The object of this study is the field of patenting of technological advances registered in the world in the field of automotive power plants. The subject of the study is the dynamics of patenting in the automotive power plant industry, associated with the need to harmonize the trajectories of technological development with global trends in energy efficiency and manufacturability, in order to ensure sustainable economic growth. Patenting in the industry is considered in the following areas: gasoline engines, diesel engines, hybrid cars, electric cars, hydrogen cars. The relevance of this study is determined by the general desire of society to innovate through the latest tools and the introduction of systemic measures to comprehensively address the problem of increasing energy efficiency and reducing air pollution caused by road transport. The paper analyzes the statistics of patents registered in the world, examines patent activity and trends in the patenting of technological advances in the automotive industry from 2010 to 2022. In the industry of gasoline and diesel engines, hybrid vehicles, electric vehicles and hydrogen vehicles, the current work investigates through systematization and analysis of important aspects of patenting statistics and innovation dynamics. For the period of 2017–2022, the average increase in the number of registered patents per year compared to the previous period was found to be 1.37 times higher for the area of "hybrid vehicles", 1.3 times higher for the area of "electric vehicles", and 26 times higher for the area of "hydrogen vehicles". A comparative analysis of the number of registered patents by areas was carried out, further patenting rates were predicted, and priority areas of research and innovation were identified

Keywords: innovation, hybrid vehicle, patent, power plant, energy source, hydrogen vehicle

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DEFINING INNOVATIVE AREAS AND PROSPECTS TO DEVELOP THE PATENTING OF TECHNOLOGICAL ADVANCES IN THE AUTOMOTIVE POWER PLANT INDUSTRY

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1. Introduction

To fulfill the tasks of the Global Agenda in the field of development until 2030, adopted at the UN Sustainable Development Summit in September 2015, it is necessary to make significant changes in the model of sustainable consumption and production. The main emphasis should be on the efficient use of natural resources, the minimization of waste and pollution, as well as the introduction of productive environmentally friendly technologies and innovations.

The tasks of the Global Agenda-2030 and the 17 Sustainable Development Goals (SDGs), which were approved by 193 UN member states, the implementation of broad consultations in the world led to the definition of goals, tasks, and key indicators of their achievement by 2030. The cluster of SDGs 8, 9, 12, 7, as well as 2 and 5 is aimed at the formation and development of a modern resource base for the growth of the country and provides for the implementation of tasks and policies in the strategic documents of the country's development. The goal is to increase the efficiency of resource use, use clean and environmentally safe technologies, introduce rational consumption models, create incentives for technical modernization and innovation, as well as transition to a circular economy with a focus on energy conservation and regenerative environmentally friendly production and consumption [1].

Road vehicles are one of the main sources of environmental pollution in areas with a high population concentration. This causes the formation of dangerously high levels of toxic substances in the air, which is directly inhaled by people. In addition, transport affects the natural environment and human health through other types of man-made impact, causing significant and irreparable damage to national health.

The consumer needs a powerful and economical engine at the same time; however, we have environmental requirements that are based on increased standards of exhaust gas toxicity, and, ultimately, the inevitable depletion of oil, coal, and gas reserves – non-renewable natural resources [2].

The relevance of this topic is predetermined by the public need for the development of tools and the implementation of systemic measures for a comprehensive solution to the problem of increasing the efficiency of energy use and reducing atmospheric air pollution by road transport. This involves reducing the energy dependence of the transport sector, improving air quality in cities, and fulfilling international obligations regarding climate change, in particular limiting and inventorying greenhouse gas emissions from road transport.

2. Literature review and problem statement

Study [3] examines the competitiveness of alternative fuels and technologies in the rapidly growing segment of passenger transport and aviation. Emphasis is on the need for additional development of strategies for focusing attention

on electricity and water in transport, but there is no analysis of existing developments and prospects for innovative development in this direction.

The main attention in [4] is paid to the mobile use of hydrogen, some proposals are put forward regarding the existing problems of technology development at the current stage, but the factors of significant influence on this process are not determined.

An assessment of the competitiveness of hydrogen technologies in the medium-term future and an overview of the potential role they can play as an option for deep decarbonization of global energy systems is presented in [5]. It is indicated that the competitiveness of hydrogen technologies no longer looks like an unrealistic prospect, however, a systematic analysis of patented innovations and promising areas of patenting in this area remains beyond the attention of scientists. Study [6] examines the production of energy based on hydrogen using fuel cells and their application in hybrid cars; it is noted that in the near future hydrogen fuel cells will play a significant role in the transport industry. Along with this, the analysis of innovations proposed in the world on this topic and the prospects for their further development in the researched field remains beyond the scope of the study. The analysis of achievements in the hydrogen fuel cell technology industry and its potential application in passenger cars are presented in [7], a modern and comprehensive review of scientific research that considers various aspects of electric vehicles is performed. However, the specified analysis does not contain comparative characteristics with other directions in the automotive industry.

Forecasting the future trend of the development of electric cars and the advantages of hybrid cars compared to gasoline and electric cars in terms of their operation and management costs are presented in [8]. However, the prospects are not evaluated, and the development of innovative processes is not forecasted.

Work [9] presents the issues of transition to electric and hybrid vehicles in the period between 2010 and 2016, notes the need for consumer support, paying attention, in particular, to the availability of infrastructure. Research focuses on the economic components of the transition to environmentally friendly vehicles and does not focus on technical innovations and their development.

The activity of patents on fuel cells and hydrogen production in the countries of the Visegrad Group depending on the vehicle fleet of these countries and the number of patent registrations in the hydrogen technology industry are analyzed in work [10]. Along with this, the study does not take into account data for all countries of the world and is focused exclusively on one area of improvement in the industry of automotive power plants.

The prospects for the development of the latest technologies are considered in work [11], the directions of technological development in the world, identified by the results of the analysis of the dynamics of co-patenting according to the Patent Cooperation Treaty procedure, are analyzed. However, the study does not specify the directions of innovation, in particular in the automotive industry, and does not cover the period of full-scale implementation of global environmental policy in transport.

