.	Latvia	0.17	69	16.5	14	69	96.83	82.16
20.	Italy	0.16	96	22.4	18	96	139.91	112.43
21.	Hungary	0.16	73	13	15	73	81.79	94.37
22.	Spain	0.13	91	17.3	14	91	131.98	106.81
23.	Bulgaria	0.12	53	2.8	10	53	22.87	81.69
24.	Ireland	0.12	193	22.2	32	193	181.73	261.95
25.	Cyprus	0.08	90	7.9	9	90	101.82	115.99
26.	Malta	0.07	100	19.6	0	100	299.3	61.72
27.	Greece	0.05	73	4.4	4	73	97.55	88.68

5 Conclusion

Alternative fuels play an important role in an environmentally friendly environment modernization. There are many types of alternative propulsion and electromobility has an important place among them. With the rise of electromobility, the need for charging infrastructure is evolving in direct proportion. In the article, the focus was on important documents that address the development of electromobility in the European Union. Subsequently, a space was created to examine the efficiency of spending funds on building infrastructure with regard to electromobility and available resources. The efficiency could be investigated using the DEA model. In order to evaluate the efficiency correctly, it was necessary to correctly determine the inputs and outputs that enter the DEA model. The input data selected were the GDP per capita in PPS of individual countries. The output data were Recharging points per 100,000 people and High-Power Public Recharges per 100km Highway in each state. All the Member States of the European Union were considered in this research. Using the DEA method, it was possible to determine which state has 100% efficiency with respect to the specified parameters. From those states

was then derived the efficiency of other states. The results of the method also show how it is possible to achieve 100% efficiency, while maintaining inputs and adjusting outputs. Countries that do not achieve 100% efficiency should focus on outputs and thus increase efficiency. This article also creates space for new research into the efficiency of electromobility in such a way that efficiency could be examined from the global perspective. Efficiency could also be examined in the terms of use of all the available alternative fuels and with them the availability of publicly accessible places to replenish the necessary raw materials. For the purposes of the article, authors have focused on the European Union countries, as they have the same strategic documents in the field of electromobility and similar conditions. Nevertheless, it is possible to examine differences in efficiency.

Acknowledgement

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

References

- [1] Directive 2014/94/eu of the European Parliament and of the council of 22 October 2014 on the deployment of alternative fuels infrastructure [online], Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094>
- [2] BALLAY, M., MONOŠI, M. Electric vehicle technologies in relation to the implementation fire service rescue operations. *Journal Crisis Management / Casopis Krizovy Manazment* [online]. 2016, **2**, p. 18-25. [accessed 2021-09-12]. ISSN 1336-0019. Available from: https://www.fbi.uniza.sk/uploads/Dokumenty/casopis_km/archiv/2016_02/0601%20Ballay%20Monosi.pdf
- [3] Global EV outlook - International Energy Agency [online]. 2021 [accessed 2021-09-12]. Available from: <https://www.iea.org/reports/global-ev-outlook-2021>
- [4] World energy model - International Energy Agency [online]. 2020 [accessed 2021-09-13]. Available from: <https://www.iea.org/reports/world-energy-model>
- [5] Electric road vehicles in the European Union. Trends, impacts and policies - European Parliament [online]. 2019. [accessed 2021-09-12]. Available from: [https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637895/EPRS_BRI\(2019\)637895_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637895/EPRS_BRI(2019)637895_EN.pdf)
- [6] Global EV stock by mode in the Stated Policies Scenario, 2020-2030 - International Energy Agency [online]. 2020 [accessed 2021-09-14]. Available from: <https://www.iea.org/data-and-statistics/charts/global-ev-stock-by-mode-in-the-stated-policies-scenario-2020-2030>
- [7] Global EV stock by mode in the Sustainable Development Scenario, 2020-2030 - International Energy Agency [online]. 2020. Available from: <https://www.iea.org/data-and-statistics/charts/global-ev-stock-by-mode-in-the-sustainable-development-scenario-2020-2030>
- [8] WAGNER, I. Passenger car sales in selected European countries in 2020, by fuel type - Statista [online]. 2021 [accessed 2021-09-13]. Available from: <https://www.statista.com/statistics/500546/share-of-fuel-types-of-passenger-car-fleet-in-europe-by-country/>
- [9] Special Report 05/2021: Infrastructure for charging electric cars is too sparse in the EU - European Court of Auditors [online]. 2021. [accessed 2021-09-15]. Available from: <https://op.europa.eu/webpub/eca/special-reports/electrical-recharging-5-2021/en/>
- [10] State of the art on alternative fuels transport systems in the European Union - European Commission, B-1049 Brussels [online]. 2020. [accessed 2021-09-15]. Available from: <https://op.europa.eu/en/publication-detail/-/publication/fd62065c-7a0b-11ea-b75f-01aa75ed71a1>

