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Analysis of the development of the global electric vehicle market using cluster analysis

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ABSTRACT

In recent decades, electric vehicles have become an integral part of the fast-growing automotive industry, representing a key element of an environmentally sustainable transport future. Against the background of rapid expansion, it is important to analyze the development of the global electric vehicle market in order to understand its structure, dynamics and prospects. In this work, we will consider two approaches to the analysis of the dynamics of the electric car market: the first approach - based on cluster analysis - is designed to identify key trends in the dynamics of the markets of different countries, the second is a phase analysis, which will make it possible to identify cyclical dynamics, as well as to evaluate the characteristics attractors (quasi-cycles) and their features in each group of countries.

1. Introduction

In recent decades, electric vehicles have become a symbol of the transition to environmentally friendly and sustainable technologies in the automotive industry. Growing public awareness of the problems of climate change and environmental pollution has stimulated demand for vehicles that put less stress on the ecosystem and are less dependent on limited oil reserves.

Every year, we see not only an increase in the number of electric cars on the road, but also a rapid increase in investments in the development of new technologies and infrastructure for electric cars. In this context, the analysis of the development of the global electric vehicle market becomes a key tool for understanding its structure, dynamics and prospects.

The variety of models and manufacturers, and differences in adopted strategies and technologies, make this market difficult to analyze. In this context, the method of cluster analysis is an important tool for identifying markets with similar characteristics. By identifying clusters and analyzing their features, you can gain a deeper understanding of market dynamics, identify potential trends, and predict its future development.

The purpose of this article is to analyze the development of the world market of electric vehicles using cluster analysis methods, as well as to study the characteristics of the resulting clusters using phase analysis. This will make it possible to obtain information about the nature of the dynamics of time series for their further forecasting, which will help manufacturers, investors and government bodies to form strategies for their behavior.

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2. Related works

Despite the rapid growth of the electric vehicle (EV) market worldwide, there remains a need for a comprehensive understanding of trends and patterns of its development. Modern conditions require new approaches to market analysis [1], in order to minimize the loss of information about the researched object, which will allow for a more perfect development of targeted strategies for interested parties. This study aims to address this gap by using cluster analysis to segment the global electric vehicle market by the nature of the dynamics of electric vehicle sales per capita, in this work, for convenience and data proportionality, calculations are performed for the number of sales per 100,000 people. By identifying individual clusters in the market, at the next stage of the work, it is possible to investigate the behavior of time series in more detail using phase analysis, which will make it possible to see whether there are common or divergent patterns of behavior in different groups of time series.

Cluster analysis is a very effective method used in forecasting and for predictive data analysis, and the availability of a large number of metrics makes it possible to obtain useful results for data sets characterized by different properties.

In modern studies, cluster analysis is widely used, including for the analysis of the electric vehicle industry. Thus, paper [2] uses intelligent data analysis and empirical analysis to study companies engaged in the production of vehicles on alternative power sources. K-means cluster analysis and multiple linear regression is used to build the LASSO regression model used to identify the parameters that have a greater impact on new vehicle sales and for subsequent correlation analysis.

The review [3] shows that the application of cluster analysis has gained popularity in the field of studying the market and users of electric vehicles, and presents a number of studies using cluster analysis to solve various related problems. The best approach for solving the problems of the studied work, the authors note, is the use of cluster analysis methods for modeling the behavior of electric car users, studying driving cycles of electric cars, classification of used electric car batteries and clustering of electric car charging stations.

Understanding the adoption potential of battery electric vehicles using large-scale consumer profile data is an important issue in performing predictive analysis of the electric vehicle market. The introduction of battery electric vehicles (BEVs) is considered an integral part of the policy to reduce fuel consumption and carbon emissions, so a better understanding of potential BEV buyers is needed to realize this idea. In [4], a data analysis approach using cluster analysis was developed through perceived preference surveys to identify potential buyers using perceived preference data.

In work [5], the application of phase analysis made it possible to detect the presence of cyclical dynamics in the time intervals studied by the authors, to assess the characteristics of attractors (quasi-cycles) and their features for each agent in the Chinese electric vehicle market.

