




Article

BASS Model Analysis in “Crossing the Chasm” in E-Cars Innovation Diffusion Scenarios

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Abstract: In the face of contemporary ecological problems, including the influence of transport and mobility on the greenhouse effect, policy makers see a solution in the technology of electric vehicles (EVs). This innovation has appeared in the automotive market around the world. In this article, Rogers’ innovation diffusion concept was used to determine if and when EVs could replace combustion engine vehicles. The aim of the article is to analyze the current situation of innovative electric vehicle (EV) technology on the European Union (EU) market and the potential and possible directions of its market diffusion. As a result of the analysis of the current situation of the EU automotive markets, three groups of countries with different market conditions regarding the development of EV technology were distinguished. The classification was carried out using the K-means clustering algorithm, based on the current level of innovation and the level of development of the LPG-(Liquefied Petroleum Gas) powered car market. Then, a group of countries with the greatest advancement in EV technology was selected for further research and market diffusion scenarios were created for this innovation using the Bass model, assuming the target market size of 70–100% of all passenger cars.

Keywords: bass model; e-cars; EVs; automotive market; Roger’s diffusion innovation model; cluster analysis; e-mobility; innovation; sustainability; green energy; greenhouse gas emissions



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1. Introduction

The subject of electric vehicles is of wide interest in the world of science. The technology is analyzed in many aspects, as is the impact of electric vehicles on the environment.

When referring to the topic of technology diffusion, it is worth citing the article of Mitra et al. [1], where the authors analyze four cases of diffusion of innovations in emerging markets. Going further, it is also worth mentioning the thematic focus of the publication, related to the attempt to determine the number of electric vehicles (incl. buses) in different countries [2,3] or an attempt to estimate the amount of energy consumed by electric vehicles [4]. An interesting perspective is also the analysis in terms of identifying opportunities for the development of the described technology in various countries and regions of the world [4,5] or the directions of further research on electric vehicles and their impact on the environment [6].

Electromobility undoubtedly has great opportunities for development due to the growing awareness of the challenges related to climate change. In many countries, which are leaders in implementing this technology, there are incentive systems promoting the purchase of electric cars: direct subsidies, subsidies, tax breaks or additional privileges, such as exemptions from tolls for tolls on tolled highways, for parking in paid zones or the ability to use buses in lanes.

The EU strategy for the integration of the energy system [7] and the hydrogen strategy adopted in July 2020 indicate what model of transformation will be promoted in EU legislation and the rules for financing investments in the energy sector. It is based on electrification dependent on renewable energy sources. The European Commission assumes that their share in electricity production will have doubled by 2030, reaching around 60%. Electrification in the first place concerns the sector of district heating and individual heating, as well as transport. Transport uses a third of all energy used in the EU, which comes mainly from oil. This means that it is responsible for a significant proportion of greenhouse gas emissions in the European Union and is a major contributor to climate change. While most other sectors of the economy, such as energy and industry, have reduced their emissions since 1990, emissions in the transport sector have increased. 30 years ago, transport was responsible for the emission of 15% of greenhouse gases, now it is already responsible for 25%. Almost 30% of total EU CO₂ emissions come from this sector, 72% of which come from road transport. In road transport, passenger cars are the main source of pollution—they are responsible for almost 61% of emissions [1].

This makes the transport sector one of the main barriers to achieving climate protection targets today. Without changing lifestyle, consumption model and the use of zero- and low-emission technologies, improvement in this area will not be possible. The European Commission has announced a very large increase in the share of heat pump technology, as well as a rapid development of the charging infrastructure and the number of electric cars. Hydrogen is to play a complementary role, although, as indicated by the European Commission, by 2050 the share of hydrogen among energy carriers will be only about 10%. However, it is necessary to achieve climate neutrality where effective electrification will not be possible, e.g., in many industrial processes or heavy transport. A reflection of the direction set out in the energy system integration strategy is the increase in the sales of electric cars throughout the European Union. In the last three years, sales of new electrically-charged cars in the EU have increased by 110% since 2018-20 [8]. According to the data from the ACEA report for 2019 [9], 58.9% of the new cars purchased in Europe at that time were gasoline cars, 30.5% diesels, and 10.6% “green” vehicles. Among them, the most numerous group, 5.9% of all cars registered in 2019 were hybrids. Cars charged from external sources—3% (including 1.9%—electric cars and 1.1%—plug-in hybrids). Cars with LPG installations and E85 fuel adapted to combustion accounted for 1.2% sales, and cars with CNG installation 0.5%.

Currently, the sale of cars powered by hydrogen fuel cells is marginal. It is only 0.04%. Transforming the above data into numbers, in 2019 there were 8.96 million buyers of gasoline cars, 4.65 million of diesel cars, 897 thousand of hybrid cars, 285 thousand of electric cars, 174 thousand of plug-in hybrids and 535 of fuel cell cars.

The EU is clearly pointing the way forward in the field of electric vehicles in its current EU strategy to reduce CO₂ emissions in transport. In order to support zero-emission politics, the European Union will aim to have at least 30 million zero-emission vehicles on its roads by 2030, as it seeks to steer countries away from fossil fuel-based transport [10]. In a planned strategy the EU will lay out measures to tackle the quarter of EU greenhouse gas emissions that come from the transport sector. However, the EU assumptions may be too optimistic due to the lack of sufficient infrastructure.

Therefore, a question arises about the future of the development of new technologies in motorization, especially the future of electric vehicles. Does it have a chance to win the automotive market? Does it have the potential to be a competitive technology with the traditional one or does it have other options?

The aim of the article is to analyze the current situation of innovative electric vehicle (EV) technology on the European Union market and the potential as well as possible directions of its market diffusion. Presented in this article analysis stands out from the rest of the attempt at clustering the EU countries in terms of the potential, including the speed of implementation of electric car technology.

2. Materials and Methods

For the aim of the study three main research question were stated:

- Q1. What is the potential for the dispersion of this innovation (technology) in the nearest future?
- Q2. Is the EU market single or diversified in terms of the potential and speed of the diffusion?
- Q3. What number of electric vehicles is spread on the market as an innovation? Thus what share of the automotive market in the European Union has been gained by this technology?

Figure 1 illustrates the conception of the methodology of research process conducted for the purposes of the presented article.

