Future Energy
Open Access Journal
ISSN 2832-0328

May 2025| Volume 04 | Issue 02 | Pages 01-11

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.4.2.1

Future Publishing LLC

Review

Review of types of diversification of electric power generation and their impact on ensuring "climate neutrality" of anthropogenic activity

Alexey R. Kulchitskiy*

Vladimir State University, t. Vladimir, 600005, Russia

ARTICLE INFO

Article history:
Received 12 January 2025
Received in revised form
16 February 2025
Accepted 26 February 2025

Keywords:
Climate neutrality, Greenhouse gases, Electricity generation, Energy sources, Diversification

*Corresponding author
Email address:
ark6975@mail.ru

DOI: 10.55670/fpll.fuen.4.2.1

ABSTRACT

One of the problems of our time is environmental pollution by emissions of harmful substances formed as a result of the functioning of industry, agriculture, power generation facilities, transport and the household sector. The operation of all these facilities is ensured by using natural energy sources, the reserves of which are not endless. Another objectively present problem is superimposed on this problem - global warming. Regardless of the causes of global warming, humanity must adapt to this process. The question is: how can we ensure "climate neutrality" on the scale of the human environment? One of the solutions to the problems is the diversification of the energy generation methods used. In addition, the main source of atmospheric pollution in populated areas is transport, the number of which has currently reached almost 1.5 billion units in the world. The transition from cars to electric vehicles, as well as to transport using hybrid motor units (which are a combination of a heat engine and an electric motor), will reduce environmental pollution in large populated areas. Much attention is being paid to technologies for generating electricity by burning hydrogen, but at present, more than 90% of hydrogen production is provided by processing natural gas, which is accompanied by the formation of harmful substances and "greenhouse gases" that enter the atmosphere and, due to transboundary air flows, spread over many hundreds and thousands of kilometers, polluting vast territories. At the same time, the use of hydrogen will increase the emission of water vapor (a product of hydrogen combustion), which is three times more greenhouse than carbon dioxide. This article does not consider the issue of the price of the energy sources used and the electricity received since the pricing process is absolutely subjective, and often, the political factor is superimposed on it.

1. Introduction

Sustainable development of any country, i.e., development without depletion of economic, environmental, and social resources and without transferring problems to future generations, is determined by a stable supply of energy [1]. At the same time, the development of the economy of all countries requires increased consumption of electricity; thus, in 2023, 1.27 times more electricity was generated worldwide than in 2013 and 1.77 times more than in 2003 (Table 1) [2]. Traditionally, the main energy sources used to generate electricity are coal, oil, and gas. Over the past 20 years, international trade in these products has grown by more than 50%, with three regions (North America, Europe, and Asia-Pacific) consuming more than 3/4 of all energy. As a result, North America has transformed from an energy importer into an exporter, but Western and Eastern Europe, as well as the Asia-Pacific region, have remained importers, with the latter consuming almost half of the world's demand [3]. It should be noted that thermal power plants (TPPs) consume billions of cubic meters of water for their cooling systems, which causes irreparable harm to the surrounding aquatic environment and the entire associated ecosystem. Thermal power plants running on fuel oil and oil, in addition to traditional harmful substances, emit a number of heavy metals into the atmosphere: vanadium and nickel (for example, 1 ton of oil contains up to 100 g of vanadium and nickel), cobalt and lead, copper, arsenic, mercury, molybdenum, uranium, and their compounds. These metals accumulate in plants that are used as food and penetrate groundwater. Large hydroelectric power plants (HPPs) also cause enormous environmental damage, leading to negative climatic, geological, landscape, biosphere, and social consequences [4].

Table 1. Total electricity production in the world and in the main producing countries

Region	2023 г.	2013 г.	2003 г.
Worldwide, TW	29924,76	23447,98	16932,83
of which, in %			
- China	31,60	23,16	11,28
- USA	15,02	18,47	24,44
- India	6,54	4,89	3,77
- Russia	3,94	4,52	5,41
- Japan	3,39	4,64	6,45
- Brazil	2,37	2,43	2,15
- Canada	2,12	2,80	3,47
- South Korea	2,06	2,29	2,05
- France	1,74	2,45	3,35
- Germany	1,72	2,72	3,60

Note: The table shows data for the 10 main electricity-producing countries.

In this regard, there is a need to reduce the harmful impact on the environment down to "zero", i.e. achieve "climate neutrality": compliance between anthropogenic emissions from sources and absorption of harmful substances by absorbers. This also applies, in particular, to “carbon neutrality”- the balance between emissions of carbon dioxide CO_2 and its absorption. That is, “climate neutrality” is understood as a state in which human activity does not lead to any impact on the climate system [5]. The European Union has set a goal of achieving "climate neutrality" by 2050, and has also set an intermediate goal of reducing greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels. This will require that electricity generation from renewable sources account for at least 32%, primarily through wind and solar energy development. At the same time, on 18 May 2022, the European Commission published the "REPowerEU" plan, which sets out several measures to accelerate the transition to clean energy [6]. One of the methods for achieving "climate neutrality" is the use of renewable energy sources (RES): sources that are naturally replenished (or renewed). In energy statistics, RES includes the following types:

A) Non-combustible renewable energy sources for electricity generation:

- Hydropower: potential and kinetic energy of water in hydroelectric power plants (electricity generated in pumped-storage installations is not taken into account);
- Tidal and wave energy in the seas and oceans: kinetic energy obtained as a result of tidal and wave motion or currents;
- Geothermal energy: energy of heat obtained from the earth's crust (in the form of hot water or steam);
- Wind energy: kinetic energy of the wind, converted in wind turbines;
- Solar energy: photovoltaic converters of solar radiation.

B) Combustible renewable energy sources:

- Biofuels: fuels from biomass (solid biofuels, biogas and liquid biofuels);
- Renewable municipal waste (waste is any substance or object that its owner disposes of or must dispose of in accordance with applicable national legislation) [7].

In 2022, the share of electricity generation from renewable energy sources in the world as a whole was 26.72%, including 32.12% in China, 23.0% in the EU, 15.53% in the USA, 5.50% in India, 3.86% in Russia, 3.53% in Japan (less than 3% in other countries) [8]. In 2023, 24.5% of electricity in the EU was already generated from renewable energy sources. At the same time, in Sweden (electricity generation from renewable energy sources 66%), solid biofuels, hydropower, and wind energy were mainly used; In Finland (50.8%) - solid biofuels, wind power, and hydropower; in Denmark (44.9%) - solid biofuels and wind power. In the transport sector, the share of energy from renewable energy sources was 10.8% (in 2004 - 1.6%, in 2022 - 9.6%; by 2030, it is planned to be 29%); while consumption varies from 33.6% in Sweden and 20.6% in Finland to 3.9% in Greece, 1.4% in Latvia and 0.9% in Croatia. Norway, which is part of the European Economic Area, also ensured a high share of renewable energy sources in the transport sector - 27.7%. For the heating and cooling sector in the EU in 2023, the share of energy from renewable energy sources was almost 25%. (total consumption for heating and cooling purposes is the final consumption of all types of energy, except electricity for purposes not related to transport, as well as heat consumption for the own needs of power plants and thermal power plants and heat losses in networks) [9].