Research on innovation regarding the use of alternative fuels for transport heat engines is reported in [12]. In work [13], the attention of scientists is paid to the modeling of work processes by determining the Wiebe function for the mathematical description of the combustion process in a diesel engine. The improvement of structures and the study of the stress-strain state of parts of power plants are given in [14] and are based on experimental tests of discrete reinforced elements of machine-building structures. Paper [15] addresses research technologies and analysis of the efficiency of working processes, diesel engines through a comprehensive assessment of fuel efficiency and toxicity of exhaust gases. The cited research is focused on solving urgent technological problems of the automotive industry, which contributed to obtaining more than 70 patents for useful models and inventions. Along with this, the studies did not analyze the patented developments in the relevant directions and prospects for their further development.

Thus, the determination of the main innovative directions in the development of the latest technologies in the automotive power plant industry and the prospects for their development and patenting is an unsolved problem that has remained out of the attention of scientists. The initial stage in solving this issue is the analysis of statistics, the study of the dynamics of patenting, and the identification of factors that influence the priorities and development prospects of the patenting of technological advances in the specified industry.

3. The aim and objectives of the study

The purpose of this study is to determine the trend in patenting of technological advances in the automotive powertrain industry from 2010 to 2022, particularly in the gasoline and diesel engine, hybrid, electric, and hydrogen vehicle industries. This will provide an opportunity by systematizing and analyzing important aspects of patenting statistics, dynamics of innovations in the automotive industry to determine priority directions and prospects for the development of the latest technologies in the industry of automotive power plants.

To achieve the goal, the following tasks were set:

– to analyze the statistics of patenting of technological advances in the industry of gasoline engines, diesel engines, hybrid cars, electric cars, and hydrogen cars from 2010 to 2022;

– to investigate the dynamics and identify the main trends in the change of patent rating in the following periods: 2010–2016 and 2017–2022;

– to investigate factors influencing the change of leadership, prospects for further development of innovations and patenting of technological advances in the industry of automotive power plants, in particular hybrid, hydrogen cars, and electric cars.

4. The study materials and methods

As an object of research, the field of patenting of technological advances registered in the world by directions in the industry of automobile power plants is accepted. The dynamics of the development of patenting in the industry of automotive power plants, related to the need to coordinate the trajectories of technological development with world trends in energy efficiency and manufacturability, to ensure sustainable economic growth, are the subject of research.

Research hypothesis: hydrogen, electric, and hybrid technologies are priority and promising innovative areas of patenting in the industry of automotive power plants under the conditions of global energy efficiency and manufacturability trends.

The research uses general scientific theoretical methods:

– analysis and synthesis – to clarify the main scientific categories of research, justify new concepts and categories, laws, principles in the case of solving research tasks;

– schematic and graphic image – for a visual representation of the obtained research results and analytical data;

– modeling and forecasting – to build a forecast of the innovative development of patenting in the world according to directions of improvement in the industry of automotive power plants.

Special methods were used in the research: comparative analysis, statistical – for a comprehensive assessment of the state of patent registration, according to directions of improvement in the industry of automotive power plants: gasoline engines, diesel engines, hybrid cars, electric cars, hydrogen cars.

Factors related to the change of global priorities in the area of innovation, modernization, and the direction of development in the areas of improvement in the industry of automobile power plants are taken into account. Thus, two main research periods were adopted for qualitative analysis, namely: 2010–2016 and 2017–2022.

The research was carried out in five directions in the automotive power plant industry, namely: gasoline engines, diesel engines, hybrid cars (hybrid power plants), electric cars (electric power plants), hydrogen cars. In order to specify the results and predict the further development and dynamics of patenting, the periods were divided into twelve sub-periods and the quantitative changes in each of them were investigated in accordance with the directions of patenting.

In the study, the statistics of patents registered in the world by the area of improvement in the industry of automotive power plants were used, presented by the European Patent Office (EPO).

In order to qualitatively assess the dynamics of patenting in the world by areas of improvement in the industry of automotive power plants, a calculation of the increase in the number of registered patents was performed. The calculation was carried out by determining the difference in their registered number for the previous and following years. The indicated dynamics of increase/decrease in the number of registered patents in the compared years. The average numerical increase in the number of patents registered in the world for each of the areas of improvement in the automotive power plant industry was calculated. The calculation was carried out by determining the ratio of the arithmetic sum of the increments in the number of patents for the corresponding studied periods to the number of studied periods.

A linear approximation is used to construct trend lines in the graphical representation of the analysis results for each area of improvement in the automotive power plant industry. Trend lines are used as a visual tool of technical analysis, which makes it possible to demonstrate in the simplest way in which direction the trend of changes in the number of patents registered in the world is moving. It is applied because the data points are located close to the straight trend line.

5. Results of investigating the dynamics and development trends of patenting by direction of the automobile industry

5. 1. Results of investigating the statistics of development patenting from 2010 to 2022

Table 1 gives summary data [16] of the number of registered patents in five areas, namely: gasoline engines, diesel engines, hybrid cars (hybrid power plants), electric cars (electric power plants), hydrogen cars.

I conduct a comparative analysis of the number of registered patents (Table 1) for the period of 2010–2022 as a whole and divide the specified period into 2010–2016 and 2017–2022.

Table 1

Number of registered in the world by areas of improvement in the automotive powertrain industry

Year	Gasoline engines	Diesel engines	Hybrid cars	Electric vehicles	Hydrogen cars
2010	8487	11733	8744	46372	465
2011	7973	11497	9470	48865	468
2012	8549	12158	11478	56397	442
2013	9785	13967	13327	63908	418
2014	11654	17775	14206	81216	553
2015	12604	18298	14461	92168	469
2016	12705	18325	15064	103181	561
2017	13813	19328	17320	123405	874
2018	14957	21143	19329	160155	952
2019	14128	20449	21815	160898	1330
2020	14453	21516	24168	164461	1722
2021	14562	22772	23433	179475	2449
2022	13012	20654	23709	176613	3057

Comparative analysis of the data listed in Table 1 for the period of 2010–2022 is illustrated in Fig. 1, *a*, *b*. The graphic representation of the analysis is a curve that reflects the trend of increase/decrease in the number of patents registered in the world in the respective directions for each year of the period under consideration. An opportunity was obtained to qualitatively investigate the dynamics of the course of the patenting process.