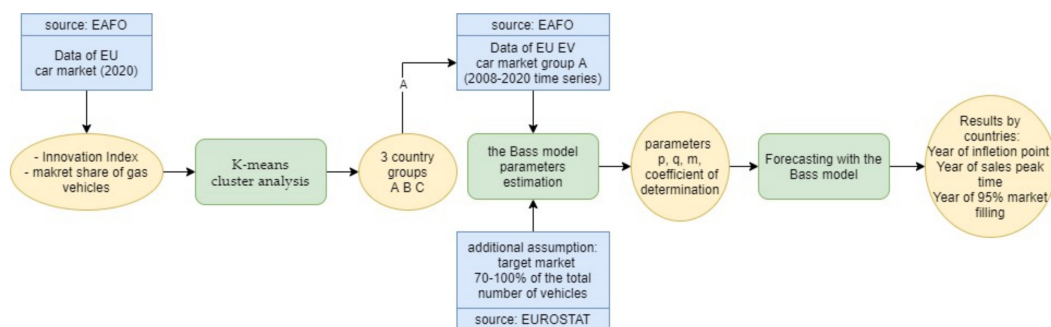


Figure 1. Methodology of the research and subsequent stages of the proceedings [own study].

According to the Deloitte report from 2020, the European market is not homogeneous. A very large differentiation of the EV market in individual European countries is observed. Growth in Northern and Western Europe is expected to outstrip that in Southern and Eastern Europe as wealthier countries (such as the United Kingdom, Germany, France, the Netherlands, Nordic countries) likely invest more in infrastructure and offer greater cash and tax incentives to accelerate initial growth [11]. Individual countries differ in terms of both the current demand for electric vehicles and the offered supply of these vehicles. The current diversification will have an impact on the long-term trend. The differences in the market situation of individual countries are shown by McKinsey's proprietary Electric Vehicle Index (EVI), which explores two important dimensions of electric mobility [12]:

- (1) Market demand analyzes, the share of EVs in the overall market, as well as factors affecting EV penetration in each country, such as incentives (for instance, subsidies), existing infrastructure, and the range of available EVs.
- (2) Industry supply explores the share of a country's OEMs in the production of EVs and EV components, such as e-motors and batteries, looking at both current and projected numbers. The EVI assesses the key performance indicators in each country and rates them on a scale from 0 to 5 for every dimension. These scores serve as the basis for the final country ranking (exhibit) (see Figure 2).

In this article, the answers to the Q1 and Q2 research questions were based on an assumption made regarding the significance of two main factors related to the use of clean energies in a given country: the share of LPG gas vehicles and the certain effectiveness of implementing alternative types of engines. On the one hand, in some countries, there is a tendency to invest in gas vehicles. For some countries, such as Turkey, Italy, or Poland, this share is significant (in the order of around three million). Therefore, the structure of vehicle classes in these countries is significantly different from countries where this type of vehicle is less popular or completely neglected. Countries that have been investing in this type of technology for many years will have different trends and needs for infrastructure development. Therefore, it was decided that the factor related to the share of gas vehicles has a significant impact on the share structure of various vehicle types.

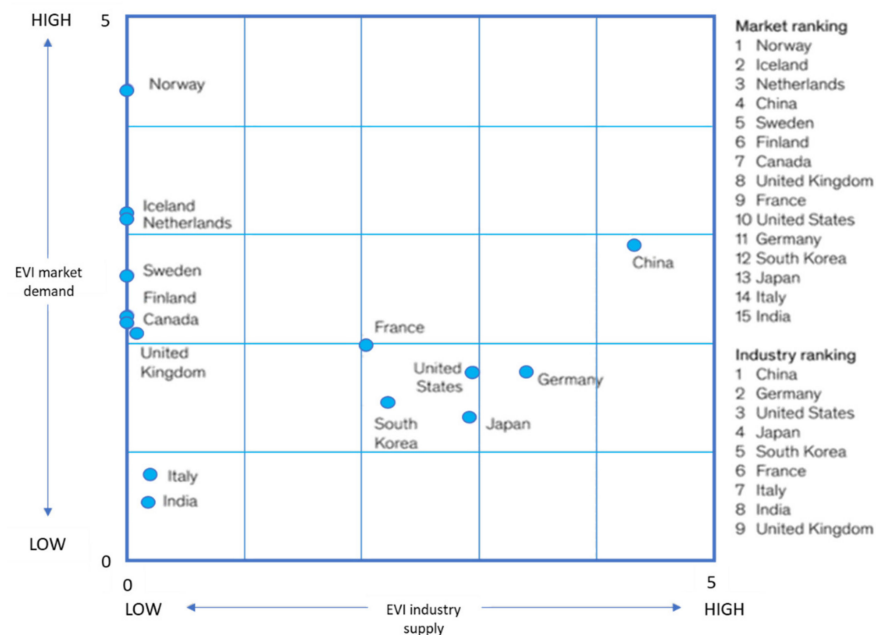


Figure 2. Overall Electric Vehicle Index (EVI) results, score (range from low of 0 to high of 5) [12].

On the other hand, a factor that takes into account the willingness to invest in modern vehicle propulsion technologies should be taken into account. It was assumed that more innovative countries will adopt modern technologies (like battery electric vehicle (BEV), plug-in hybrid electric vehicle (PHEV) vehicles, and hydrogen cells) more quickly. Based on European Alternative Fuels Observatory (EAFO) data [13], it was possible to obtain information about the year in which the first registration of a given type of vehicle took place. As the available data begin in 2008, this year was adopted as a reference point. For each country, the following coefficient was calculated:

$$Innovation\ Index_{country} = \sum_{i \in \{BEV, PHEV, H_2\ cell\}} first\ registration_i - 2008, \quad (1)$$

where $[first\ registration]_i$ —a year of the *first registration* of BEV, PHEV, or hydrogen cell type of car. In the absence of implementation of a given innovation, the registration date was assumed as 2021. Then, based on the innovation index, a ranking was created and the “1” value was assigned to the country with the smallest innovation index.

As the obtained data appeared to be very differentiated depending on the country, the grouping of countries according to similarity was applied. Clustering was carried out on the basis of two features: the level of LPG technology in the automotive market and the innovation index. Three levels of the share of LPG-powered vehicles in individual automotive markets were adopted: low, medium and high, and three levels of innovation—low, medium and high. Then the method of k-means grouping with $k = 3$ was used. The k-means method was chosen because it is a non-hierarchic method and is commonly used when the number of groups to be obtained is known [14,15]. Here, arbitrary, the division into three groups were set. The authors decided that this method is sufficient because only two factors determined the clustering of countries. As part of the mentioned above cluster-analysis, three basic groups of the EU countries were identified, for the purposes of this article called groups A, B, C. The differences between the groups result from the diffusion rate of electric car technology, as well as the country’s potential for the development of the technology. The precise division into three main country groups are shown in the Results chapter.