2. Global warming and anthropogenic factor

2.1 Greenhouse effect and greenhouse gases

The greenhouse effect is a phenomenon of secondary heating of the atmosphere by long-wave (infrared) radiation from the surface of the planet, returned back to the surface by some gases in the atmosphere. These gases were given the name: "greenhouse gases" - GHG. The GHG included six gases, of which carbon dioxide CO_2 has the greatest greenhouse activity; methane CH_4 is in second place. The sources of GHG are both natural processes (volcanoes, fires, decay) and anthropogenic activity. It was noted that if in the middle of the 19th century, the concentration of CO_2 in the atmosphere was 280 ppmv, then by 1992 it was 370 ppmv, and by the end of the 21st century an increase to 490...1260 ppmv is expected (depending on the scenario). Constant monitoring of changes in atmospheric temperature across the planet has shown that in the last third of the 20th century, the rate of increase in atmospheric temperature has increased significantly. The international community came to the conclusion that anthropogenic factors (emissions from industrial and agricultural enterprises, vehicles, power generation facilities, and the household sector) are to blame for this, causing an increase in the concentration of GHG in the atmosphere (Table 2) [10, 11].

2.2 Quotas for greenhouse gas emissions

In 1997, in Kyoto (Japan), at the third conference of the countries participating in the United Nations Framework Convention on Climate Change (UNFCCC), standards (quotas) for GHG emissions in terms of CO_2 were adopted (Table 3) [12]. According to this decision, countries had to reduce their emissions by an average of 6% compared to the 1990 level between 2008 and 2012. If we take into account that this limitation was not in effect before 2008, the actual level of the required reduction in CO_2 emissions could reach 20...25% for a number of countries. In order to prevent "global warming", the Kyoto Protocol proposed the following mechanisms for achieving the goal: "clean development", "joint cooperation" and "trading of quotas". The "clean development" mechanism encouraged countries to expand the areas of natural absorbers of harmful substances: 1 hectare of forest plantations provides, on average, the absorption of up to 10 tons of CO_2 per year. The "joint cooperation" mechanism was formally aimed at helping highly developed countries to introduce modern technical solutions into production that ensure a reduction in GHG emissions. However, the amount of GHG emission reduction was credited to developed countries, which could thus solve the problems of fulfilling their quotas, but not the problem of air pollution in their own countries. The use of the “quota trading” mechanism allowed countries with a positive balance in GHG emissions to sell the right to additional GHG emissions in the same volume to any other state. Accordingly, no positive impact on reducing air pollution in the purchasing countries was achieved. Thus, the last two mechanisms were purely formal in nature and were not aimed at reducing environmental pollution in countries with increased emissions of harmful substances into the atmosphere.

In order to combat climate change and its negative consequences, an agreement was adopted at the next conference in Paris on December 12, 2015, aimed at significantly reducing global GHG emissions and limiting the increase in global temperature in the 21st century to 2.0-1.5°C. In 2018, delegates to the next conference, which took place in Poland, adopted a set of rules specifying the procedure for implementing the Paris Agreement. And in 2023, during the first round of the “global stocktake”, progress in achieving the goals of the Paris Agreement was assessed [13]. Nevertheless, in 2023, GHG emissions (in carbon dioxide equivalent) increased by 2.1%, exceeding the record level set in 2022. In particular, emissions of carbon dioxide from fuel combustion increased by 7%, and methane emissions - by more than 5% [3].

Table 2. Characteristics of anthropogenic greenhouse gases

Name	Designation	Greenhouse activity	Source of origin
Carbon dioxide	CO_2	1	Combustion of solid, liquid and gaseous substances.
Methane	CH_4	21	Gas production, leakage through seals in main pipelines and gas cylinder installations of motor vehicles, intestinal fermentation, manure disposal.
Nitrous oxide	N_2O	310	Production of nitrogen fertilizers and nitric acid.
Hydrofluorocarbons	$C_xH_yF_z$ (HFC)	140...11700	Substitute for chlorofluorocarbons: packaging, refrigeration equipment, fire extinguishers, cleaning agents, aerosols.
Perfluorocarbons	CF_4, C_2F_6 (PFC)	6500...9200	Used in aluminum casting, substitute for chlorofluorocarbons.
Sulfur hexafluoride	SF_6	23900	Used in the manufacture of high-voltage switches and magnesium casting.

Table 3. Emission and absorption of CO_2 in the territory of the UNFCCC member countries (1997)

Country*	Emission		Area, sq. km (thousand)	Forest, % of territory	Absorption by forests, thousand tons	Balance,** thousand tons
	Quota, thousand tons	Share, %				
Total Emissions	13728	100*	-	-	-	-
USA	4956	36,1	9363	30	2808	-2147
Russia	2389	17,4	17075	46	7854	**5466**
Japan	1167	8,5	370	67	248	-919
Germany	1016	7,4	356	31	110	-906
UK	590	4,3	244	10	24	-566
Canada	453	3,3	9976	54	5387	**4934**
Italy	426	3,1	301	23	69	-356
Poland	412	3,0	312	28	88	-324
France	371	2,7	551	27	149	-222
Australia	288	2,1	7687	19	1461	**1172**
Netherlands	165	1,2	41	8	3	-161
Belgium	110	0,8	30,5	21	6	-103
Austria	55	0,4	84	32	26	-28
Sweden	55	0,4	450	68	305	**250**
Finland	55	0,4	338	76	257	**202**

Legend: * data are provided for 15 of the 34 countries participating in the Kyoto meeting in 1997, which accounted for more than 90% of the quota for greenhouse gas emissions in terms of CO_2;
** positive balance - in the event that GHG absorption exceeds the quota.

2.3 Factors affecting CO_2 emission and absorption

CO_2 present in the atmosphere is absorbed by vegetation and microorganisms during photosynthesis, resulting in the formation of carbohydrates $C_n(H_2O)m$ and oxygen. Every year, as a result of photosynthesis on Earth, due to the absorption of about 300 billion tons of CO_2, about 150 billion tons of organic matter are formed, and almost 200 billion tons of free oxygen O_2 are released. At the same time, humanity's contribution to the formation of CO_2 is no more than 10 billion tons annually. All this contributes to the effective restoration of vegetation, especially in areas where massive deforestation is taking place. According to data for 2023, increased GHG emissions (in terms of CO_2 emissions) were noted in a number of the countries listed below (Table 4) [7].

