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On Forecasts of the Global Energy Transition

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Abstract. Assessment of the real potential of renewable energy sources shows the groundlessness of forecasts of their future dominance in the global energy sector and hopes for the possibility of changing by this means the observed climatic processes. Forecasts of the expected global energy transition, at least until mankind mastered the energy of thermonuclear fusion, are groundless. Until then, the main source of energy for the world economy, as during the previous two centuries, can only be the still abundant resources of hydrocarbons available in the earth's crust. In developing and implementing its energy programs Russia should be guided exclusively by the domestic realities and interests, without regard to the trends and decisions dominating in the West.
Keywords: *world energy; renewable energy sources; hydrocarbon resources; low-carbon energy; hydrogen energy; global energy transition*

Introduction

Forecasts are one of the important types of scientific products, which allow assessment of the prospects of various directions and optimal allocation of efforts and resources. Although forecasts cannot predict scientific discoveries and the emergence of fundamentally new technologies, they provide certain reference points of development within the available horizon of events, usually extending no more than a few decades. Of course, not all of them are justified, but if they claim to be predictive, they must adequately take into account the real picture of the surrounding world and the physical processes taking place in it.

The ECO journal debate on plans and forecasts for low-carbon development and the energy transition in Russia and the world in the medium (up to 2030) and long (up to 2060) periods, and the socio-economic impact of different scenarios in this area opens with a review of the book by Prof. Thain Gustafson Klimat. Russia in the Age of Climate Change [Gustafson, 2021]. It is not our task to analyze in detail its content and conclusions, which are quite typical for a large number of similar recent works. We want to discuss the very basic concept of such forecasts and, above all, the ideas they develop about the global energy transition that awaits the world in the near future.

According to Wikipedia, which reflects generally accepted or most popular approaches, “in recent years the term ‘energy transition’ has been used to refer to the transition to sustainable energy through the greater integration of renewable energy sources into everyday life (the transition to a so-called ‘green economy’)”[1]. That is, the expected energy transition is justified by the need for a global rejection of traditional energy sources in favor of “low-carbon” energy, which in modern conditions can only be realized through renewable energy sources (RES).

In general, in the history of civilization a global energy transition already took place at the turn of the 18th and 19th centuries. Then mankind moved from renewable, but inefficient energy based on the muscular energy of animals, wind and biofuel (firewood) to a more efficient coal and then hydrocarbon energy. In the fairly distant future mankind will undoubtedly transition from the currently used fossil energy sources to thermonuclear energy. This is inevitable, if only because fossil fuels, including uranium resources for nuclear power, are not infinite, and other global energy sources, except fusion energy, are not yet known in the world around us.

[1] Energy transition. Wikipedia.
URL: https://ru.wikipedia.org/wiki/%D0%AD%D0%BD%D0%B5%D1%80%D0%B3%D0%B5%D1%82%D0%B8%D1%87%D0%B5%D1%81%D0%BA%D0%B8%D0%B9_%D0%BF%D0%B5%D1%80%D0%B5%D1%85%D0%BE%D0%B4

It is hardly possible or worthwhile to consider as a global energy transition the gradual introduction into the world's energy industry of various fossil fuels: coal, oil, and gas. Neither in terms of the scale of change in their relative contribution to the energy balance, nor in terms of the rate of change, nor in terms of their technological impact on the world energy sector and the economy, are these changes, which have been occurring smoothly for two centuries and are continuing at the present time, pulling them toward the global energy transition. Thus, in the absence of realistic expectations of a transition to thermonuclear energy in the next few decades, any prospects for the global energy transition are reduced to the question of the fundamental possibility of replacing the currently dominant hydrocarbon energy with known RES. Therefore, before discussing the mechanism, timing and consequences of such an energy transition, and developing its roadmaps, it is necessary to understand: is the reverse transition from hydrocarbon fuels to renewable energy sources possible in principle as a result of scientific and technological progress? The real forecast of the world energy and economic development, and to a large extent the forecast of Russia's development, depends on the answer to this crucial question.

The Real Potential of RES

All the known varieties of RES: hydropower, wind power, sea waves, tides, biofuels, etc., with the exception of geothermal power, which is very small in its potential, are derived from solar radiation, the only real external source of energy to the Earth. As early as the 1970s, in works by Jay Forrester, Dennis Meadows, and Edward Pestel [Forrester, 1978; Meadows, et al., 1972; Meadows, et al, Pestel, 1988], as well as the works of Russian experts in global dynamics N.N. Moiseev [Moiseev, 1997], V.G. Gorshkov [Gorshkov, 1995] and others, have established that at current per capita energy consumption levels in developed countries, no more than 500 million people could exist on Earth using renewable energy sources. Now the Earth population exceeds this figure almost 20 times and continues to grow rapidly, as well as the average per capita energy consumption.

Since all varieties of RES are derived from the solar radiation coming to the Earth, there is no point in analyzing the advantages and disadvantages of each of them in detail. It is quite enough to consider on the basis of the known basic physical parameters of solar radiation the fundamental question of its real potential as a primary source of RES available to us, just as in due time on the basis of basic physical principles the fundamental question of the possibility of creating a "perpetual motion machine" was solved.