3. Methodology and materials

A group of 22 countries with the largest sales of electric cars in the world were selected for the study, these are such countries as: Australia, the Netherlands, the USA, Spain, Korea, Sweden, France, Finland, Switzerland, Canada, Great Britain, Poland, Portugal, Austria , China, Denmark, Germany, Norway and Italy. According to Tridens [6], China, the EU and the USA are the regions that accounted for about 95% of global sales of electric vehicles in 2022. Based on monthly data on sales of electric cars in countries from 2016 to 2022 [7] and population data [8], an indicator of the number of sales of electric cars per 100,000 population was obtained, which is used as time series values. Let us present the analyzed data in a general form:

$$X^{\,i} = \left(x^i(t)\right), \qquad i = \overline{1,22}, \qquad t = \overline{1,84}$$

Where, i is the country index, t is the ordinal index of observation.

Without violating the general approach, in the future we will mark the time series of sales without indicating the country number, that is:

$$X = \big(x(t)\big), \;\; t = \overline{1,84}$$

In this study, we will use two metrics based on different parameters, according to which data clustering occurs, for further interpretation of the obtained results.

As the first metric, the Euclidean metric was chosen, as is the most common in applications. The distance between two points $x = (x_1, x_2, \dots, x_n)$ and $y = (y_1, y, \dots, y_n)$ in Euclidean space is determined by the formula [9]:

$$d\,(x, y) = \sqrt{(x_1 - y_1)^2 + \,(x_2 - y_2)^2 + \cdots + (x_n - y_n)^2} = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$

In our calculations, the use of this metric will make it possible to group countries based on the similarity (proximity) of sales volumes of electric vehicles.

The second metric – the Pearson metric – makes it possible to obtain clusters of countries that are most correlated with each other in terms of sales dynamics. This metric is calculated according to the following formula[10]:

$$K(x, y) = \frac{\sum_{i=1}^{N} x_i y_i}{\sqrt{\sum_{i=1}^{N} x_i^2 \sum_{i=1}^{N} y_i^2}}$$

For both metrics, the union was performed according to Ward's method. This method uses a variance approach to estimate the distances between clusters. Briefly, this method involves minimizing the sum of squares of any two (hypothetical) clusters that can be formed at each step.

At the stage of analysis of the obtained clusters, we will use the method of phase analysis, which is one of the effective methods of obtaining information about the nature of the dynamics of the system under consideration [11]. For the time series, which characterizes the dynamics of sales in the market of electric cars per 100,000 people, we will use the following method of presentation, with the help of which it is possible to return from the observed state of the system to its previous state. This "return" is implemented by the method of time delays and is carried out by constructing a phase trajectory (phase portrait) of dimension ρ:

$$F_\rho(X) = \{(x(t), x(t+1), \dots, x(t+\rho-1))\}, t = \overline{1,n}$$

which is a set of points called the "ρ-history". For any time series, the list of all its ρ-histories defines the corresponding set of points in pseudo-phase (or lag) space. In this case, when using the terms "phase portrait" or "phase trajectory" it is mean that the neighboring points of the set $F_\rho(X)$ for clarity, segments of a straight or curved line connect them.

Therefore, the graphical representation of the system on the pseudo-phase plane (or in the phase space), along the coordinate axes of which the values of the variables of the system are plotted, is called the phase portrait of the system. The behavior of phase points in time, which is describe by a phase trajectory, and a set of such phase trajectories for any initial conditions form a phase portrait.

4. Results of cluster analysis

The cluster analysis was performed in the STATISTICA 13 software environment, and the visualization of the results can be seen in the tree diagrams.

The dendrogram of the results of the cluster analysis according to the Euclidean metric is shown in Fig. 1. The Euclidean metric clearly identifies two large clusters that contain smaller subgroups within them, and one country, Norway, stands out as a third cluster.