Table 4. Countries with the highest CO_2 emissions (2023)

Country	Total emission, Mt	Emission, t/person	Emission, Mt/1000 sq.km	Relative concentration*
China	12603	8,86	1,32	22,0
USA	5130	14,94	0,52	8,7
India	3121	2,17	0,95	15,8
Russia	2176	14,96	0,13	2,2
Japan	1038	8,35	2,75	45,8
Iran	936	10,34	0,54	9,0
Indonesia	861	3,06	0,45	7,5
Saudi Arabia	726	21,82	0,34	5,7
Canada	599	15,25	0,06	1,0
South Korea	594	11,48	5,92	98,7
Germany	589	6,97	1,65	27,5
Mexico	560	4,31	0,28	4,7
Brazil	525	2,49	0,06	1,0
South Africa	478	7,56	0,39	6,5

Note: * relative concentration: minimum emission - for Brazil is taken as 1.0, and for other countries - relative to Brazil.

Calculating the quota for carbon dioxide emissions per capita or $1 of gross domestic product (GDP) does not provide objective data on the degree of impact on the environment [13]. The harm caused to the environment by any harmful substances is proportional to their concentration in the air, which is determined by the ratio of the total emission and the area of the country. This criterion - the emission of a substance per unit area - objectively shows the degree of harm from GHGs in each country (see Table 4). When solving the problem of atmospheric pollution, it is necessary to take into account not only the characteristics of gases, but also the geographical location of the region (relative to which the calculations are made), the intensity of solar (primary) and Earth (secondary) radiation in the entire spectrum of radiation, as well as the spectral characteristics of the atmosphere: absorption, transmission and reflection of long-wave radiation, the state of the atmosphere (the presence of aerosols, smoke, dust) and a number of others. For example, absorption of infrared radiation by CO_2 is observed in the wavelength ranges of 1.35…1.58, 1.8…2.05, 2.4…3.4, 8.5…13.0 µm, etc.; in other ranges, the transmission efficiency exceeds 80% of all radiation [14]. This fact indicates that not all long-wave radiation is absorbed by carbon dioxide. The presence of water vapor in the atmosphere has a significant impact on the spectral characteristics of the atmosphere, the transmission and absorption spectra of which are similar to the spectra of CO_2. In our time, the greenhouse effect is up to 78% (on average) due to water vapor and only 22% to carbon dioxide. However, water vapor was not included in the list of GHGs. At the same time, anthropogenic CO_2 (taking into account the natural factor) makes up about 10% of its total amount, that is, the share of anthropogenic CO_2 in the overall greenhouse effect was only 2%, and a reduction in its role by 5% within the framework of the Kyoto Protocol would mean a reduction in the overall greenhouse effect by 0.1% [15]. Thus, the development of measures to reduce CO_2 emissions into the atmosphere without taking into account the effect of water vapor on the degree of heating of the atmosphere is unproductive. In addition, it should be taken into account that about 90% of carbon dioxide is dissolved in the world's oceans: when water is heated, the solubility of gases decreases, and gases are released into the air; when water is cooled, on the contrary, CO_2 is absorbed by water. Accordingly, this process has no significant relation to anthropogenic activity (industry development, agriculture, transport, etc.). Of interest are the data for 1934, according to which the CO_2 content in the atmosphere fluctuated from 250 to 350 ppmv [16]. These data were given long before the concept of "global warming" arose and at a time when there were far fewer cars and industry was much less developed. But the figures given more than 50 years later in the Kyoto Protocol, which should characterize the negative consequences of industrial development, strangely completely coincide with the values given in 1934, characteristic of normal natural conditions. It should be noted that the greenhouse effect is 78% due to water vapor and only 22% due to carbon dioxide; the contribution of other gases is significantly less [17]. At the same time, the relative content of water vapor in the atmosphere is 0.2-2.5%, and carbon dioxide is 0.03-0.05%; the relative content of other greenhouse gases does not exceed $3 \cdot 10^{-4}$% [18, 19]. However, water vapor was not included in the number of GHGs.

2.4 Geological facts

According to data for the last 66 million years, the current global warming is only an exit from the Ice Age, which began about 5 million years ago. During most of the studied period (about 80%), temperatures much higher than the current ones by 8-15°C prevailed, and ice caps were completely absent at the poles. At the same time, the Little Ice Age ended only in the middle of the 19th century, and it is quite natural that a warming process is currently underway [20].

In addition, there are data obtained from the results of drilling wells to a depth of several thousand meters in Antarctica and Greenland, during which cores were extracted containing air bubbles from the eras when snow was deposited and the bubbles contained air from those eras. As a result, it was revealed that the change in the concentration of carbon dioxide in the atmosphere does not precede warming but occurs after warming. And this is quite understandable (as noted in paragraph 3.1.3). However, these processes are weakly associated with human activity [21]. Of course, in recent years, climate changes have occurred on our planet. But they are expressed not in unidirectional warming of a man-made nature but in an increase in the contrast of synoptic processes and weather anomalies in the continental parts of the planet: an abnormally hot month is replaced by an abnormally cold one, an abnormally dry one by an abnormally wet one, and the said contrast alternates in time and space.

2.5 On modeling natural processes

Modeling of these processes is used to assess the possible consequences of climate change on the planet. However, in order to obtain an adequate result, it is necessary to include various scenarios for the development of such processes among the initial data. Modeling climate change is an extremely complex task, and therefore, conclusions obtained on the basis of inadequate models, at best, will not give the expected result. For example, such a factor as air pollution by solid and liquid substances, on the one hand, is undesirable, but on the other hand, these substances, being in the atmosphere, scatter and reflect solar radiation. Therefore, a reduction in such pollution, as a result, leads to an increase in air temperature in a limited area, which has been confirmed on the basis of climate observations over the past decade in China: a decrease in air pollution has led to a more significant increase in temperature in some industrial cities than the warming associated with greenhouse gas emissions [22]. Thus, there is a clear need to develop climate change models that provide an analysis of the multifactorial influence on processes occurring on a planetary scale [23]. This point of view was expressed by several hundred scientists from dozens of countries: 109 from Australia, 49 from Canada, 79 from France, 160 from Italy, 61 from the Netherlands, 112 from the USA, etc. [24].

3. Diversification of electricity generation

3.1 Types of electricity generation and types of energy sources

Sources of electricity generated from renewable energy sources (RES) include hydroelectric power plants (except for hydroelectric power plants that generate electricity using pumped stations using water previously pumped under pressure), as well as power plants that generate electricity from solid biofuels (including waste), wind, solar and geothermal installations [7]. In 2023, coal retained its position as the dominant fuel for electricity generation with a stable share of about 35%, the share of natural gas also remained stable at about 23%, and power plants running on fuel oil contributed just over 2% of total electricity generation. The share of RES in total electricity generation was about 30%; At the regional level, South and Central America contributed the most, 72%; in Brazil, which accounts for over 40% of regional electricity consumption, wind and solar contributed 17% and 71%, respectively. Nuclear power remained at around 9%, due to new construction in China and the reactivation of power plants in France and Japan, offset by the closure of power plants in Germany. Table 5 shows the consumption of energy sources used for electricity generation by region in 2022/2023 [3].