Fig. 2 shows a comparison of the average number of registered patents in the world by areas of improvement in the automotive power plant industry for the periods 2010–2016 and 2017–2022.

The increase in the number of patents b_i is calculated for each area of patenting according to formula (1):

$$b_i = a_k - a_j, \quad (1)$$

where a_j is the number of patents registered in the year under study;

a_k – the number of patents registered in the year preceding the year under investigation;

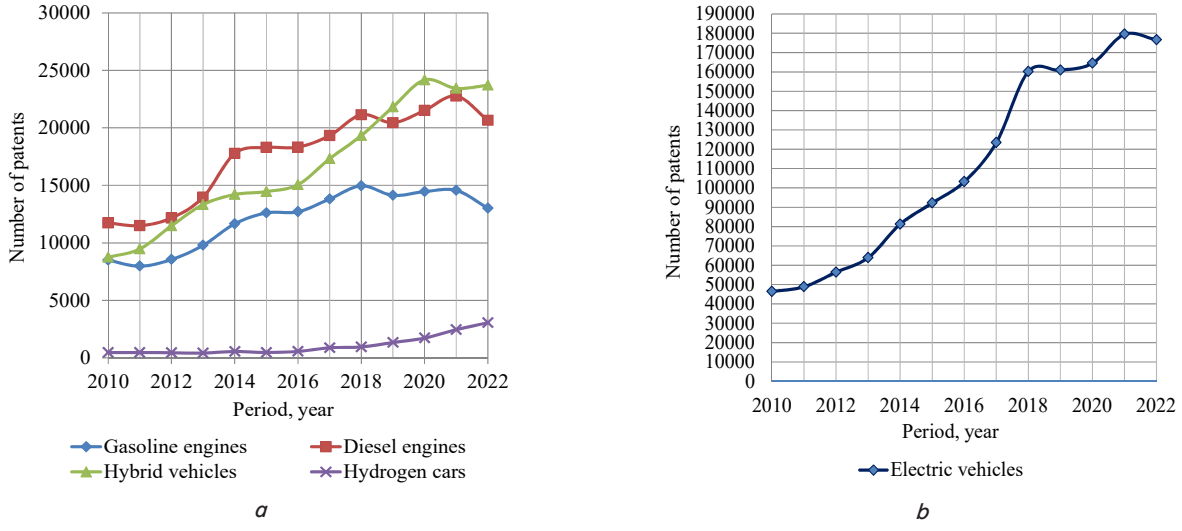
i is the designation of the period for which the calculation is carried out, i=(1,2...6).

The average increase in the number of registered patents for each area of patenting according to formula (2):

$$\overline{b_i} = \frac{\sum_{i=1}^{n} b_j}{n}, \quad i = (1 \ldots n), \quad (2)$$

where n is the number of research periods.

The results of the calculation of the increase in the number of registered patents in comparison with their number for the past year and the following year, in relation to the number of patents registered in the world in terms of improvement in the automotive power plant industry, are summarized and given in Tables 2, 3.



a *b*

Fig. 1. Comparative analysis of the number of patents registered in the world by areas of improvement in the automotive power plant industry: *a* — comparative analysis of the number of patents registered in the world by areas of improvement (gasoline engines, diesel engines, hybrid cars, hydrogen cars); *b* — analysis of the number of patents registered in the world by the area of improvement — electric cars

Table 2

Results of calculation of the increase in the number of patents registered in the world in the following areas: gasoline and diesel engines

Comparative periods of the study, year	Gasoline engines		Diesel engines	
	Increase in the number of patents	Average increase in the number of patents	Increase in the number of patents	Average increase in the number of patents
2010–2011	–514 ↓	694	–236 ↓	1098
2011–2012	+576 ↑		+661 ↑	
2012–2013	+1236 ↑		+1809 ↑	
2013–2014	+1869 ↑		+3808 ↑	
2014–2015	+950 ↓		+523 ↓	
2015–2016	+51 ↓		+27 ↓	
2016–2017	+1108 ↑	51	+1003 ↑	371
2017–2018	+1144 ↑		+1715 ↑	
2018–2019	–829 ↓		–694 ↓	
2019–2020	+325 ↑		+1067 ↑	
2020–2021	+109 ↓		+1256 ↑	
2021–2022	–1550 ↓		–2118 ↓	

Table 3

Results of calculating the increase in the number of patents registered in the world in the following areas: hybrid cars, electric cars, hydrogen cars

Comparative periods of the study, year	Hybrid cars		Electric vehicles		Hydrogen cars	
	Increase in the number of patents	Average increase in the number of patents	Increase in the number of patents	Average increase in the number of patents	Increase in the number of patents	Average increase in the number of patents
2010–2011	+726 ↑	1053	+2493 ↑	9468	+3 ↑	16
2011–2012	+2008 ↑		+7532 ↑		–26 ↓	
2012–2013	+1849 ↓		+7511 ↓		–24 ↓	
2013–2014	+879 ↓		+17308 ↑		+135 ↑	
2014–2015	+255 ↓		+10952 ↓		–84 ↓	
2015–2016	+603 ↑		+11013 ↑		+92 ↑	
2016–2017	+2256 ↑	1441	+20224 ↑	12305	+313 ↑	416
2017–2018	+2009 ↓		+36750 ↑		+78 ↓	
2018–2019	+2486 ↑		+743 ↓		+378 ↑	
2019–2020	+2353 ↓		+3563 ↑		+392 ↑	
2020–2021	–735 ↓		+15014 ↑		+727 ↑	
2021–2022	+276 ↑		–2862 ↓		+608 ↓	