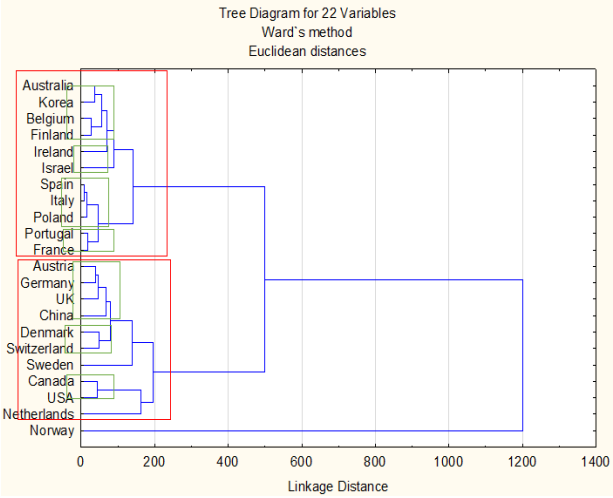

Fig. 1. Dendrogram of clusters by Euclidean metric

The composition of the clusters is presented in Table 1.

After analyzing the volumes of sales in the obtained clusters, it was determined that the average level of sales during the research period is 4.91 cars per month per 100,000 people, in the second cluster this indicator is 12.57 cars, in the third cluster – 58.15 cars per 100,000 people.

Table 1

Composition of clusters according to the Euclid metrics

Cluster 1	Cluster 2	Cluster 3
Australia	Austria	Norway
Belgium	Great Britain	
Israel	Germany	
Ireland	Denmark	
Spain	Canada	
Italy	China	
Korea	The Netherlands	
Poland	USA	
Portugal	Switzerland	
Finland	Sweden	
France		

Norway has long been a leader in sales of electric cars, the main reasons for this are a competent government policy aimed at encouraging citizens to purchase this type of transport. The main instruments of state policy that contribute to the increase in sales of electric cars are [12]:

- reimbursement of part of the cost of the purchased car to the citizens of the country;
- owners of electric cars are completely exempted from annual payment of transport fee and road tax;
- other incentives in the form of paying only half the price for ferry crossings, free parking and even the possibility of using public transport lanes.

Thus, the Norwegian government manages to achieve the desired results of the implementation of public policy. Other countries of the world also use similar incentive tools to increase sales of electric cars among the population, but the results of their work and the awareness of citizens are

somewhat lower, which is demonstrated by the sales of electric cars per 100,000 people in the first and second clusters.

When clustering according to the Pearson metric, the proximity of indicators is evaluated by the degree of their correlation, so it can be said that clustering occurs based on the similarity of the dynamics of time series. The dendrogram of clustering according to this metric is shown in Fig. 2, it clearly shows three clusters, in two of which smaller subgroups can be distinguished. The compositions of the clusters are shown in Table 2.

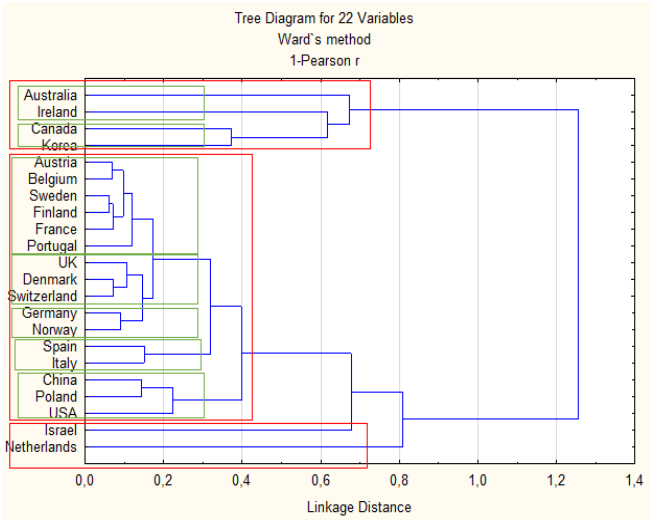

Fig. 2. Dendrogram of clusters by Pearson's metric

Table 2

Composition of clusters by pearson's metric

Cluster 1	Cluster 2	Cluster 3
Australia Ireland Canada Korea	Austria Belgium Great Britain Germany Denmark Spain Italy China Norway Poland Portugal USA Finland France Switzerland Sweden	Israel The Netherlands

Looking at the fact that the second cluster includes the majority of countries, it can be assumed that the dynamics of electric car sales are influenced by factors that are significant for the entire world market, such as:

- Technological innovations: Advances in battery technology, increased range, shorter charging times, and other technical improvements make electric vehicles more attractive to buyers;

- Price: The cost of EVs, including both initial cost and operating costs (eg charging versus refueling) plays a key role in the buyer's decision;
- Charging infrastructure: Availability of convenient and accessible charging stations, both domestic and public, as well as charging time, affects the convenience of using an electric car [14];
- Marketing policies: The effectiveness of marketing campaigns and campaigns can affect the awareness and confidence of potential buyers about electric vehicles;
- Trends and public opinion: Growing awareness of environmental issues, increased interest in sustainable mobility, and public support for environmentally friendly technologies may also drive demand for electric vehicles [13].