At the same time, the consumption of energy sources used to generate electricity per capita in the region in 2023 was (Gcal/person):

- North America - 230.0;
- CIS countries - 163.7 (including Russia - 216.6);
- Middle East - 142.9;
- Western and Central Europe - 115.2;
- Asia-Pacific - 67.3 (including China - 119.8);
- South and Central America - 58.3;
- Africa - 14.3;
- World average - 77.0 [3].

To ensure the stability of electricity generation, many countries are diversifying their electricity generation means (Table 6) [7]. In terms of the prevalence of diversification, the greatest progress has been noted in China and the United States - these countries have implemented 8 types of electricity generation each, and together they provide the highest generation for all types.

At the same time, China provided the largest generation of electricity by five types of energy sources: coal, hydropower (HPP), wind power (WPP), solar energy (SPP), geothermal, and bioenergy (GTEB), and USA – by three types of energy sources: natural gas, oil and nuclear energy (NPP). Nevertheless, despite the development of diversification, thermal power plants are leading in the structure of electricity production in all regions of the world. The exception is Latin America, where preference is given to hydroelectric power plants, which is due to the natural conditions of this region. The largest producers of electricity: China - 29.0% of the world's total output, the USA - 16.0%, India - 5.8%, Russia - 3.9%, Japan - 3.7% and the rest of the world together - 41.5%. At the same time, for different regions of the world, the source of electricity generation is stations of different operating modes, and these figures differ significantly (Table 7) [25, 26].

Taking into account the volume of electricity generation, the following conclusion can be drawn: 1) electricity is mainly generated at thermal power plants (TPPs), and 2) the main sources are coal (due to China) and natural gas (due to the USA). As for the focus on renewable energy sources, the utilization rate of installed capacities, for example, wind generators, is only 25%, which is due to the vulnerability of these types of electricity generation to natural disasters: sometimes there is wind, sometimes there is no wind, sometimes there is sun, sometimes there is snowfall that covers solar panels, sometimes there is icing of wind generator blades.

Accordingly, sometimes electricity generation is quite high, and sometimes practically zero. In this regard, this type of electricity generation cannot yet be considered stable and guaranteeing independence from traditional types of energy generation [27]. When generating electricity at nuclear power plants, which is a significant share in the scale of such regions as the USA, Russia, and Europe, then in this case, there is a large emission of water vapor H_2O at cooling towers during the cooling of water used to cool the reactors. It should be noted that each ton of steam emitted from the cooling tower into the ground layer of the atmosphere, where the "greenhouse effect" is formed, is equivalent to the "greenhouse effect" to 360 kg of carbon dioxide. Accordingly, for each "kWh" of electricity generated at nuclear power plants, 3.6 kg of water vapor is emitted into the ground layer of the atmosphere [28]. Thus, for now, electricity generation in the world is mainly provided by burning coal and natural gas.

Table 5. Consumption of energy carriers used for electricity generation by world regions (2022/2023), EJ

Region	Oil	Gas	Coal	NPP	HPP	RES	Total
North America	43,8/ 44,0	**39,40/ 39,8**	10,5/ 8,8	**8,2/ 8,23**	6,4/ 5,8	9,51/ 10,0	117,9/ 116,7
South and Central America	12,5/ 13,0	5,8/ 5,8	1,2/ 1,2	0,2/ 0,2	7,0/ 7,0	3,6/ 4,1	30,4/ 31,3
Western and Eastern Europe	28,6/ 28,3	17,9/ 16,7	10,0/ 8,4	6,7/ 6,60	5,2/ 6,0	11,1/ 11,9	79,6/ 77,9
CIS countries	9,0/ 9,2	21,4/ 21,5	5,5/ 5,5	2,1/ 2,1	2,33/ 2,4	0,1/ 0,2	40,4/ 40,7
including Russia*	7,1/ 7,2	16,1/ 16,3	3,8/ 3,8	2,0/ 2,0	1,9/ 1,9	0,1/ 0,1	31,1/ 31,3
Middle East	17,8/ 18,3	20,4/ 20,8	0,4/ 0,4	0,2/ 0,4	0,2/ 0,3	0,3/ 0,4	39,3/ 40,5
Africa	8,5/ 8,5	6,3/ 6,2	4,1/ 4,1	0,1/ 0,1	1,5/ 1,5	0,5/ 0,5	20,9/ 20,9
Asia-Pacific region	**71,2/ 75,1**	33,3/ 33,7	**129,8/ 135,7**	6,6/ 7,0	**17,9/ 16,7**	**20,1/ 23,6**	**278,8/ 291,8**
TOTAL:	**191,6/ 196,4**	144,3/ 144,4	161,5/ 164,0	24,1/ 24,6	40,6/ 39,6	45,2/ 50,6	607,3/ 619,6

Table 6. Top-16 Countries for power generation sources (2023)

Country	Coal	Gas	Oil	HPP	WPP	SPP	GTEB	NPP	Number of genera-tion types
China	1	3	2	1	1	1	1	2	**8**
USA	3	1	1	4	2	2	2	1	**8**
Germany	10	9	10	-	3	5	4	-	**6**
India	2	-	3	6	5	3	6	-	**6**
Japan	4	8	6	-	-	4	5	7	**6**
Brazil	-	-	8	2	4	6	3	-	**5**
Canada	-	5	9	3	9	-	-	6	**5**
Russia	6	2	5	5	-	-	-	4	**5**
South Korea	8	-	-	-	-	10	9	5	**4**
Spain	-	-	-	-	7	7	-	8	**3**
Britain	-	-	-	-	6	-	8		**2**
Vietnam	9	-	-	10	-	-	-	-	**2**
Indonesia	5	-	-	-	-	-	7	-	**2**
Italy	-	-	-	-	-	9	10	-	**2**
Saudi Arabia	-	6	4	-	-	-	-	-	**2**
Sweden	-	-	-	-	10	-	-	10	**2**

Note: this table shows data on countries that have at least two types of electricity generation in operation. The numbers next to each country indicate the place this country occupies among all countries (not only those listed in the table) for this type of generation in terms of generated electricity. Those countries that have implemented only one type of electricity generation (even if they were in the top 10 countries with the highest generation for this type of generation) are not included in the table.