- [11] Alternative fuels for sustainable mobility in Europe. Clean transport, Urban transport - European Commission [online]. 2021 [accessed 2021-09-15]. Available from: https://ec.europa.eu/transport/themes/urban/cpt_en
- [12] Alternative fuel infrastructures for heavy - duty vehicles. Requested by the TRAN Committee, PE 690.888 - European Parliament [online]. 2021 [accessed 2021-09-15]. Available from: https://erticonetwork.com/wp-content/uploads/2020/06/KL0420116ENN.en_.pdf
- [13] Number of electric LDV chargers by scenario, 2020-2030 - International Energy Agency [online]. 2020 [accessed 2021-09-15]. Available from: <https://www.iea.org/data-and-statistics/charts/number-of-electric-ldv-chargers-by-scenario-2020-2030>
- [14] SYNAK, F., KUCERA, M., SKRUCANY, T. Assessing the energy efficiency of an electric car. *Communications - Scientific Letters of the University of Zilina* [online]. 2021, **23**(1), p. A1-A13 [accessed 2021-09-15]. ISSN 1335-4205, eISSN 2585-7878. Available from: <https://doi.org/10.26552/com.C.2021.1;A1-A13>
- [15] FARRELL, M. J. The Measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)* [online]. 1957, **120**(3), p. 253-290 [accessed 2022-01-15]. ISSN 00359238, eISSN 23972327. Available from: <https://doi.org/10.2307/2343100>
- [16] CHARNES, A., COOPER, W. W., RHODES, E. Measuring the efficiency of decision making units. *European Journal of Operational Research* [online]. 1978, **2**(6), p. 429-444 [accessed 2022-01-15]. ISSN 0377-2217. Available from: [https://doi.org/10.1016/0377-2217\(78\)90138-8](https://doi.org/10.1016/0377-2217(78)90138-8)
- [17] AIGNER, D. J., LOVELL, C. A. K., SCHMIDT, P. Formulation and estimation of stochastic frontier production function models. *Journal of Economics* [online]. 1977, **6**, p. 21-37 [accessed 2022-01-15]. ISSN 0304-4076. Available from: [http://dx.doi.org/10.1016/0304-4076\(77\)90052-5](http://dx.doi.org/10.1016/0304-4076(77)90052-5)
- [18] BATTESE, G., CORRA, G. S. Estimation of a production frontier model: with application to the Pastoral Zone of Eastern Australia. *Australian Journal of Agricultural Economics* [online]. 1977, **21**, p. 169-179 [accessed 2022-01-15]. eISSN 1467-8489. Available from: <https://doi.org/10.22004/ag.econ.22266>
- [19] KINACI, H., NAJJARI, V., ALP, I. Using data envelopment analysis and stochastic frontier analysis methods to evaluate efficiency of hydroelectricity centres. *Gazi University Journal of Science*. 2016, **29**(1), p. 167-176. eISSN 2147-1762.
- [20] If the least squares method is applied - Stuklopečat.Sk (in Slovak) [online]. 2018. [accessed 2022-01-15]. Available from: <https://sk.stuklopečat.com/obrazovanie/81411-gde-primenyaetsya-metod-naimenshih-kvadratov.html>
- [21] ALBORES, P., PETRIDIS, K., DEY, P. K. Analysing efficiency of waste to energy systems: using data envelopment analysis in municipal solid waste management. *Procedia Environmental Sciences* [online]. 2016, **35**, p. 265-278 [accessed 2021-09-20]. ISSN 1878-0296. Available from: <https://doi.org/10.1016/j.proenv.2016.07.007>