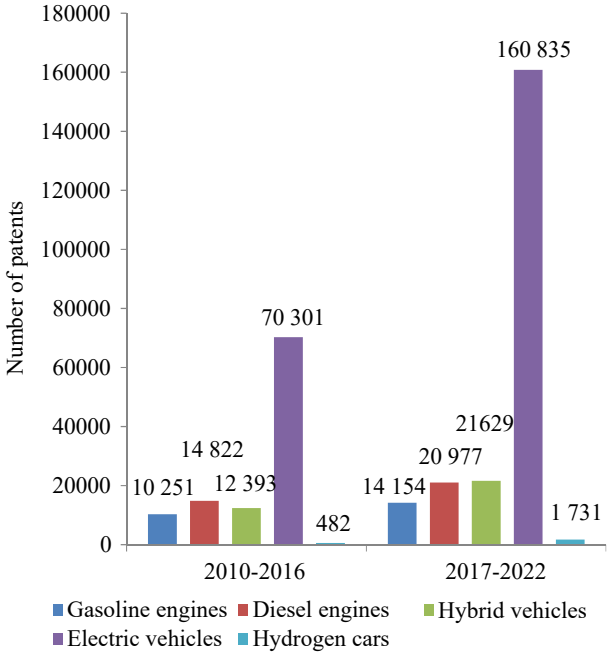


Fig. 2. Average number of patents registered

The results given in Tables 1, 2 provide an opportunity to carry out a qualitative analysis of the obtained indicators and to study their dynamics.

5. 2. Results of investigating the dynamics and ranking of patents for the periods 2010–2016/2017–2022

To carry out a qualitative analysis for the periods of 2010–2016 and 2017–2022, Fig. 3–12 graphically demonstrate the data from Table 1 for each direction of patenting, graphically display the average indicators, with the constructed trend lines.

Analysis of calculation data for the period of 2010–2016 (Fig. 2–7, Tables 1–3):

– in the area of improving gasoline engines, the average value of the number of registered patents is 10,251 patents. The average result exceeds the number of patents registered in this area in 2010 by 1.21 times. The last indicator is the growth rate of the number of patents registered in the area of improving gasoline engines in the specified period;

– the average value of the number of patents registered in the area of improvement of diesel engines was 14,822 patents. The average result exceeds the number of patents registered in this area in 2010 by 1.26 times. The last indicator can be defined as the growth rate of the number of patents registered in the area of improving diesel engines in the specified period;

– the average value of the number of patents registered in the area of improving electric vehicles was 70,301 patents. The average result exceeds the number of patents registered in this area in 2010 by 1.51 times. The last indicator can be defined as the growth rate of the number of patents registered in the area of improving electric vehicles in the specified period;

– the average value of the number of patents registered in the area of improvement of hybrid cars was 12,393 patents. The average result exceeds the number of patents registered in this area in 2010 by 1.42 times. The last indicator can be defined as the growth rate of the number of patents registered for the improvement of hybrid cars in the specified period;

– the average value of the number of patents registered in the area of improvement of hydrogen cars was 482 patents. The average result exceeds the number of patents registered in this direction in 2010 by 1.04 times. The last indicator can be defined as the growth rate of the number of patents registered in the area of improving hydrogen cars in the specified period;

– the largest average indicator (growth rate) of the number of registered patents for the given period in the area of improving electric vehicles. This indicator exceeds the corresponding growth rates in the areas: "gasoline engines" – by 1.25 times, "diesel engines" – by 1.2 times, "hybrid cars" by 1.06 times, "hydrogen cars" – by 1.51 times;

– the highest average value of registered patents in the area of "electric cars". The value is greater relative to the number of patents registered in the areas: "gasoline engines" – 6.86 times, "diesel engines" – 4.74 times, "hybrid cars" – 5.67 times, "hydrogen cars" – in 145.85 times;

– the largest average increase in the number of registered patents in the area of "Electric vehicles" – 9,468 patents/year, which exceeds the corresponding indicators in the areas: in the area of "gasoline engines" – by 13.64 times, "diesel engines – by 8.62 times", " hybrid cars" – 8.99 times, "hydrogen cars" – 591.75 times.

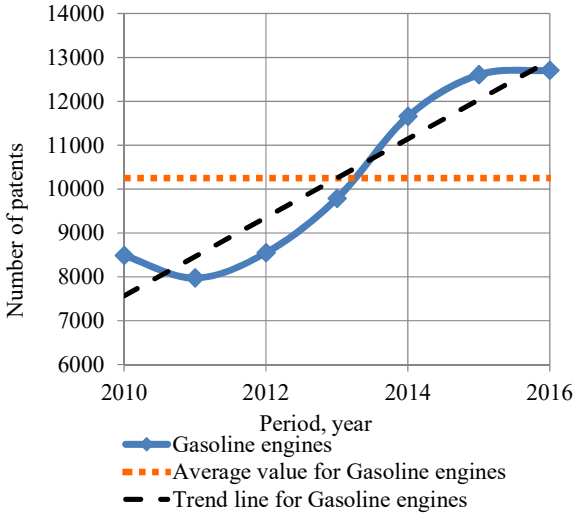


Fig. 3. Analysis of the number of registered patents in the field of improvement of gasoline engines for the period of 2010–2016

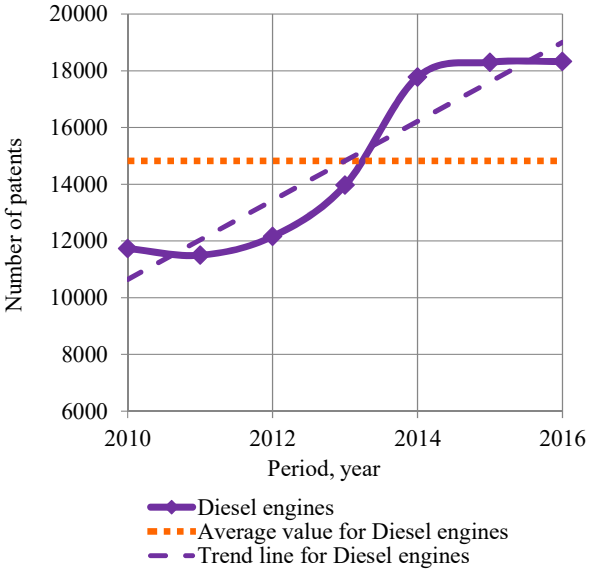


Fig. 4. Analysis of the number of registered patents in the area of improving diesel engines for the period of 2010–2016