Considering the fact that the countries included in these clusters have similarities in the dynamics of sales of electric cars, it is advisable to conduct a phase analysis for the representatives of each cluster in order to identify their common features. To do this, we will construct phase portraits in two-dimensional pseudo-phase (lag) space for the third cluster and two subgroups of the second cluster.

Figures 3-5 show the phase portraits of the respective representative countries of each cluster, their analysis shows the obvious presence of cyclicity and the presence of drift of cyclic attractors (quasi-cycles) in the behavior of electric car sales volumes. Most quasi-cycles rotate clockwise, and their drift occurs along the bisector of the coordinate angle. This indicates a trend towards growth in sales volumes.

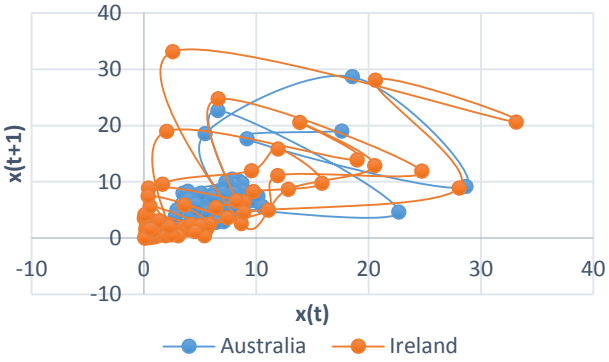

Fig. 3. Phase portrait of the first cluster representatives

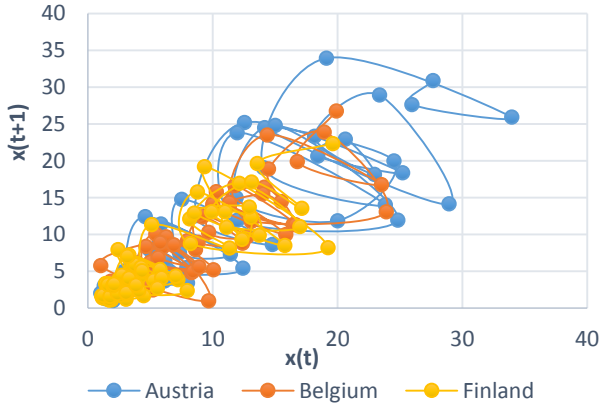

Fig. 4. Phase portrait of the second cluster representatives

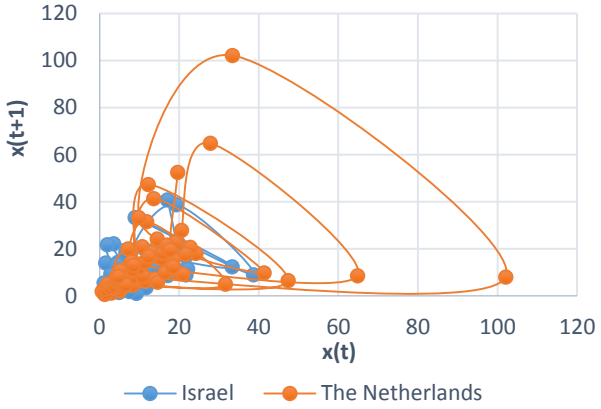

Fig.5. Phase portrait of the second cluster representatives

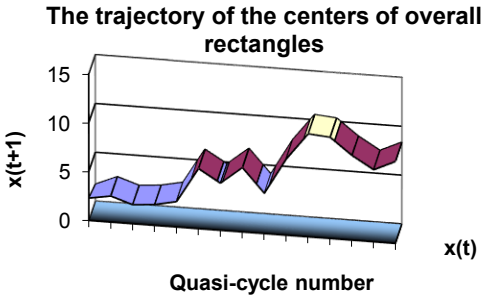

Fig.6. The length of quasi-cycles of representatives of the first cluster

Analysis of the length of quasi-cycles in sales dynamics shows its unstable nature in all identified clusters (this confirms the presence of an overwhelming number of short quasi-cycles with a length of 3-4 months). However, the presence of longer quasi-cycles (up to 10 months) and a higher indicator of their weighted average value (belongs to the interval [4,5; 6]) is characteristic of the countries of Cluster 1, which indicates a tendency to form a tendency towards trend-resistant dynamics. The most unstable is the sales dynamics in the countries belonging to Cluster 3 (the weighted average value of the quasi-cycle lengths belongs to the interval [3.75; 3.99]). However, a characteristic feature of this cluster is the largest volumes of sales and, accordingly, a large amplitude of quasi-cycles. This indicates that the consumption of electric vehicles per capita is increasing significantly in these countries. For example, in the Netherlands, the monthly sales volume for the entire period from 2016 to 2022 ranged from 0.71 to 102.11 sold electric cars per 100,000 population, and the maximum amplitude of quasi-cycles reached 94 units.

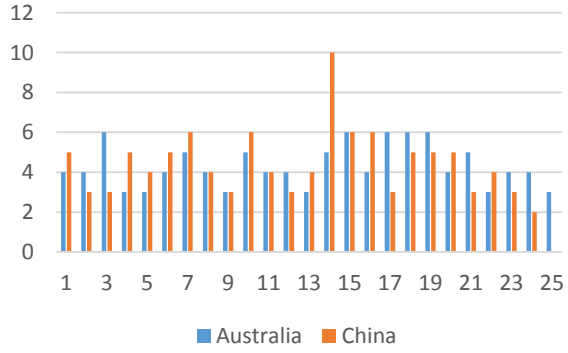