- [22] CHOI, K. S., KIM, W. J. An Analysis on the efficiency of low-cost airlines in Korea. *Journal of The Korean Society for Aeronautical and Space Sciences* [online]. 2018, **46**, p. 436-444 [accessed 2021-09-25]. ISSN 2093-274X, eISSN 2093-2480 Available from: <https://doi.org/10.5139/JKSAS.2018.46.5.436>
- [23] ILIYASU, A., MOHAMED, Z. A., TERANO, R. Data envelopment analysis models and software packages for academic purposes. *Pertanika Journal of Scholarly Research Reviews* [online]. 2015, **1**(1), p. 27-32 [accessed 2021-09-25]. eISSN 2462-2028. Available from: <https://core.ac.uk/download/pdf/234560142.pdf>
- [24] MALIK, M., EFENDI, S., ZARLIS, M. Data envelopment analysis (DEA) model in operation management. *IOP Conference Series: Materials Science and Engineering* [online]. 2018, **300**, 012008. ISSN 1757-8981, eISSN 1757-899X. Available from: <https://doi.org/10.1088/1757-899X/300/1/012008>
- [25] JABLONSKY, J. Solving DEA models in spreadsheets and modelling languages. In: 8th International Conference on Modelling, Simulation and Applied Optimization ICMSAO: proceedings [online]. IEEE. 2019. Available from: <https://ieeexplore.ieee.org/document/8880322>
- [26] KUBAS, J., SOLTES, V., MISIK, J., STOFKOVA, Z. Efficiency of using financial resources and their impact on security in a local context. *Procedia Engineering* [online]. 2017, **192**, p. 498-503 [accessed 2021-09-25]. ISSN 1877-7058. Available from: <https://doi.org/10.1016/j.proeng.2017.06.086>
- [27] MOZAFFARI, M. R., DADKHAH, F., JABLONSKY, J., WANKE, P. F. Finding efficient surfaces in DEA-R models. *Applied Mathematics and Computation* [online]. 2020, **386**, 125497. ISSN 0096-3003. Available from: <https://doi.org/10.1016/j.amc.2020.125497>
- [28] YILMAZ, B., YURDUSEV, M. A. Use of data envelopment analysis as a multi criteria decision tool - a case of irrigation management. *Mathematical and Computational Applications* [online]. 2011, **16**(3), p. 669-679 [accessed 2021-09-30]. eISSN 2297-8747. Available from: <https://doi.org/10.3390/mca16030669>
- [29] PRIEVOZNIK, P., STRELCOVA, S., SVENTEKOVA, E. Economic security of public transport provider in a three-dimensional model. *Transportation Research Procedia* [online]. 2021, **55**, p. 1570-1577 [accessed 2021-09-25]. ISSN 2352-1465. Available from: <https://doi.org/10.1016/j.trpro.2021.07.146>
- [30] Alternative fuels. Electricity - year 2020 - European Alternative Fuels Observatory [online]. 2021. [accessed 2021-09-30]. Available from: <https://www.eafo.eu/alternative-fuels/electricity/charging-infra-stats#>

-
- [31] GDP per capita in PPS - year 2020 - Eurostat [online]. 2021. [accessed 2021-09-30]. Available from: <https://ec.europa.eu/eurostat/databrowser/view/tec00114/default/table?lang=en>
- [32] SILANC, P. A valuation of the eco-efficiency using the DEA models - a double stage (in Slovak). *EAPG Working Paper Series* [online]. 2013, WP No. 8. [accessed 2021-09-25]. ISSN 1338-2632. Available from: https://nhf.euba.sk/www_write/files/katedry/khp/eapg/wp008.pdf