Formally the resource of incoming solar radiation to the Earth is huge – the upper boundary of the Earth's atmosphere for a year reaches a colossal flow of solar energy – ~5.6–1024 J. This value is approximately 5,000 times greater than mankind's annual demand for energy. About 35% of this energy is reflected back into space by the Earth's atmosphere. The rest is used to heat the Earth's surface, the evaporation and deposition cycle in the atmosphere, wave formation in the seas and oceans, air and ocean currents and winds, and photosynthesis. During all these processes the high-potential energy of solar radiation in the ultraviolet and visible range is converted into the low-potential energy of the heated Earth surface (its average temperature is about 20 oC), which is emitted by our planet as infrared radiation back into outer space.

Why renewable solar energy cannot be the basis of the world's industrial energy industry, the outstanding Russian scientist Academician P. L. Kapitsa explained 50 years ago on the basis of the notion of energy flux density [Kapitsa, 1976]. Indeed, the amount of energy dissipated in the space around us is enormous. But how to extract it? All varieties of RES use "low-potential energy", the density of which in the applied energy carrier (energy source) is extremely low. To imagine the difference between the low-potential energy abundantly dispersed around us and the high-potential energy used in traditional energy, it is enough to compare the flow of energy carried by a blowing breeze or gentle sunlight with the concentrated energy in the combustion chamber of a gas turbine or in a nuclear reactor. It is the problem of concentrating and using the scattered low-potential energy that all renewable sources operate on, without exception, that is the main obstacle to their industrial use.

To illustrate, let us make a simple estimate of the potential of solar radiation, and hence of all secondary energy sources generated by it. The solar radiation flux at noon at the equator is ~1 kW/m^2. Taking into account the change of day and night, its average value is three times lower, and in middle latitudes it is even two times lower and is ~150 W/m^2. With a real efficiency of solar panels of less than 24%, to provide an average power of 1 kW it is necessary to collect and convert radiation from an area of ~30 m^2 into electricity [Arutyunov, 2021].

Global energy production in 2019 was 160,000 TWh[2]. In order to produce this amount of energy using solar panels, an area of ~6,1011 m^2, or 0.6 million km^2, would need to be equipped with them. Taking into account the auxiliary areas for equipment, substations, energy conversion and storage systems, roads, transmission lines, etc., the required area would exceed 1 million km^2, i.e. about 1% of the Earth's land surface [Arutyunov, 2021]. To cover such an area with complex technological equipment, the Earth's crust will lack not only the rare elements necessary for the production of solar panels, but even the usual structural materials. And the removal of such a large area from economic use and natural ecosystems would cause irreparable damage to both. As for other types of RES, their energy flux density is even lower, so producing the same amount of energy from them would require about ten times as much space as solar power.

To conclude this section, we note that meeting the world's ever-growing energy needs, without which its progressive development could not be conceived, will inevitably upset the thermal balance of the planet and cause its surface tem-

[2] BP Statistical Review of World Energy, 2020. URL: https://www.bp.com/content/dam/bp/ business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

perature to rise, regardless of the source of this energy. For example, an increase in the absorption of solar radiation when it is converted into electricity will lead to a decrease in the albedo of the planet. And maintaining its thermal equilibrium as an isolated cosmic body, in accordance with the Stefan-Boltzmann law, will require an increase in the infrared radiation emitted back into space, i.e. its surface temperature [Arutyunov, 2021a].

Climatic factor

What is the reason for the continued active interest in renewable energy sources? The initial reason was the awareness of the finitude of fossil hydrocarbon resources and the inevitability of their future exhaustion, which was formed in the 1970s and served as the impetus for work under the auspices of the Club of Rome. But at the beginning of this century it became clear that in the Earth's crust there are still huge resources of unconventional hydrocarbons (shale oil and gas, gas hydrates, etc.) [Arutyunov, Lisichkin, 2017], which can supply the world economy for many decades, up to the practical development of fusion energy. And after the "shale revolution" of 2008, the threat of a global energy crisis is no longer relevant.

The current interest in renewables is related primarily to climate problems and fears of their serious consequences. The very fact of the increase in the average temperature of the Earth's surface in the last period is not in doubt, although the discussion about its origin continues, and there are still different points of view about the causes and the durability of the observed trend. Despite the existence of objective evidence of natural factors influencing the increase in the average temperature of the Earth's surface [Kondratyev, 2004; Shpolyanskaya, 2019], the prevailing view, reflected in the materials of the Intergovernmental Panel on Climate Change (IPCC), was the anthropogenic impact on the atmosphere composition, reflected by a rapid increase in its concentration of greenhouse gases, primarily CO_2, which in 2019 reached almost 410 ppm, although back in 1900 it was 296 ppm[3].