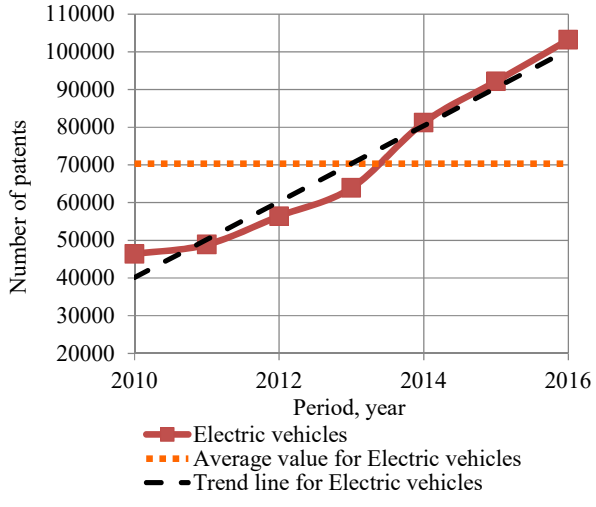


Fig. 5. Analysis of the number of registered patents in the field of improvement of electric vehicles for the period of 2010–2016

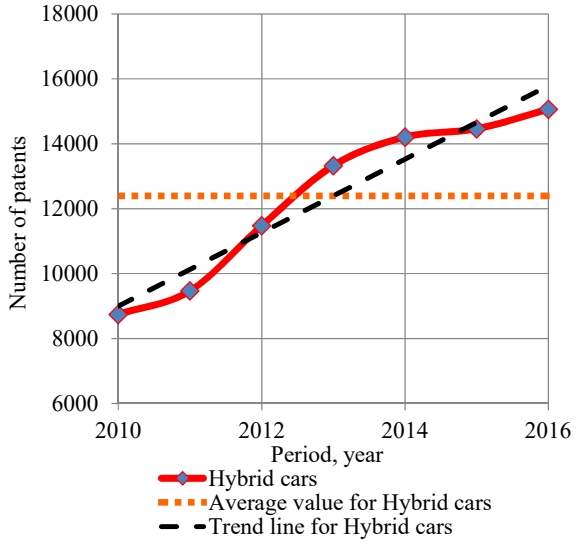


Fig. 6. Analysis of the number of registered patents for the improvement of hybrid cars for the period of 2010–2016

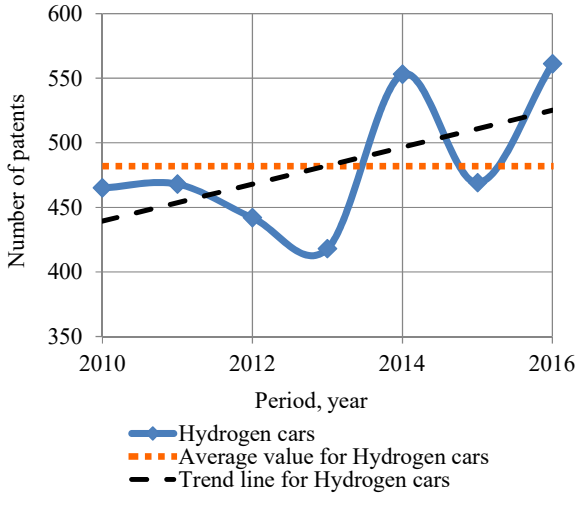


Fig. 7. Analysis of the number of registered patents for the improvement of hydrogen cars for the period of 2010–2016

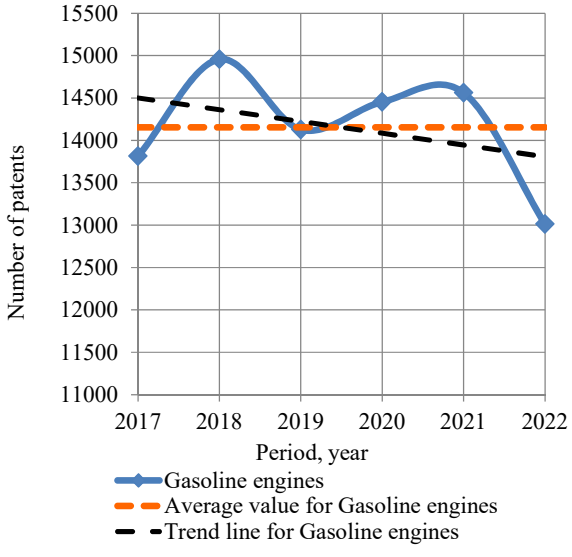


Fig. 8. Analysis of the number of registered patents in the area of improving gasoline engines for the period of 2017–2022

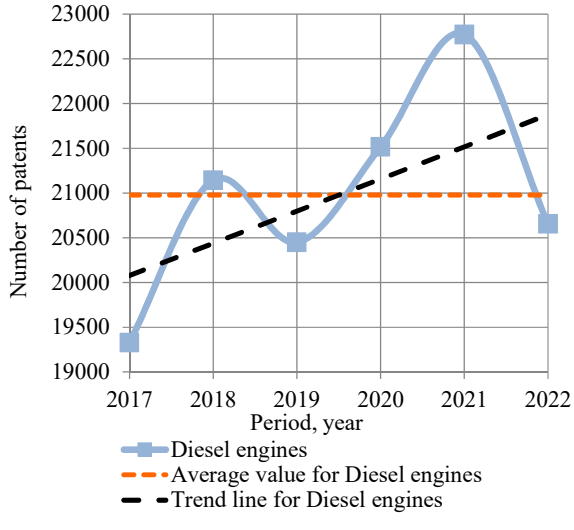


Fig. 9. Analysis of the number of registered patents in the area of improving diesel engines for the period of 2017–2022