The Rogers innovation market diffusion concept was chosen to answer the third research question (Q3). Referring to this concept, the additional question was stated:

Q3.1. In which phase of market innovation diffusion is electric vehicle technology in the European Union market?

Innovation diffusion is the process of spreading innovation over time, through specific communication channels among members of a given social system. Diffusion is a kind of a social change in which there are accelerated changes in the structure and functions within the social system as a result of accepting or rejecting a given innovation. The four main building blocks of this process are: innovation, communication channel, time and the social system. Communication is the process of creating and sharing information between individuals of a given population in order to achieve mutual understanding. Such communication is a two-way interaction, and in the case of diffusion, the object of communication is a new idea or product. Communication channels are the means by which messages get from one person, or a source of information, to another. The connection of units with such information distribution channels creates a communication network [16].

Time in the innovation diffusion model has different characteristics. First, in the process of adopting an innovation, it is the time needed to go through the decision-making process. It is also the relative speed with which innovation is adopted by members of the social system. The time parameter can also measure the number of adapters of a specific innovation in a given time period, i.e., the rate of adoption is defined as the relative speed with which members of the social system adopt the innovation. It is usually measured by the time it takes for a given percentage of members of the social system to adopt an innovation [16]. The social system is defined as “a set of interrelated individuals who are involved in joint problem solving so as to achieve a common goal,” members of the social system can be individual or organizational individuals, as well as groups or subsystems. -covering a given, separated set of units is a jointly achieved goal [17]. Innovativeness is defined as the degree to which a given person, relatively earlier than other system users, adopts new ideas, and the level of innovation allows for the division of consumers into the categories of adapters [16]. The process of making decisions on the diffusion of innovation is the activity of searching for and processing information, which motivates an individual to reduce the uncertainty as to the advantages and disadvantages of a new solution. Two factors determine the type of decision to adopt an innovation:

- whether the decision was made freely and voluntarily,
- and who makes the decision.

On the basis of these considerations, three types have been identified—types of decisions in the process of diffusion of innovation [16]:

- (1) An optional, individual decision to innovate made by an individual independently of other individuals in the social system.
- (2) Collective decision to innovate made jointly by all units of the social system and most of them follow the common agreements.
- (3) The official decision on innovation was made “top-down”, i.e., administratively for the entire social system, by a group of people with an influential position and power.

The decisions taken in an official manner are adopted the fastest and most effectively, as they leave no room for the individual’s free choice. Rogers states [16] that innovation generates uncertainty, it provides an individual or an organization with new alternatives in solving problems or new products to meet needs. However, the individual, being unsure of these new possibilities, is strongly motivated to continue searching for information and confirming his or her decision.

The author defines “uncertainty” as the degree of perception of a certain number of alternatives, taking into account the probability of an event and the use of a given alternative. The information searched for by the individual allows them to choose one of the alternatives and reduce the state of uncertainty and inconvenience. The user’s decision to adopt a new solution is made through a cost-benefit analysis where uncertainty is the main obstacle. People will accept an innovation if they believe that it increases the usefulness of the solution used so far. Uncertainty often causes a decision to be postponed

until further evidence is obtained. The final decision is largely determined by personal characteristics, and the variety of adapters allows them to be categorized.

The pace at which innovation is adopted is reflected by the diffusion curve in the decision-making process, in which the individual moves from the initial knowledge of innovation to shaping the attitude towards innovation, making a decision to accept or reject, and then to implement the resolution and use new ideas, and finally confirm the undertaken decisions during use. The total number of adopters of an innovation, i.e., the cumulative number of adapters, takes the form of an “S”-shaped curve. In mathematics, an S-curve is known as a logistic function. In the beginning, the number of innovators slowly increases, then the number increases sharply, reflecting the steep increase in the S-curve. Finally, when more than half of consumers purchased a new solution, the pace of adoption stabilizes [18]. The bell-shaped curve, on the other hand, is used to characterize the distribution over time of five categories of system members in terms of innovation. These groups are the already mentioned categories of adapters [18]. The categories of adapters are divided according to their features and characteristics. The model of diffusion of innovation by Rogers—created as a result of empirical research—proves that there are several categories of innovation users who represent different approaches to novelty. Innovators are a small, initial group of the “brave”, they like risk and are eager to try new things. Early adopters are the first group of users to form an opinion of the product while purchasing with some caution. The early majority adopts a new product earlier than the general public, observing opinion leaders. The late majority are skeptics, accepting a new solution only when it is tested by other users. The last group consists of laggards who are afraid of novelty and change and adopt innovation only when it is common and necessary. Figure 3 shows the course of adoption of innovations in time for individual categories of adopters, on the horizontal axis is the time needed to adopt the innovation and on the vertical axis the number of innovation users. The navy blue curve reflects a normal bell shape showing the number of adapters over time and broken down by category. In contrast, the yellow curve is an S-curve showing the cumulative number of adapters that rises slightly and then increases sharply as the innovation spreads. Both curves depict the same innovation diffusion phenomenon. With the adoption of the innovation (navy blue curve) by subsequent groups of consumers, the cumulative market share of users grows (yellow curve) and finally reaches the saturation level [18]. It is worth noting that in the Rogers model the final fragment of diffusion is somewhat arbitrary, because some laggards adapt innovations after a very long time or do not imitate [17].

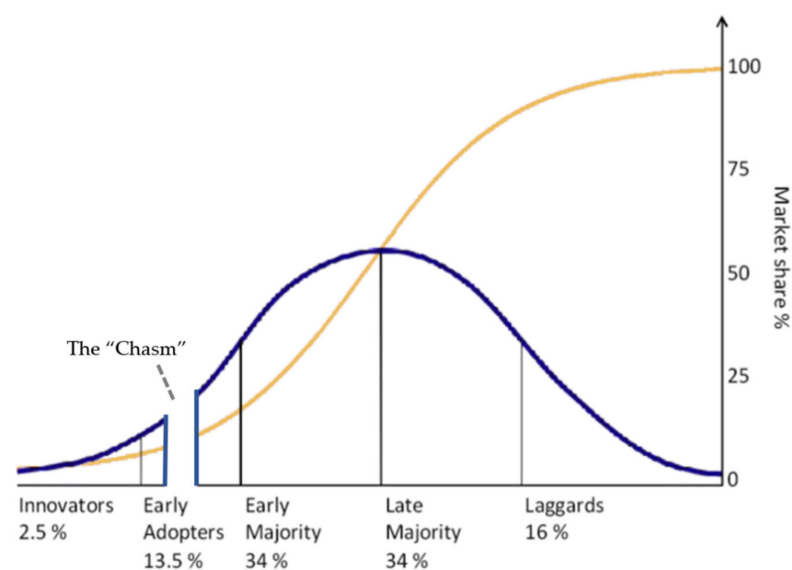


Figure 3. The course of adoption of innovations in time for individual categories of adopters [19].