Table 7. Structure of electricity generation (in %)

Source	Регион (2020 г.)				World production (2023)
	RUSSIA	USA	EUROPE	ASIA	
Coal	14,0	17,1	14,8	57,2	35
Natural gas	44,7	38,0	19,6	11,3	23
Renewable (excluding hydro)	0,3	12,2	23,8	10,2	16,2
Hydroelectric power plants	19,6	13,4	16,9	14,2	14
Nuclear power	19,9	17,9	21,6	5,1	9,1
Other	1,5	1,4	3,2	2,0	2,7

As a result, both products of incomplete combustion (partially oxidized hydrocarbons and methane in their original form, as well as coal in the form of soot) and products of complete combustion (CO_2 and H_2O) are released into the atmosphere. Although methane decomposes in the atmosphere much faster than carbon dioxide, in the first 10 years after the emission of CH_4, its greenhouse activity is approximately 80 times stronger than that of CO_2 [29].

3.2 Hydrogen production

The most common type of energy carrier is hydrocarbons C_nH_m, which, when burned, form oxidation products such as carbon monoxide CO (carbon monoxide), carbon dioxide CO2 (also known as carbon dioxide), products of incomplete oxidation of hydrocarbons C_aH_b, carbon C. "Claims" to CO are due to the fact that this gas, when inhaled, displaces oxygen from the blood, leading to suffocation, and among C_aH_b there are carcinogenic ones (for example, benzopyrene $C_{20}H_{12}$), provoking the development of cancer [30]. Of all possible gaseous fuels, only hydrogen does not contain carbon, and therefore, hydrogen can be considered the most environmentally friendly gas, the immediate combustion product of which is water:

$$H_2 + O_2 + T^oC \rightarrow H_2O \qquad (1)$$

A by-product of hydrogen combustion (as with the combustion of any type of fuel) is nitrogen oxide NO (a product of the oxidation of nitrogen contained in the air by oxygen, which is also part of the air), provided that 2000oC is reached during combustion [31]. However, hydrogen in its pure form is practically never found in nature; it is part of numerous chemical compounds, the most famous of which is water H_2O. Accordingly, obtaining hydrogen in its pure form requires energy expenditure. The cost factor is one of the main ones determining the demand for hydrogen as an energy source on an industrial scale. Therefore, the transition to hydrogen energy means large-scale production of hydrogen, its storage, distribution, and transportation. Therefore, at "low" prices for traditional motor fuel, hydrogen technologies will be economically unattractive. However, at "high" prices, the picture changes significantly: hydrogen, with centralized production based on natural gas, coal, and nuclear energy, requires lower costs compared to traditional technologies for producing fuels for internal combustion engines (ICE) [32]. To compare hydrogen production technologies, the degree of environmental friendliness of the corresponding technology was taken as a basis: the more CO_2 is released during hydrogen production, the less environmentally friendly the corresponding technology is. And each such technology - for simplicity - was given a "color" definition [33]:

- "White" hydrogen (natural, golden, geological)- is naturally produced or is present in the earth's crust;
- "Green" hydrogen is the most environmentally friendly of those produced since it is obtained by electrolysis of water H_2O and provided that electricity comes from renewable energy sources (RES);
- "Yellow (orange)" hydrogen is also obtained by electrolysis, but the source of energy is nuclear power plants (NPP). There are no CO_2 emissions, but large emissions of water vapor are noted due to the cooling of hot water coming from reactors using cooling towers;
- "Grey" hydrogen is produced by steam reforming of methane CH_4, i.e. the feedstock for this reaction is natural gas;
- "Turquoise" hydrogen is produced by decomposing CH_4 into hydrogen and solid carbon by pyrolysis (high-temperature action with a lack of oxidizer). This production produces a relatively low level of carbon emissions, which can either be buried or used in industry, for example, in the production of steel or tires, and thus does not enter the atmosphere;
- "Emerald" hydrogen is produced by decomposing biomethane and natural gas using thermal plasma electrolysis;
- "Blue" hydrogen is produced by steam reforming of methane, but with the condition of carbon capture and storage, which reduces carbon emissions by about 2 times;
- "Brown" hydrogen is obtained by gasifying brown coal to form synthesis gas (syngas): a mixture of carbon dioxide, carbon monoxide, hydrogen, methane, and ethylene, as well as a small number of other gases;
- "Black" hydrogen, for which coal is the feedstock.

Currently, about 96% of the world's annual hydrogen production is obtained from fossil fuels using technologies such as steam methane reforming (48%), oil reforming (30%), and coal gasification (18%) [25]. However, the most common process is the production of hydrogen from methane (reforming process), the product of which is also carbon dioxide. Accordingly, in a hydrogen plant with a capacity of one million cubic meters of H_2 per day, about 0.3-0.4 million standard cubic meters of CO_2 are emitted into the atmosphere daily. At the same time, capturing CO_2 requires approximately 25-30% of the additional costs of hydrogen production [34, 35]. A method that allows one to do without using fossil fuels is water electrolysis, the process of splitting water into its constituent elements - hydrogen and oxygen - using electric current. However, to implement this process, in addition to electricity, water is also needed, and purified water is at that. Thus, to obtain 1 ton of hydrogen by electrolysis, an average of 9 tons of purified water is required, and to obtain 1 ton of purified water, 2 tons of the original (unpurified) water are needed. Thus, to obtain 1 ton of hydrogen, 18 tons of water are needed, and taking into account various losses, this will be 20 tons [36].

About 95% of the hydrogen produced is produced by methods based on fossil fuels, and the production of hydrogen from water using electricity and biomass is only 4% and 1%, respectively. About half of all hydrogen produced is obtained as a result of gasification and thermocatalytic processes of CH_4, followed by heavy oils, oil, and coal. The reaction between CH_4 and steam in a catalytic converter splits off hydrogen atoms, and carbon dioxide is formed as a by-product. The use of fossil fuels for hydrogen production should be associated with carbon capture systems. Hydrogen can also be produced from methanol or gasoline, although CO_2 is again an unwanted byproduct. Thus, producing hydrogen from low- and zero-carbon energy sources, including renewable electricity, biomass, and nuclear energy, could be a long-term goal of a hydrogen utopia [26].

3.3 Electricity generation and transport

The growth in the production of electric transport is mainly due to the desire to reduce environmental pollution in populated areas (and especially in large cities and metropolitan areas) due to the operation of motor vehicles. The latter is equipped with heat engines, the energy generation of which is provided by burning hydrocarbon fuels - mainly diesel fuel and gasoline. In 2021, electricity consumption in the world by all types of electric transport (the most detailed information is provided for this year) - electric cars, electric forklifts, trams, trolleybuses, electric trains, and metro trains - is small, mainly within 2% of the total electricity generation. The highest relative consumption is observed in the countries of the former USSR, which is due to the widespread use of electric rail transport (Table 8) [37, 38]. Almost all electric transport consumes electricity generated at stationary stations. But the nature of electric transport operation has its own characteristics: during daylight hours, electricity consumption is insignificant, in the evening and at night, when the overwhelming majority of electric vehicles are put on charge, electricity consumption increases significantly. If charging is carried out from one local power grid, emergency power outages may occur. All this causes uneven loading of power generating capacities. Three methods are implemented in vehicles to drive an electric motor: 1) the use of hybrid motor units (HMU), when the internal combustion engine can work either independently or to assist the electric motor, while providing recharging of the traction battery (TB) with the help of a generator, 2) recharging of the TB from an external source powered by the power grid, 3) recharging of the TB from fuel cells. Electric vehicles generally provide smooth operation, good acceleration when starting from a standstill, and require less maintenance than cars with internal combustion engines. However, electric vehicles have three problems compared to cars: a short range on a single charge, poorly developed infrastructure, and a long charging time.