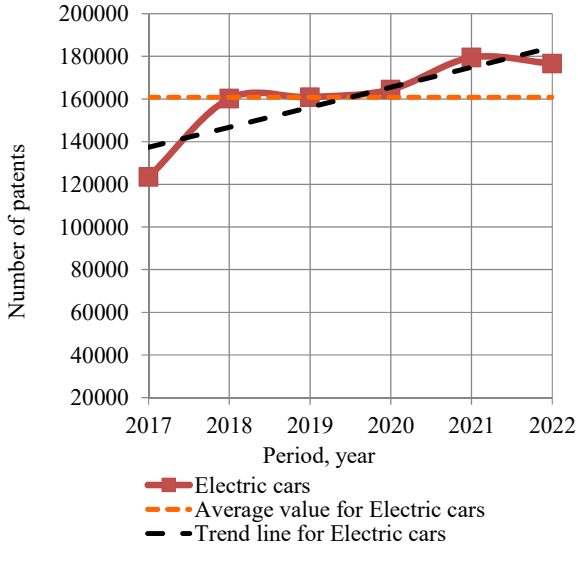


Fig. 10. Analysis of the number of registered patents for the improvement of electric vehicles for the period of 2017–2022

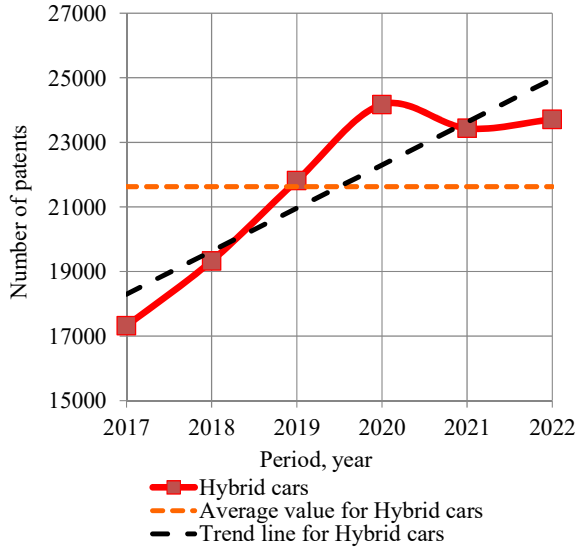


Fig. 11. Analysis of the number of registered patents in the area of improving hybrid cars for the period of 2017–2022

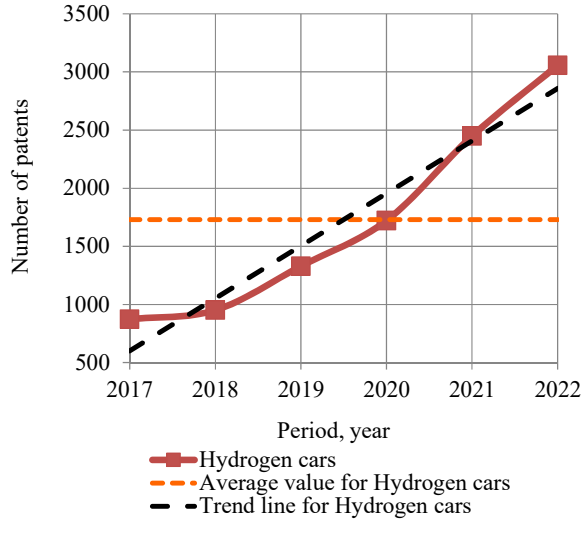


Fig. 12. Analysis of the number of registered patents for the improvement of hydrogen cars for the period of 2017–2022

Analysis of calculation data for the period of 2017–2022 (Fig. 2, 8–12, Tables 1–3):

– in the area of improving gasoline engines, the average value of the number of registered patents is 14,154 patents. The average result exceeds the number of patents registered in this direction in 2017 by 1.02 times. The last indicator reflects the growth rate of the number of patents registered in the area of improvement of gasoline engines in the specified period;

– the average value of the number of patents registered in the area of improvement of diesel engines was 20,977 patents. The average result exceeds the number of patents registered in this direction in 2017 by 1.08 times. The last indicator reflects the growth rate of the number of patents registered in the area of improving diesel engines in the specified period;

– the average value of the number of patents registered in the area of improvement of electric vehicles was 160,835 patents. The average result exceeds the number of patents registered in this direction in 2017 by 1.3 times. The last indicator can be defined as the growth rate of the number of patents registered in the area of improving electric vehicles in the specified period;

– the average value of the number of patents registered in the area of improvement of hybrid cars was 21,629 patents. The average result exceeds the number of patents registered in this direction in 2017 by 1.25 times. The last indicator can be defined as the growth rate of the number of patents registered for the improvement of hybrid cars in the specified period;

– the average value of the number of patents registered in the area of improvement of hydrogen cars was 1731 patents. The average result exceeds the number of patents registered in this direction in 2017 by 1.98 times. The last indicator can be defined as the growth rate of the number of patents registered in the area of improving hydrogen cars in the specified period;

– the largest average indicator (growth rate) of the number of registered patents for the given period in the area of improving hydrogen cars. The indicator exceeds the corresponding growth rates in comparison with other directions: "gasoline engines" – by 1.94 times, "diesel engines" – by 1.83 times, "hybrid cars" – by 1.58 times, "electric cars" – by 1.52 times;

– the highest average value of registered patents in the area of "electric cars". The indicator is higher in relation to the number of patents registered in the areas: "gasoline engines" – 11.36 times, "diesel engines" – 7.67 times, "hybrid cars" – 7.44 times, "hydrogen cars" – at 92.91 (this indicator decreased by 1.57 times compared to the previous period);

– the largest average increase in the number of registered patents in the area of "Electric vehicles" – 12,305 patents/year. The indicator exceeds the corresponding indicators by directions: "gasoline engines" – 241.27 times, "diesel engines" – 33.17 times, "hybrid cars" – 8.54 times, "hydrogen cars" – 29.58 times;

5. 3. Results of the study of factors influencing leadership, prospects for innovation, and patenting of technological advances

The analysis of global trends in energy efficiency and technology, which are rapidly being implemented to ensure sustainable economic growth, is the basis for the selection of influencing factors:

– introduction in the world at the legislative level of the latest conceptual principles that shape economic development for the long term (greening, energy saving, reorganization of global energy systems);

– development of technologies for obtaining, storing, and transporting environmentally-friendly fuels;

– infrastructure development (maintenance, customer support service).