One of the researchers exploring Rogers' concept was Moore. Moore, in his famous publication *Crossing the Chasm* [20], discussed the gaps and barriers that must be overcome to move from one customer group to the next. The largest gap, which he calls "the chasm", exists between the early adopters and the early majority. When firms manage to bridge this gap, they are already on the way from marginal product to mainstream product and further to broad development and profitability.

There are several factors influencing customers' decisions to accept or reject an innovation. The first is a relative advantage over the previous solutions known to the market. Another is compatibility, understood as the degree to which an innovation can be adapted to the life of the recipient, the user of the product. The third factor is the ease of use of the new solution. The easier the product is to use, the sooner the recipient will start using it. The last two factors are the ability to check and test an innovation before adoption, and visibility, the degree to which the use of an innovation is visible to others. This factor is very important in the dissemination of information about innovation and arousing interest and willingness to have a given product through a kind of desire to "catch up" with its users, which can be a very important purchase motive.

The Bass model can be used to identify the stage at which the studied innovation is located in the analyzed country/region. Taking into account the diversification of the market potential for the adaptation and development of the described technology, in this article, the Bass model was developed for the A-group countries with the greatest potential. The "A-group countries" term will be described in details in the Results section.

The usage of the Bass model requires the assumption of target market size. According to the data presented in commercial reports of global and especially European EV market, global EV sales rose a dramatic 65% from 2017 to 2018, for a total of 2.1 million vehicles, with sale figures steady through 2019. The subsequent outbreak of the coronavirus pandemic, however, resulted in a 25% decline in EV purchases during the first quarter of 2020. Despite these setbacks, EV demand is again expected to rise and hit 10% of global passenger vehicle sales by 2025, rising to 28% in 2030 and 58% in 2040 [11,12]. The share of new car sales taken up by EVs will vary considerably across markets. China is about to achieve a domestic market share of around 48 per cent by 2030—almost double that of the United States (27 per cent), and Europe should achieve 42 per cent. Based on the current growth rate of the market in the A-group countries the target market size for them was assumed at the level of 70–100%.

A descriptive approach to the innovation evolution was presented using the Rogers model, which defines particular groups (stages of innovation development). For calculations, the Rogers model is most often presented in an analytical form as the Bass model (this relationship is shown in Figure 4). It is important to underline, that the previous graph (Figure 3) depicts the market shares and the representation of the Rogers curve for diffusion of innovation. The diagram of Figure 4 below depicts the Bass curve versus the Rogers curve. The Bass curve for each country will be different, therefore the authors decided to show the general relationship between the course of the Bass curve and the Rogers curve (Figure 4).

The classic Bass model is presented by Equation (2) [21]:

$$f(t) = \frac{dF(t)}{dt} = \left(p + \frac{q}{m}F(t)\right)(m - F(t)), \quad (2)$$

where it is assumed that the zero moment means the start of diffusion of innovation ($t = 0$), it is the point of introducing technology to the market for a quantity buyer. The following notations were used:

$F(t)$ is the total number of innovation users by time t (numbers of EVs in the market from the moment of technology introduction to the current time t),

$f(t)$ —number of innovation users that adopt it at fixed time t , (t usually means a certain time interval, e.g., the whole year),

m —the total number of innovation users (total number of EV on market),

p —the innovation coefficient,
 q —the imitation coefficient.

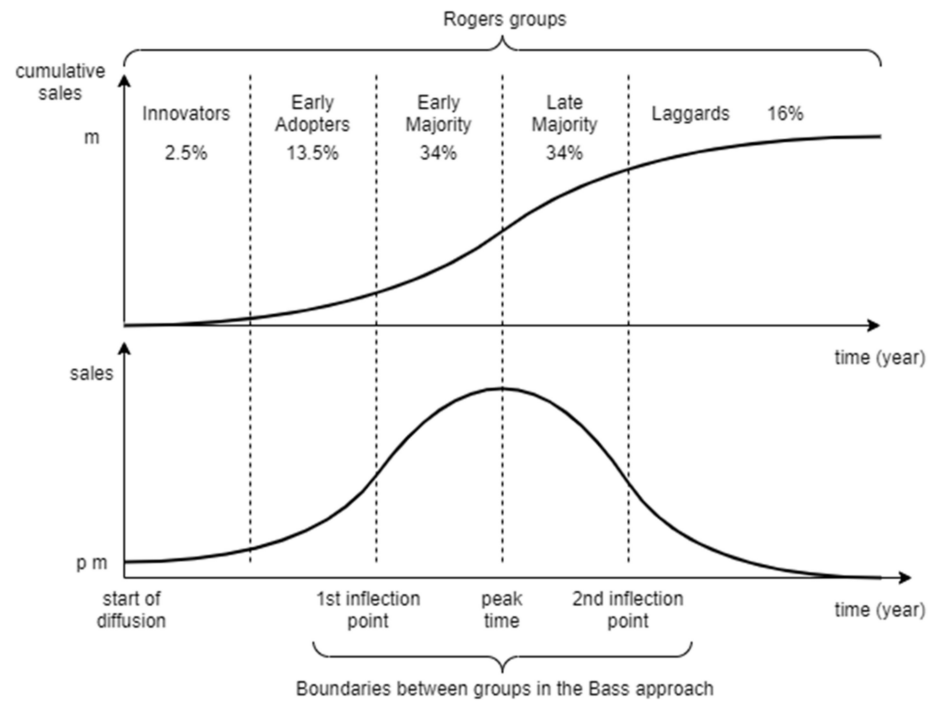


Figure 4. Sales and cumulative sales in the Bass model with Rogers group convention.