In the case of using a gas-fueled mixture, combustion products are emitted into the atmosphere. To reduce atmospheric pollution in this case, it is possible to use hydrogen as an alternative fuel. The organization of the working process, in this case, is ensured by introducing hydrogen into the intake manifold, where it will mix with air and, already in the form of a hydrogen-air mixture, enter the engine cylinders. The further course of the ignition and combustion process will depend on the ignition method: either from a spark plug or as a result of mixture compression by a piston - in this case, the HCCI process (Homogeneous Charge Compression Ignition) is implemented, but in this case, the stability of the engine is low [39-41]. However, engine exhaust gases still contain harmful substances (carbon monoxide, dispersed particles, partially oxidized hydrocarbons) as a result of the combustion of lubricating oil entering the combustion chamber, as well as nitrogen oxides.

Currently, the number of electric vehicles is relatively small: as of the end of 2023, the fleet of electric vehicles reached 40 million units (of which 22.0 million units were in China). Of this number, 69% of electric vehicles are equipped only with TAB, the rest are hybrids; fuel cell electric vehicles (FCEV) are not included in this number. The leaders in electric vehicle sales are three regions: China (60%), Western Europe (25%; mainly Germany, Norway, the Netherlands, Iceland, Denmark) and the USA (10%); the rest of the world accounts for 5%. Accordingly, the saturation of electric vehicles in countries varies: in Norway, there was one electric vehicle per 7 people; in the Netherlands - per 33; in Germany - per 44; in China - per 100; in the USA - per 114; in Japan - per 306 [42, 43]. The key factors, without the implementation of which it is impossible to spread electric transport, are, firstly, the sufficiency of the charging infrastructure and its compliance with the design of the charging ports on electric transport. Secondly, the charging time of traction batteries is significantly longer than the time of refueling cars with traditional fuel. Thirdly, an increase in the mileage on a single battery charge requires an increase in the capacity of the TB, which entails an increase in the weight and size of the batteries (and, accordingly, the weight and size of the electric car), as well as the time of their charging. Lithium-ion batteries are most widely used in electric transport due to their high energy density and the absence of the "memory effect", which allows them to be recharged at any degree of discharge.

Table 8. Electricity generation and consumption in the regions of the world (2021)

Region	Electricity generation, TW·h	Annual consumption of electricity		
		Totak, TW·h	Electric transport	
			TW·h	% of output
Total in the world including:	28323,0	23734,0	455,0	1,6
North America	5397,3	4657,9	22	0,4
Central and South America	1330,3	1090,9	5	0,4
Western and Central Europe	3850,3	3279,8	74	1,9
Middle East	1294,4	1035,1	1	0,1
Africa	884,2	681,3	5	0,6
Asia and Oceania	13895,5	11779,3	253	1,8
Former USSR countries	1670,9	1209,8	95	5,7
including Russia	1114,5	1090,4	n.a.	n.a.

But their significant drawback is that they are effective up to an ambient temperature of "minus" 7°C, not lower, which predetermines the mileage on a single battery charge in winter by 20 ... 30% less than in summer. The range of an electric vehicle on a single charge is determined by two factors: the capacity of a fully charged battery pack and the efficiency of its electric transmission. For most electric vehicles, the following ratio is valid: 3.0-6.0 km / (kWh) due to the TB. At the same time, energy consumption depends on such factors as the TB temperature (it is desirable to maintain a constant temperature), maintaining the climate in the cabin (the consumption for heating or cooling the cabin depending on external conditions), driving style (each driver has his own style: some are calm, some are aggressive), operating conditions (electric vehicles have an advantage in city traffic with frequent braking and stops, when, thanks to regenerative braking, the TAB is recharged). Recharging. Most electric vehicles can be charged from an AC outlet (120 V or 240 V), and some - from direct current. However, since batteries can only store direct current, the alternating current must be converted to direct current before it can be used to charge the electric vehicle using an onboard charger. At a grid voltage of 110-120 V, it is possible to charge the battery for a range of about 60 km in 8-13 hours. The charging speed, in this case, is limited by the amount of electricity available at the outlet, not by the capacity of the electric vehicle's onboard charger. However, higher levels of battery discharge require proportionally longer charging times. With a grid voltage of 220-240 V and an increase in current to 80 A (depending on the vehicle), the charging time can be reduced by a factor of 10. However, this maximum charging speed is rarely achieved since the ability to convert alternating current to direct current becomes the limiting factor [44]. Thus, recharging electric vehicles from external sources requires a developed infrastructure of charging stations and the electric vehicles themselves, capable of providing charging in a short time and having a high capacity. Otherwise, the use of electric vehicles will be limited to one locality and will require a lot of time. Recharging at night from a home electrical network is only possible in private homes; how to implement this in multi-story buildings seems difficult. Given the size of large cities, the "greenest" motorized type of transport at present is public electric transport: trams, trolleybuses, metro, electric buses, and electric trains. The more people regularly use public rather than personal motorized transport, the lower the specific emission of pollutants per person in the city will be (helping to achieve "climate neutrality"), and as technology develops, various types of shared transport, that is, shared on-demand, will also find wider application [45]. Fuel cells (FC) are devices for converting the chemical energy of fuel into electrical energy; they provide electricity generation due to oxidation-reduction transformations of reagents coming from outside, as a result of which the batteries are recharged. Hydrogen and air are used as reagents (the latter as a source of oxygen, which is cheaper than using pure oxygen). Unlike a battery, which is discharged while it is used to power electrical components, FCs act as constantly working energy sources as long as they are supplied with fuel. The main problems of cars with FCs are associated with high production and operating costs, as well as a lack of electrical capacity for hydrogen production and the safety of its use. Improvement of the FC itself and infrastructure elements are decisive factors for commercializing hydrogen as a motor fuel for motor vehicles. Hydrogen can be transported in a fuel tank by vehicle. However, the low volumetric energy density of hydrogen under ambient conditions requires storage in cylinders with an operating pressure of up to 20.0-70.0 MPa, but even at the highest pressure, the energy density of hydrogen is only 4.4 MJ/l versus 31.6 MJ/l for gasoline. When using liquefied hydrogen (cooled to minus 253°C), its energy density increases to 8.0 MJ/l. However, the compression and liquefaction processes themselves require energy expenditure: during liquefaction, energy consumption is from 25 to 45% of the energy of the liquefied hydrogen [46], which causes additional consumption of hydrogen and, accordingly, natural resources for its production.