Isolated factors influence the change in leadership, prospects for further development of innovations and patenting of technological advances in the industry of automotive power plants.

The change in leadership, the prospects for the further development of innovations, and the patenting of technological advances in the automotive power plant industry are represented by the results of the analysis of the growth rates and growth of registered patents and their comparison for the periods of 2010–2016 and 2017–2022:

– in the comparison of the growth rate of the number of registered patents for the period of 2010–2016, a significant positive trend in the growth rate of the number of patents registered in the area of improvement of electric vehicles and hybrid engines is observed compared to other areas;

– in the period of 2010–2016, there is an unsustainable growth (increase/decrease) in the number of patents registered compared to the previous year for all areas of patenting;

– a comparison of the growth rates of patents for the period of 2017–2022 shows a significant positive trend in the growth rate of the number of patents registered in the area of improvement of hydrogen cars, and a decrease in the rate of patenting in other areas;

– for the period of 2017–2022, there is an unsustainable growth (increase/decrease) in the number of registered patents compared to the previous year for all areas of patenting;

– the growth rate of the number of patents registered in the area of improvement of gasoline engines in the period of 2017–2022 is 1.19 times lower than in the period of 2010–2016, the rate of patenting in this direction is slowing down;

– the growth rate of the number of patents registered in the area of improving diesel engines in the period of 2017–2022 is 1.17 times lower than in the period of 2010–2016, the rate of patenting in this direction is slowing down;

– the growth rate of the number of patents registered in the area of improvement of electric vehicles in the period of 2017–2022 is 1.16 times lower than in the period of 2010–2016, the rate of patenting in this direction is slowing down;

– the growth rate of the number of patents registered in the area of improving hybrid cars in the period of 2017–2022 is 1.14 times lower than in the period of 2010–2016, the rate of patenting in this direction is slowing down;

– the growth rate of the number of patents registered in the area of improvement of hydrogen cars in the period of 2017–2022 is 1.9 times higher than in the period of 2010–2016, there is a rapid increase in the rate of patenting in this area;

– in the period from 2017 to 2022, there is a decrease in the average increase in the number of registered patents per year compared to the previous period for the area "gasoline engines" by 13.6 times, for the area "diesel engines" by 2.96 times. Along with this, there was an increase in this indicator for the "hybrid cars" direction by 1.37 times, for the "electric cars" direction by 1.3 times, and for the "hydrogen cars" direction by 26 times.

6. Discussion of results of investigating innovative areas and prospects for the development of patenting of technological advances

The results of investigating the statistics of patenting of technological advances in the industry of automotive power plants in 2010–2022 determine the largest number of patents registered in the world, in the area of improving electric vehicles (Fig. 1, *b*, Table 1). There is a significant quantitative gap with other directions, despite a sharp decline in 2021 2022. Next in terms of the number of patents are the areas of improvement of hybrid cars and diesel engines (Fig. 1, *a*, Table 1). However, for the period of 2019–2022, the number of patents for the improvement of hybrid cars increased compared to the number of patents for the improvement of diesel engines. The next link in the number of patents is the improvement of gasoline engines. And the lowest number of patents is the area of improvement of hydrogen cars (Fig. 2).

The results of investigating the dynamics and the identification of the main trends in the change in the rating of patents in the following periods: 2010–2016 and 2017–2022 (Fig. 2–12, Tables 1–3) indicate stable positive indicators in the area of patenting "electric cars". The trend towards an increase in the number of registered patents for this area persists in all the studied periods and makes it possible to predict positive dynamics in the future. At the same time, the average indicator for the period of 2017–2022 for the area "hydrogen cars" increased sharply compared to the previous period. In the period of 2017–2022, there is a persistent pronounced trend of decreasing activity in patenting in the area of "gasoline engines", as evidenced by the data on indicator calculations and the construction of a trend line (Fig. 8). In the specified period, there are sharp changes in patenting activity in the area of "diesel engines", a sharp decline in the number of registered patents from 2021 to 2022 to almost the level of 2019 is noted. This gives reason to predict a decline in activity in this area in the future.

The results of investigating the factors that influence the change of leadership, the prospects for the further development of innovations, and the patenting of technological advances in the industry of automotive power plants, in particular, hybrid, hydrogen cars, and electric cars, testify to their significant influence. First of all, it is manifested in the orientation of innovations in the industry of automotive power plants on ecological systems. This is confirmed by the fact that in the period of 2017–2022, there is a decrease in the average increase in the number of registered patents per year compared to the previous period for the areas of energy installations operating on non-renewable energy sources. Along with this, there was an increase in this indicator for ecological power plants, which includes a sharp increase in the area of hydrogen cars.

The results are explained by the impact factors identified in the study, which are based on the principles of a principled way to reduce emissions from transport around the world. This is confirmed by the declared need for drastic reduction of greenhouse gas emissions in the world. In particular, by 2030, transport is set to reduce greenhouse gas emissions by approximately 20 % from their 2008 level. Also, to halve the use of cars "on traditional types of fuel" in urban transport by 2030, to gradually abandon them in cities by 2050. The implementation of these changes requires, first of all, a strategy of action, and innovations are of fundamental importance in this [17]. Scientific research should contain a full cycle – research, innovation, and implementation – which is implemented in an integrated way, focusing on the most promising technologies, and connecting all interested participants [18].