The analytical solution of Equation (2) can be written in the form:

$$f(t) = m \frac{(p+q)^2}{p} \frac{e^{-(p+q)t}}{\left(1 + \frac{q}{p}e^{-(p+q)t}\right)^2} \tag{3}$$

The bell-shaped function $f(t)$ describes the current sale of electric vehicles on the market. Formally, the function described by Equation (3) is asymmetric, the initial sales value is usually greater than 0 and related to the number of innovators, and therefore also depends on the innovation coefficient p . The original Bass model does not take into account the aging of technology and the natural replacement of vehicles. Therefore, for this article, it was decided to use the solution of the form of Equation (4):

$$F(t) = m \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}}, \tag{4}$$

which represents the current total number of vehicles on the market.

The peak time of function (3) can be written as Equation (5) [22]:

$$t_{peak} = \frac{1}{p+q} \ln\left(\frac{q}{p}\right), \tag{5}$$

It is essential that $p < q$ and that the maximum of the function $f(t)$ occurs after the technology is introduced to the market. The time moments in which the inflection points of Equation (3) occur can be defined as follows (see Figure 4):

$$t_{infl} = t_{peak} \pm \frac{\ln(2 + \sqrt{3})}{p+q}. \tag{6}$$

The article considers forecasting the development of innovation evolution based on the information before the first inflection point (sometimes also called LIP—left inflection point). Forecasting ahead of this point is a very challenging task [1]. It was noted in [13] that in this type of forecast very large errors may be generated. The nonlinear least square (NLS) method was used to estimate the parameters p and q of the Bass model. More specifically, due to the instability of the solutions, the iterative calling of the NLS method with different initial conditions of the p , q , and m parameters was used (more details see Appendix A).

3. Results and Discussion

3.1. The Innovation Index Measures

Table 1 lists the number of various vehicles types on the market for individual countries of the European Union. Also, information on the dates of the first registrations of BEV, PHEV, and hydrogen-powered vehicles was presented. These data were used to calculate the innovation index according to the Formula (1), and then to create the ranking. The Gas/Total column contains the percentage of gas vehicles in relation to other alternative fuel types (hybrids are not taken into account). All data presented were collected for 2020, presented by the European Alternative Fuels Observatory (EAFO) [13]. Gray columns were used to classify countries into particular groups.

Table 1. Number of registered vehicles with alternative drive and evaluation of innovation, based on the moment of introducing selected types of drives to the market. Data for the European Union countries for 2020 based on EAFO [13].

Country	BEV	PHEV	H ₂	CNG, LNG, LPG	Gas/Total (%)	1st reg. BEV (Year)	1st reg. PHEV (Year)	1st Reg. H ₂ (Year)	Innovation Index	Innovation Ranking
Austria	41,646	14,545	44	6060	9.73%	2008	2011	2010	5	1
Belgium	33,703	74,988	64	32,873	23.21%	2009	2012	2014	11	5
Bulgaria	1404	953	0	190,829	98.78%	2012	2012		21	13
Croatia	1353	553	0	60,732	96.96%	2014	2014		25	16
Cyprus	251	320	0	212	27.08%	2012	2014		23	15
Czech Republic	6504	3301	1	193,741	95.18%	2010	2012	2020	18	10
Denmark	30,516	26,749	148	134	0.23%	2009	2012	2013	10	4
Estonia	1769	256	0	7693	79.16%	2011	2012		20	12
Finland	9697	45,620	1	12,366	18.27%	2008	2012	2013	9	3
France	277,001	132,309	385	146,456	26.33%	2008	2012	2014	10	4
Germany	308,139	287,037	738	434,405	42.16%	2008	2011	2013	8	2
Greece	1104	2031	0	252,891	98.78%	2012	2014		23	15
Hungary	6101	4652	0	27,412	71.82%	2011	2012		20	12
Iceland	5499	9698	22	1644	9.75%	2008	2012	2015	11	5
Ireland	11,278	9659	0	0	0.00%	2010	2013		20	12
Italy	55,307	44,212	35	3,566,000	97.28%	2011	2012	2014	13	7
Latvia	846	196	0	48,042	97.88%	2012	2013		22	14
Liechtenstein	222	9	0	0	0.00%	2018	2018		33	17
Lithuania	1945	1559	0	97,977	96.55%	2012	2013		22	14
Luxembourg	4032	4516	2	407	4.54%	2011	2012	2018	17	9
Malta	1934	637	0	120	4.46%	2012	2014		23	15
Netherlands	182,481	108,652	390	133,563	31.42%	2012	2013	2016	17	9
Norway	319,540	134,420	195	226	0.05%	2008	2011	2013	8	2
Poland	6556	5919	0	3,373,065	99.63%	2011	2012		20	12
Portugal	36,882	27,710	0	56,932	46.85%	2008	2011		16	8

Table 1. Cont.

Country	BEV	PHEV	H ₂	CNG, LNG, LPG	Gas/Total (%)	1st reg. BEV (Year)	1st reg. PHEV (Year)	1st Reg. H ₂ (Year)	Innovation Index	Innovation Ranking
Romania	5563	1847	0	236,507	96.96%	2011	2012		20	12
Slovakia	1863	1643	0	54,495	93.96%	2011	2011		19	11
Slovenia	3665	792	0	11,030	71.22%	2012	2013		22	14
Spain	45,057	43,481	9	75,740	46.10%	2011	2012	2018	17	9
Sweden	58,240	132,440	47	43,908	18.71%	2008	2012	2015	11	5
Switzerland	52,008	32,824	144	15,897	15.76%	2010	2011	2015	12	6
Turkey	2899	1026	0	4,872,032	99.92%	2012	2014		23	15
United Kingdom	206,998	240,361	228	22,500	4.79%	2008	2011	2014	9	3

The method of classifying countries with different potential for the development of the discussed technology is cluster analysis. Figure 5 shows three groups of EU countries with different development dynamics in the e-car context.