Fig.7. Trajectory of movement of the centers of overall rectangles (Israel)

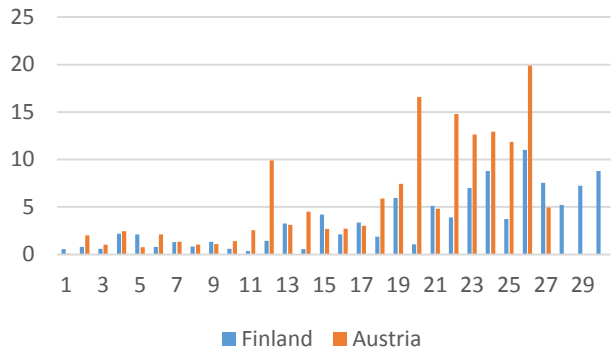

Fig.8. Amplitude of quasi-cycles of the representatives of the second cluster

A more in-depth analysis of the dynamics of the length and amplitude of quasi-cycles makes it possible to predict the drift trajectory of cyclic attractors (quasi-cycles). This determines the prospective direction of new research.

1. Conclusion

The use of cluster and phase analysis to study the development of the global market of electric vehicles provided valuable information about its dynamics and evolution. With the help of clustering, we identified separate groups of countries with similar characteristics regarding the dynamics and volumes of sales of electric vehicles. Such segmentation allows for the development of strategies for further analysis and forecasting of data adapted to the unique properties of each cluster.

In addition, the phase analysis made it possible to detect the presence of cyclical dynamics in some time intervals, to evaluate the characteristics of attractors (quasi-cycles) and their features for each individual country.

Our analysis highlights the multifaceted nature of the EV market, which is influenced by technological advances, government policies, economic factors and consumer preferences. As EVs continue to gain momentum as a viable alternative to traditional internal combustion engine vehicles, there is an urgent need for all stakeholders to collaborate and innovate to overcome existing barriers and accelerate the transition to a greener and more sustainable transportation ecosystem.

For the development of this research, a further deeper study of the influencing factors on the dynamics and volumes of sales of electric cars in each cluster is necessary. As well as a more detailed study of the identified features of phase portraits - determination of the characteristics of quasi-cycles and analysis of the dynamics of overall dimensions of quasi-cycles and their centers of gravity.

This study is useful for government organizations, automakers, investors, consumers, and researchers, environmental and international organizations that are involved in the study of the electric vehicle market and need information for predictive analysis or a more detailed study of the dynamic properties of the electric vehicle market.

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