Among the most promising alternative fuels is hydrogen. The advantage of hydrogen is the inexhaustibility of its resources in nature and the possibility of obtaining it from renewable raw material sources. Hydrogen has a very high energy density (approximately three times more than traditional fuels) and unique kinetic characteristics. Hydrogen is an ideal ecological fuel, as its combustion products do not contain carbon dioxide and carbon monoxide. Study [19] showed that adding

hydrogen to gasoline from 2 % to 4 % could increase engine efficiency by 4–5 %, reduce emissions of nitrogen oxides by 30–35 %, and carbon dioxide by 10–15 %. In general, adding hydrogen to gasoline could be an effective way to improve the environmental friendliness of hybrid power plants based on internal combustion engines. However, studies show that the optimal amount of hydrogen addition may depend on various factors, such as the type of engine, operating mode, etc. Therefore, in order to achieve maximum efficiency, it is necessary to conduct detailed research and optimization of the process of adding hydrogen to gasoline under specific operating conditions .

In contrast to [20], which reports the results of patenting research in the areas of "electric cars" and "hybrid cars" for the period of 1990–2010, the obtained results broadly represent the areas of research and cover the research period of 2010–2022. This makes it possible to predict the further development of patenting in the current period and for the future, to compare the results not only for environmental technologies but also for technologies that use non-renewable energy sources. Taking into account [21], which presents an overview of the development trends of fuel cell electric vehicles, based on the analysis of patent data from China, Germany, Japan, the Republic of Korea, and the United States from 2002 to 2021. We note the narrow focus of this study in comparison with the current research.

The main factors for determining the influencing factors are the adoption by the General Assembly of the United Nations (UN) of the current Sustainable Development Goals, which are planned to be achieved by 2030. Also, their inclusion in the UN Resolution [22] and monitoring of their implementation, which contains available data on the main indicators of achieving goals [23]. The focus of the world community on the implementation of the main tasks aimed at the development of society determines the positive dynamics of patenting of hydrogen, electric, and hybrid technologies as innovative directions of development in the industry of automobile power plants. This is primarily due to the systematic solution of environmental and economic problems on a planetary scale, for the sake of the progressive existence of humanity. The focus of scientists on energy-saving, ecological technologies, the implementation of new political solutions to change the existing trends in the development of transport by 2050, explains the negative dynamics of patenting in the areas of "gasoline engines" and "diesel engines". On these grounds, taking into account the development of innovations in the generation of environmentally clean energy sources, it is possible to predict the further negative dynamics of patenting in relation to developments related to non-ecological energy power plants. Along with this, on the above-mentioned grounds, a rapid increase in the patenting of technological advances aimed at the use of energy power plants on environmentally safe types of fuel is predicted in the future.

The results from the current study provide an opportunity to solve problematic issues, namely, to determine the main innovative areas for the development of the latest technologies in the industry of automotive power plants. This is possible due to the identification of factors that influence the change of leadership, prospects for further development of innovations, and patenting of technological advances in the industry of automotive power plants. Also, it is possible due to a qualitative study of the statistics of patenting of technological advances in the industry of gasoline engines, diesel engines, hybrid cars, electric cars, and hydrogen cars. Establishing the trends of changes in the number of registered patents in all studied periods, which makes it possible to predict positive dynamics in the future, is also a basis for solving the problematic issue.

The research is focused on generalized directions, the technological features of the subject of patenting in each area are not considered, which imposes certain restrictions on the actual conditions of application of the proposed results. Limitations should be taken into account when interpreting the results of the study and applying them to real conditions and situations in the field of innovative development of the automotive power plant industry.

It should be noted that the presented research does not contain a mathematical model for forecasting, however, it could serve as the next stage in the continuation of scientific research into this topic.

The further development of this study is to devise technologies for mathematical modeling of development trends and forecasting in each area, taking into account the peculiarities of the subject of innovative search.

7. Conclusions

1. In the period from 2017 to 2022, in accordance with the results of the study, there was a steady trend to increase the interest of scientists in the introduction of innovations in the industry of automotive power plants, namely, in environmental directions. These areas are electric cars and hydrogen cars. There is a steady increase in the number of registered patents, which predicts further growth in the number of registered patents in these areas, which is connected with the focus of the economic course of the countries of the world on environmental safety.

2. The results of analysis of the dynamics and the identification of the main trends in the change in the rating of patents for the periods of 2010–2016 and 2017–2022 indicate stable positive indicators in the area of patenting of "electric cars". An increase in the number of registered patents in this segment is observed during all considered periods, which indicates the possibility of positive dynamics in the future. At the same time, sharp changes in the activity of patenting diesel engines during the specified period are noted, due to global economic changes and the repurposing of global strategies for the ecological modernization of transport. These factors provide grounds for predicting a further decrease in activity in this direction. The rapid dynamics of patenting in the field of "Hydrogen cars" indicates the possibility of even greater growth in the coming years, which is connected with the use of hydrogen as the most environmentally friendly and unlimited energy source in the automotive industry.

3. The results can be explained by isolated influencing factors, which are based on the principal direction towards reducing transport emissions worldwide. The significant influence of these factors is manifested in the orientation of innovations in the field of automotive power plants on ecological systems. This is confirmed by the fact that during the period of 2017–2022, a decrease in the average annual increase in the number of registered pat-

ents was recorded compared to the previous period for the areas of energy installations that work on non-renewable energy sources. The development and implementation of advanced technologies for the production, transportation, and storage of hydrogen, the development of infrastructure for consumer support, make it possible to predict the development of hydrogen cars running on fuel cells or pure hydrogen in the distant future. However, in the near future, worth noting is the possibility of creating hybrid fuel with the addition of hydrogen, as a partial solution to the problems of decarbonization in the automotive power plant industry.

Conflicts of interest

The author declares that he has no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The author confirms that he did not use artificial intelligence technologies when creating the current work.

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