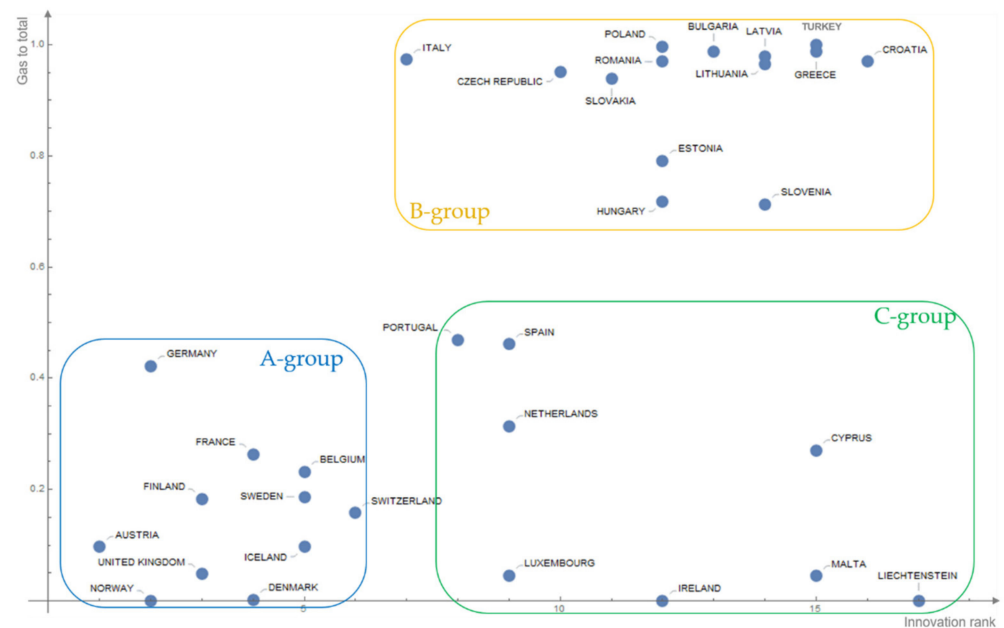


Figure 5. Cluster analysis of the EU-countries [own elaboration].

Group A brings together countries that are leaders in the development of electric technology. A characteristic of the A-group countries is provided in the appendix to this article. Group B was mainly addressed to all countries that have a lower level of EVs market development but are characterized by a large share of LPG-powered vehicles. Group C gathers all countries that do not show a clear division into the dominance of the share of one of the technologies, electric or LPG. The interesting case is the Netherlands, which, despite having a large share of the EVs market, was assigned to group C due to the fact that it has an equal share of LPG vehicles. The spatial distribution of individual groups is presented on the map in Figure 6.

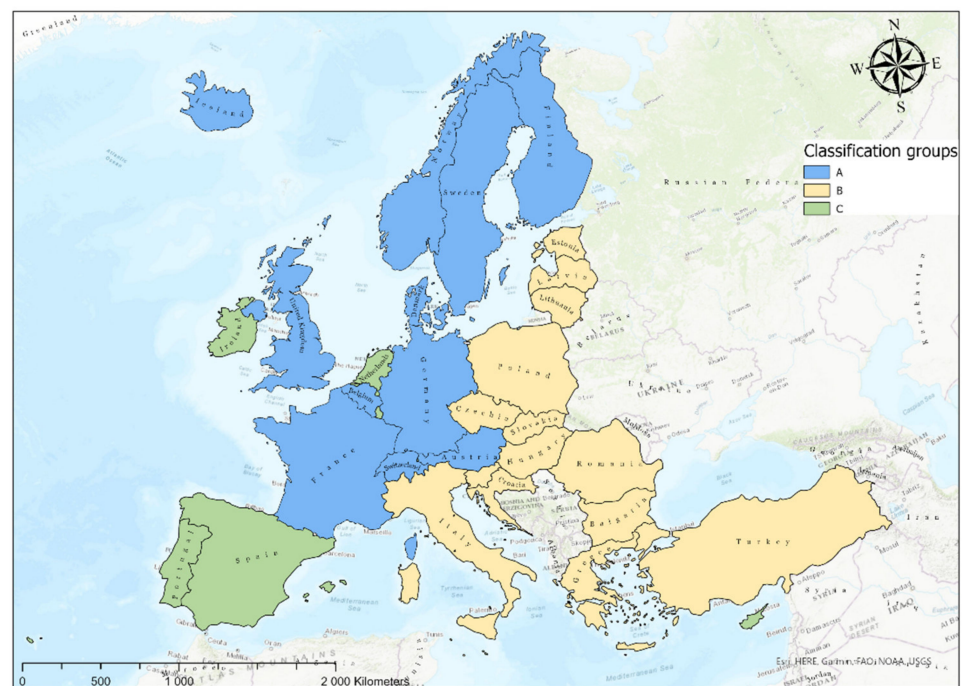


Figure 6. Spatial distribution of the cluster analysis of the EU-countries [own elaboration].

3.2. The Results of Bass Analysis

Based on the collected historical data, the Bass model was created. Subsequently, the forecast pointing to the development of electric vehicles for the countries belonging to group A was made. The results are presented in the Table 2.

Historical data on the basis of which the models were built, were taken from the European Alternative Fuels Observatory (EAFO) [13] and cover the range from 2008 to 2020. Annual data show the number of registered vehicles on the market. It has been formally assumed that EV electric vehicles are PHEV and BEV vehicles.

For countries from Group A, due to the conditions and policies, it is reasonable to assume that practically the entire market will be taken by electric vehicles. Therefore, in the Bass model, the target market restriction was adopted $m \in (0.7M, M)$, where M is the total car market. Information on M comes from Eurostat, it is the last available number of registered vehicles in each country.

In the broader context of technology development, it is worth noting that in some countries, LPG vehicles or hybrids (combining electric and internal combustion engines) are much more popular. Therefore, the assumption of almost complete market penetration was made only for group A, while for the remaining groups B and C, such an assumption is not obvious. The optimal solution from the point of view of the Bass model estimation is not to limit the size of the market at all. Unfortunately, in most cases, such solutions do not give acceptable results.

Additionally, restrictions were introduced for the innovation coefficient $10^{-7} < p < 0.5$ and for the imitation coefficient $0.1 < q < 0.9$. The introduced limitations result from the literature analysis in the field of Bass modeling (exemplary lists of coefficients can be found in [23]). In practice, these coefficients practically never exceeded the indicated range. It is possible to reduce these ranges even more, although the intention was not to interfere with the natural solutions generated during estimation, but only to reject those that are unreliable.

Table 2. Results of model parameters estimation for individual countries from group A (parameters medians from 1000 calls of the NLS method with different initial conditions for each country) [own study].