4. Conclusion

The documents adopted from 1992 to 2022 at international conferences on climate change on the planet noted that there is currently an increase in the average global temperature. At the same time, responsibility for this process is attributed to anthropogenic influence in connection with the development of industry and agriculture, which led, in particular, to an increase in the emission of so-called "greenhouse gases" (GHG). It was noted that carbon dioxide CO_2 has the greatest impact on the "greenhouse effect", since its mass emission into the atmosphere is the largest of all GHG. However, water vapor H_2O, which has three times greater greenhouse activity, was not included in the number of GHG. In addition, analysis of the composition of gases contained in ice cores obtained as a result of deep drilling in Antarctica and Greenland has shown that changes in the concentration of carbon dioxide in the Earth's atmosphere do not precede warming but occur after it. This process is due to the fact that 90% of CO_2 is dissolved in the World Ocean, and with an increase in ocean temperature, the solubility of gases in water decreases, while in the case of cooling, it increases. Accordingly, the development of measures to reduce "climate neutrality" without taking into account the effect of water vapor on the degree of heating of the atmosphere is unproductive. The current state of modeling the causes of climate change shows that the climate models used are inadequate for atmospheric processes. This includes, in particular, the failure to take into account the influence of water vapor on the "greenhouse effect" and the relationship between the processes of changing the concentration of CO_2 in the atmosphere and the temperature of the World Ocean, the ambiguity of the influence of the factor of atmospheric pollution by solid and liquid substances that scatter and reflect solar radiation on the processes of heat and mass exchange. This also includes the failure to take into account such a planetary phenomenon as periodic cycles of cooling and warming: at present, a warming process is underway that began in the middle of the 19th century, when the Little Ice Age ended. Regardless of the causes of global warming, to ensure "climate neutrality" it is necessary to develop appropriate measures, one of which is the diversification of energy supplies to the population, industry, and agriculture. The basis of energy security in countries is the electric power industry, the generation facilities of which are classified by the type of energy source used. Each type of generation has its own advantages and disadvantages (not taking into account the cost of their construction, maintenance, and disposal). At present, electricity is mainly generated at thermal power plants (TPPs) by burning hydrocarbon fuels - natural gas and coal, which is accompanied by the formation of products of complete and incomplete combustion (among which are the so-called "greenhouse gases") and their subsequent release into the atmosphere. The operation of nuclear power plants (NPPs) is accompanied by the release of a large volume of water vapor into the atmosphere (due to the operation of the cooling system); power plants using renewable energy sources (RES) have minor environmental damage, but their efficiency and stability are still low, since they depend on weather conditions. In 2023, 35% of electricity generation worldwide was provided by burning coal, 23% by burning natural gas, 2% by burning fuel oil. The share of renewable energy sources was about 30%. Using hydrogen as an energy carrier instead of hydrocarbon fuel to provide electricity generation at thermal power plants is environmentally cleaner. But there is practically no pure hydrogen in nature, and currently 96% of hydrogen is obtained by processing natural gas - an environmentally far from the most harmless method, which is accompanied by the formation and emission of harmful substances into the atmosphere and an increase in the "greenhouse effect". 6. Reducing air pollution in populated areas by replacing cars equipped with internal combustion engines (ICE) with electric vehicles equipped with electric motors helps to ensure "climate neutrality". But environmental pollution in the locations of power generation stations (necessary for charging traction batteries - TB), including those using hydrogen as fuel, is accompanied by the spread of harmful substances by air currents for many hundreds and thousands of kilometers. Some share of electricity generation is provided by the operation of heat engines installed in hybrid electric vehicles, which provides partial recharging of TB. The use of hybrid motor units (HMU) allows the use of hydrogen in heat engines, but its combustion products are not only water vapor but also nitrogen oxide (as a product of high-temperature oxidation of nitrogen by oxygen, which is part of the air). Thus, the use of HMU in transport is a palliative solution to the problem.

Ethical issue

The author is aware of and complies with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the corresponding author.

Conflict of interest

The author declares no potential conflict of interest.

References

[1] Karpenko V. M., Yuan H. Diversification of the energy consumption structure as a tool for ensuring national energy security. / Proceedings of the Belarusian State Technical University, 2022, series 5, No. 1, - pp. 145-1551.

[2] Total electricity production. - [Accessed: 21.01.2025]. Available:https://statbase.ru/datasets/electricity/electricity-generation/.

[3] Statistical Review of World Energy / Energy Institute, 73rd edition, 2024. 7-76 p.

[4] Golovin A. A., Solodukhina O. I., P'yannikova E. A. Assessment of the potential and prospects for using renewable energy sources to diversify electricity supply. / Online journal "Russian Journal of Resources, Conservation and Recycling". - [Accessed: 01/22/2025]. Available at: https://resources.today/issue-1-2020.html

[5] Paris Agreement, adopted 12 December 2015, in force 04 November 2016 [Internet resource]. - [Accessed: 05.06.2021]. Available at: https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement _ russian_.pdf

[6] DIRECTIVE (EU) 2023-2413 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 October 2023. / Official Journal of the European Union. – [Accessed: 21.01.2025]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413.

[7] [Accessed: 21.01.2025]. Available at: https://ec.europa.eu/eurostat/ statistics-explained/index.php?title

[8] [Accessed: 21.01.2025]. Available at: https://statbase.ru/datasets/electricity/ electricity-generation/.

[9] [Accessed: 17.01.2025]. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_ energy_ statistics#cite_ref-2

[10] UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (May 9, 1992.). - [Accessed: 17.01.2022]. Available at: https://www.wipo. Int/wipolex/ru /text/195895

[11] United Nations. Kyoto protocol to the United Nations framework convention on climate change. - [Accessed: 14.02.2024]. Available at: https://unfccc.int/ resource/ docs /convkp/kpeng.pdf

[12] [Accssed: 09.08.2003]. Available at: https://www.un.org/ru/climatechange/ paris-agreement /

[13] [Accessed: 08.08.2023]. Available at: https://worldpopulationreview. com/country-rankings/greenhouse-gas-emissions -by-country /

[14] Handbook of lasers / Translated from English edited by A.M. Prokhorov, in 2 volumes. Vol. 1. – Moscow: Soviet Radio, 1978. – 504 p..

[15] [Accessed: 25.02.2017]. Available at: https://regnum.ru/news/ innovatio/ 2242564.html /.

[16] Technical encyclopedia / ed. OK. Martens. – 2nd edition. – M: Gostekhizdat OGIZ RSFSR, 1937. – T. 4. – P. 231 – 234Flint R.F. History of the Earth. / Moscow: Progress, 1978. - 359 p.