Country	p	q	m	m/M (%)	R ²	1st Infl. Point (Year)	Sale Peak Time (Year)	95% Market Share (Year)
Austria	0.0000499	0.391	4124,046	83%	0.9990	2029	2032	2039
Belgium	0.0000169	0.483	5,853,782	100%	0.9957	2027	2029	2035
Denmark	0.0000102	0.594	2,594,469	100%	0.9790	2025	2027	2032
Finland	0.0000023	0.663	2,909,114	84%	0.9996	2025	2027	2031
France	0.0000188	0.436	32,034,000	100%	0.9939	2028	2031	2038
Germany	0.0000015	0.686	35,534,209	75%	0.9891	2025	2027	2031
Iceland	0.0001242	0.423	241,265	70%	0.9826	2024	2027	2034
Norway	0.0008073	0.387	1,926,364	70%	0.9956	2021	2024	2032
Sweden	0.0000184	0.544	4,869,979	100%	0.9953	2025	2027	2032
Switzerland	0.0000675	0.435	4,602,700	100%	0.9981	2027	2030	2037
United Kingdom	0.0000309	0.436	22,062,318	70%	0.9971	2027	2030	2037

The results indicate that all countries in Group A should reach 95% saturation with innovation in the years 2031–2039. However, the share of electric vehicles in the total market fluctuates as assumed between 70% and 100%. The key assumption is that the first inflection point is exceeded. The Rogers model usually assumes that, if a market share of approximately 12–16% is achieved, it means that the innovation has a very good chance of being adopted by the entire market. Based on the model, it can be seen that Norway is closest to the inflection point (2021).

It can be seen that the coefficient of determination, denoted R² indicates very good properties of the models. However, fitting the points to the curve ahead of the left inflection point is usually associated with a high degree of instability. Small changes in the coefficients p and q make the fit equally good, but the estimated final quantity m changes very significantly.

The non-linear least squares method was used to approximate the parameters of the Bass model. It is very important to note that if the fit function is not linear in its parameters, the least squares problem requires an iterative solution algorithm. The most popular numerical methods used by symbolic packets are the Gradient Descent Method, the Gauss-Newton Method, and the Levenberg-Marquadt method [24]. The calculations were made in the Wolfram Mathematica 12.0 package, using the NonlinearModelFit function. The Levenberg-Marquadt method was used in the following model simulations. However automatic method selection was set for a constrained curve fit.

Since in most cases we have only a few sales observations, it turned out that the solutions are unstable and very sensitive to initial conditions. Therefore, an iterative call to the least squares method with different initial conditions was performed ($p = p_0 + \Delta p i$, $i \in 0 \dots n_i$, $q = q_0 + \Delta q j$, $j \in 0 \dots n_j$, $m = m_0 + \Delta m k$, $k \in 0 \dots n_k$).

The results of 12,000 simulations—estimation of the parameters of the Bass model for the first country from Table 2 (Austria) are presented below in Figures 7–9. The simulation parameters were as follows: $p_0 = 10^{-7}$, $\Delta p = 0.05$, $n_i = 10$, $q_0 = 0$, $\Delta q = 0.1$, $n_j = 10$, $m_0 = 0$, $\Delta q = 10^5$, $n_k = 120$.

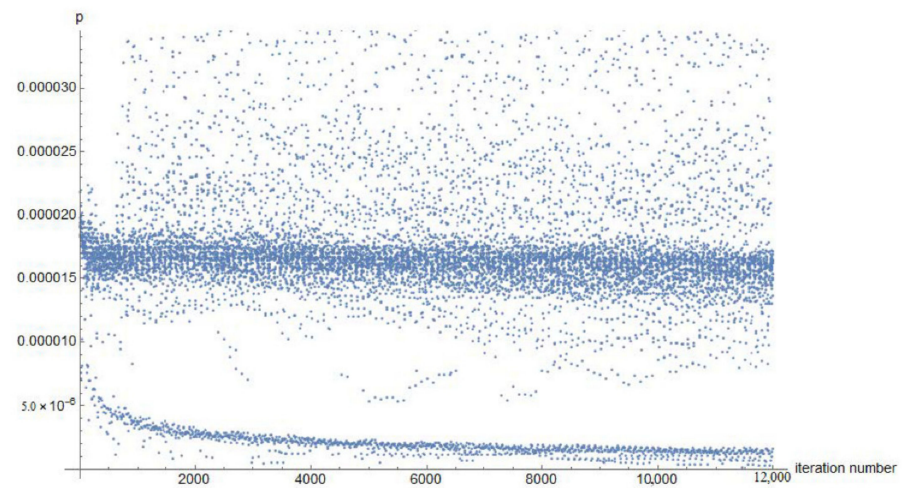


Figure 7. The results of the estimation of the innovation coefficient (p) for Austria in successive iterations of the nonlinear least squares method [own study].

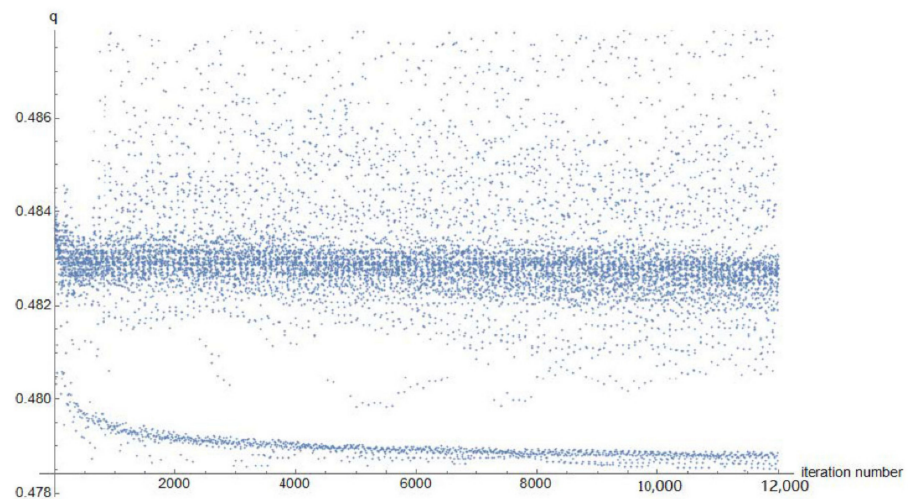


Figure 8. The results of the estimation of the imitation coefficient (q) for Austria in successive iterations of the nonlinear least squares method [own study].