[17] Flint R.F. History of the Earth. / Moscow: Progress, 1978. - 359 p.

[18] Danilov-Danilyan V.I., Losev K.S. Environmental challenge and sustainable development. - Moscow: "Progress-Tradition", 2000. - 416 p.

[19] Mar K.A., Unger C., Walderdorff L., Butler T. Beyond CO2 equivalence: The impacts of methane on climate, ecosystems, and health. https://www.sciencedirect.com/science /article/pii/S1462901122001204? via%3Dihub -

[Accessed: 04.03.2020]. Available at: //doi.org/ 10.1016/j.envsci.2022.03.027
[20] Water vapor and the "greenhouse effect". - [Accessed: 04.03.2020]. Available at: https://regnum.ru /news /innovatio/ 2086744.html
[21] [Accessed: 11.05.2021]. Available at: https://maglipogoda.ru/grafik-srednej-globalnoj-temperatury-za-poslednie-66-mln-let/
[22] Глобальное потепление и озоновые дыры - наукообразные мифы – [Accessed: 15.11.2023]. Available at: https://www.eprussia.ru/epr/17/978. htm
[23] The Pollution Paradox: How Clean Air Can Warm the Planet- [Accessed: 14.11.2023]. Available at: https://fupubheadlines.com/the-paradox-of-pollution-how-clean-air-may-heat-the-planet
[24] Global warming is not a crisis!' / NECSUS #3 2013, VOL. 2, NO. 1, 'GREEN – 112 P. / Available at: https: www.necsus-ejms.org Published by: Amsterdam University Press //doi.org/10.25969/mediarep/15075
[25] World Climate Declaration, January 1, 2020. – [Accessed: 14.11.2022]. Available at: https://techstartups.com/wp-content/uploads/2023/08/WCD-version-081423.pdf
[26] Global Electric Power Industry Review 2024. - [Accessed: 03.09.2024]. Available at: https://aenert.com/ru/novosti-i-sobytija/monitoring-novostei-ehnergetiki/n/globalnyi-obzor-ehlektroehnergetiki-2024-rekordnye-30-vozobnovljaemykh-istochnikov-ehnergii-v-mirovom-p/
[27] Electric Power Industry of the World. - [Accessed: 21.08.2024]. Available at: https://foxford.ru/wiki/geografiya/elektroenergetika-mira?utm_ referrer=https %3A%2F% 2Fyandex.ru%2F
[28] How Europe is freezing, abandoned to its fate by alternative energy. - [Accessed: 15.02.2021]. Available at: https://zen.yandex.ru/media/dbk/kak-zamerzaet-evropa-broshennaia-na-proizvol-sudby-alternativnoi-energetikoi-60265fab331cb7635255542e
[29] Anisimov V.R., Klimov A.V. History of scientific research on vehicles with hydrogen power plants. / Bulletin of Moscow State Technical University "MAMI", Vol.17, No.2, 2023. - pp.127-135. //doi.org/10.17816/2074-0530-139224
[30] Water vapor and the "greenhouse effect". - [Accessed: 04.03.2020]. Available at: https://regnum.ru/news/innovatio/2086744.html
[31] Carcinogens: properties and danger of benzopyrene. - [Accessed: 27.08.2024]. Available at: https://medaboutme.ru/articles/ kantserogeny_svoystva_i_ opasnost_benzapirena/
[32] Zeldovich Ya.B., Sadovnikov P.Ya., Frank-Kamenetsky D.A. Nitrogen oxidation during combustion. Moscow-Leningrad: Publishing house of the USSR Academy of Sciences, 1947. – 148 p.
[33] Sinyak Yu.V., Petrov V.Yu. Assessment of the impact of damage from environmental pollution on the competitiveness of hydrogen as a motor fuel, 2008. - [Accessed: 30.08.2024]. Available at: http://library.vscc.ac.ru/ Files/articles /124083314763-77.pdf
[34] Hydrogen classification by color. - [Accessed: 26.03.2024]. Access at: https://neftegaz.ru/tech-library/energoresursy-toplivo/672526-klassifikatsiya-vodoroda-po-tsvetu/?ysclid= lu7v9u3eqv 644594181
[35] Hosseini S.E., Wahid M.A. Hydrogen production from renewable and sustainable energy resources: Promising green energy carrier for clean development/ // Renewable and Sustainable Energy Reviews, Volume 57, May 2016, Pages 850-866. - [Access date: 06/30/2024]. Accessed at: https://www.sciencedirect.com/science/article/abs/pii/ S1364032115014951?via%3 Dihubhttps: //doi.org/10.1016/j.rser.//doi.org /10.1016/j.rser.2015.12.112
[36] The Green Hydrogen Problem No One Is Talking About. - [Accessed: 30.06.2024]. Available at: https://www.ruscable.ru/article/problema_ zelenogo_vodoroda_ o_kotoroj_nik/
[37] Report on the functioning of the Unified Energy System of Russia in 2021. - [Accessed: 09.10.2024]. Available at: https://www.so-ups.ru/fileadmin/files /company/reports/disclosure /2022/ups_ rep2021.pdf;
[38] World energy. Electric energy balances. - [Accessed: 09.10. 2024]. Available at: https:// www.eeseaec.org/balans-elektriceskoj-energii
[39] HCCI and CAI engines for the automotive industry. / WOODHEAD PUBLISHING LIMITED, Cambridge England, 2007. - 557 p
[40] Kavtaradze R.Z. Thermophysical processes in diesel engines converted to natural gas and hydrogen. / Moscow: Publishing house of Bauman Moscow State Technical University, 2011. – 238 p.;
[41] Fomin V.M. Hydrogen energy of automobile transport. / Moscow: Publishing house of Bauman Moscow State Technical University, 2006. – 334 p.
[42] Top 10 countries by the presence of electric vehicles. - [Accessed: 27.09.2024]. Available at: https://dzen.ru/a/ZHEECfWKyhhbjq Cy?ysclid=m1kjv1tsh 7996350137
[43] Electric vehicles (global market). - [Accessed: 21.10.2024]. Available at: https://www.tadviser.ru/index.php/ Article: Electric vehicles_ (global_ market)
[44] AAA ELECTRIC VEHICLE RANGE TESTING / American Automobile Association, Inc. 2019 – 66 p
[45] Trofimenko Yu. "We do not expect a mass abandonment of offices and relocation to the countryside." - [Accessed: 09.06.2024]. Access at: https://plus-one. vedomosti.ru/my-ne-ozhidaem-massovogo-otkaza-ot-ofisov-i-pereezda-za-gorod
[46] Problems of hydrogen energy. - [Accessed: 08.27.2024]. Access at: https://dzen.ru /a/Xu4u4PHUUUhvLRIR