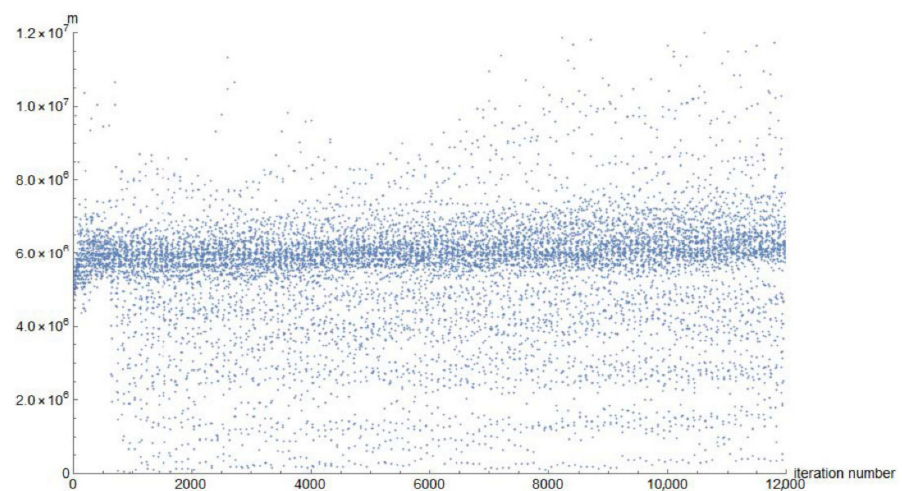


Figure 9. The results of the estimation of the EV market size (m) for Austria in successive iterations of the nonlinear least squares method [own study].

As can be seen in the figures, the estimation results significantly depend on the parameters. Figures 7 and 8 show two main local minima $p = 0.000017$ $q = 0.483$ and $p = 0.000002$ $q = 0.479$. The existence of these optima is dictated by the way points of observation (sales data) are arranged and it is not a general trend for all countries. Nevertheless, there is usually an optimum towards which most solutions tend.

Note that performing a single estimation with the NLS method can generate practically any result for the size of the market (from 0 to $12 \cdot 10^6$). Only a broader look at a number of simulations allows the evaluation of the development tendency. Due to the occurrence of local minima and solutions inconsistent with the interpretation (e.g., negative market size), the median was chosen as an estimator of the final parameter value. The histogram for the market size estimation results from Figure 4 is presented below (Figure 10).

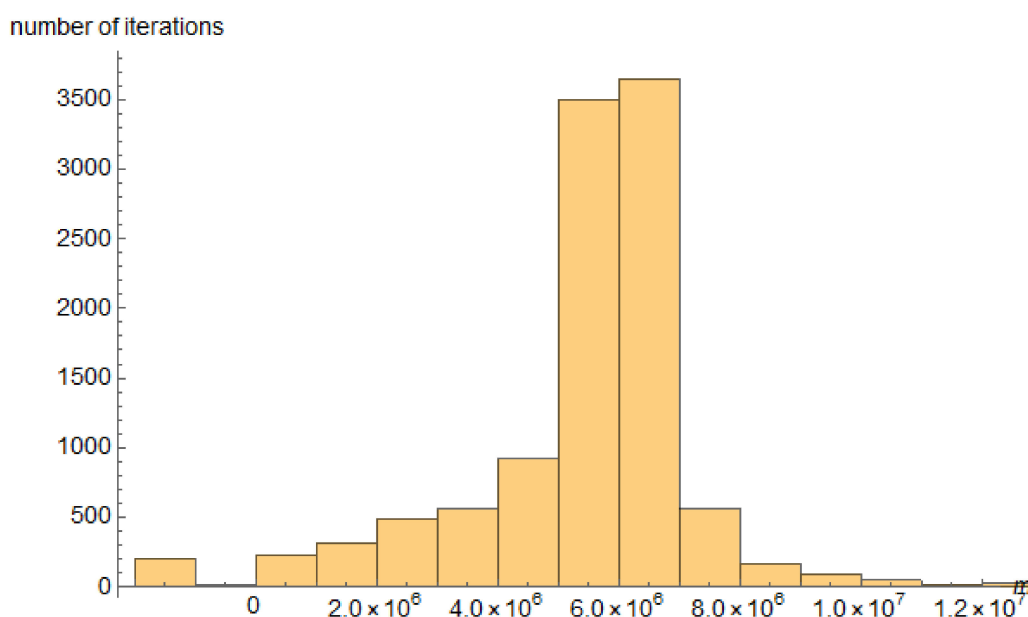


Figure 10. Histogram for market size (m) simulation results [own study].

4. Conclusions

Nowadays electric vehicles are widely regarded as solving many of the negative effects of their conventional counterparts. Given their potential to reduce local air pollution and greenhouse gas emissions, consumers, businesses and governments are increasingly supporting electric vehicles [25], which in the near future will lead to an increase in the share of new vehicle sales worldwide. The EV market is growing dynamically and despite a slight slowdown in the world's economies caused by the COVID-19 pandemic, the share of electric cars in the automotive market is growing. However, the dispersion of this innovation varies greatly, both globally and in Europe. The European Union countries can be divided into three groups in terms of the development potential of the e-car market. The market in the Group A countries seems to have the greatest development potential and innovation is already at a stage where its significant diffusion may occur. Norway is supposed to achieve the inflection point this year (2021). The scenarios for the automotive electric market in other countries will certainly be different, which will be the subject of further research.

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Appendix A

A-Group Country General Characteristics

According to the analysis conducted by the authors, the countries with the greatest potential for developing electric car technology are those from the group A, i.e., Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Norway, Sweden, Switzerland and United Kingdom.

According to the latest data from June 2020 of the International Energy Agency (IEA) [26], the largest share of new electric cars in the total number of cars sold can be recorded in Norway. It amounts to as much as 55.93%. So far, it is the only country in the world where more electric cars are sold than internal combustion cars. The following places are followed by: Iceland (22.6%), the Netherlands (15.4%) (despite that, the Netherlands was included in group C in the conducted clustering due to the relatively large share of LPG cars in the market), Sweden (11.43%), Finland (6.9%), China (4.94%, outside the EU) and Germany (3.01%).

Based on the above data, it can be concluded that Norway is the most electrified country in the world in terms of private transport.

A-group countries have particular systems of incentives promoting the purchase of the electric cars. These could be [27–29]:

- (1) legal regulations: i.e., Norway, France, UK, Austria, Iceland, Switzerland
- (2) tax advantages: i.e., Norway, Germany, UK, Denmark or
- (3) financial: i.e., Germany, France, UK, Belgium, Sweden, Finland as well as a combination of all three ways.

Electric car purchase support programs apply to both private individuals and those using company cars. It is worth emphasizing that the extensive program of supporting the introduction of electric cars to the market is not characteristic of the A-group countries. Of the 28 Members of the European Union, 24 have introduced instruments to support electromobility. An additional factor supporting the diffusion of innovation in the form of electric cars is undoubtedly the wealth of the society. All A-group countries are characterized by a high standard of living for their citizens, as well as a high degree of innovation, what makes them a favorable place for the development of electric car technology.

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