It should be noted that the observed temperature trend in itself is nothing unusual, and similar fluctuations have already been repeatedly noted in the history of our planet's climate. However, Western European politicians react very painfully and even aggressively to the observed processes, which is quite understandable. The current climatic, and hence economic well-being of Western Europe is based on a delicate balance of climatic processes, maintained by the warm Gulf Stream. And if for most other regions of the world the consequences of the expected climatic changes will not be too painful, and maybe even favorable, including Russia, for Europe a radical change in the parameters of the Gulf Stream will turn into a climatic and, consequently, economic catastrophe. Recall that the critical value of temperature increase, the excess of which will lead to irreversible changes in the glacier cover of the planet, the level of the global ocean and the nature of the circulation of currents in the atmosphere and the ocean is estimated only in 2 oC [Randalls, 2010].

In an attempt to stop the observed but poorly understood climate processes, and despite the lack of scientific evidence that they are caused by anthropogenic factors [Shpolyanskaya, 2019], and even more so that the ongoing efforts can actually change their course, representatives of 196 countries adopted in 2015. Paris Agreement on Climate. Its goal is to develop and implement a strategy to reduce anthropogenic emissions of greenhouse gases, primarily CO_2. The main culprit of climate woes is energy, which from the mid-19th century to the present is based on hydrocarbon fuels by more than 80%, even though the contribution of modern agricultural production to the global anthropogenic greenhouse gas emissions is at least not lower. The main stated goal of the Paris Agreement[4] is to reduce the share of

[3] The Intergovernmental Panel on Climate Change. URL: https://www.ipcc.ch/

[4] Paris Agreement. URL: https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_russian_.pdf

hydrocarbon sources in the global energy balance, which can only be achieved by switching to alternative energy sources. The obvious inability to meet today's world energy needs through renewables forces us to look for other solutions, one of which was the transition to "hydrogen energy" announced several years ago.

Hydrogen energy: problems, problems, problems…

A huge flow of publications in recent years on hydrogen energy and ambitious programs of its development announced by many states, supported by solid financing, do not allow to ignore this topic. Moreover, hydrogen power engineering is declared to be a decisive factor in solving climate problems and one of the main components of the coming energy transition.

It is true that hydrogen can be considered an environmentally friendly fuel, because its combustion only produces water vapor. But it is not always taken into account that there are no significant resources of free hydrogen in the Earth's crust and atmosphere. Strictly speaking, hydrogen is not an energy source, but only a secondary energy carrier that can only be obtained from primary energy sources. And for hydrogen to be considered an environmentally friendly fuel, it must be obtained from environmentally friendly sources. In addition, with any technology of its production, the total energy consumption and its cost to the consumer will always be higher than with the direct use of the primary energy sources from which it is derived. And the full ecological consequences of using hydrogen will be determined by the ecological impact of all the primary sources used to produce it.

When discussing the merits of hydrogen energy, the default assumption in most cases is that the necessary hydrogen will be produced exclusively from "clean" renewable energy sources, although, as already mentioned, these are not capable of fully meeting global energy needs, and their real contribution to the global energy sector does not exceed a few percent. Today the world produces less than

90 million tons/year of hydrogen, mostly for the needs of oil refining and petrochemicals, which is 100 times less than the volume needed to replace hydrocarbon energy. As it is easy to calculate, due to the potential of all currently existing RES in the world, no more than 50 million tons of hydrogen can be produced per year [Arutyunov, 2021b]. This is almost 200 times less than what is needed to replace the modern hydrocarbon energy, while its volume, according to forecasts, will at least double by the middle of this century. At the same time the cost of "green" or "clean" hydrogen produced on the basis of RES, about five times higher than the "gray" produced on the basis of hydrocarbon conversion and providing 99% of its current production. The mentioned difference in cost is not eliminated by technological innovations, as it is caused by the difference in thermodynamics of hydrogen production by steam conversion of hydrocarbons and electrolysis of water on the basis of renewable energy [Arutyunov, 2021b; Arutyunov, 2022].

However, even relatively cheap but ecologically unattractive "gray" hydrogen as an energy source is several times more expensive than natural gas. And the proposed technologies for increasing the environmental attractiveness of hydrogen by capturing and burying the CO_2 generated during its production, or using the pyrolysis technology of natural gas, will increase its cost and consumption of natural gas at least two or three times more, but will not lead to a significant reduction in global CO_2 emissions [Arutyunov, 2021b; Arutyunov, 2022].

Unfortunately, the problems of hydrogen energy are not limited to hydrogen production processes. Hydrogen is the lowest-caloric of the fuels actually considered. The density of liquid hydrogen is six times lower than liquid methane, 11 times lower than gasoline [Pearson et al., 2012]. Therefore, despite its high gravimetric energy content, its volumetric heat of combustion is 2.5 times lower than CH4 and 4 times lower than that of gasoline. And the volumetric energy content of hydrogen gas is 4 times lower than that of natural gas.

But this does not exhaust the consumer disadvantages of hydrogen as a fuel. Energy consumption for compression of hydrogen is 8.5 times higher than for CH4. And if now about 7% of all energy produced in Russia is spent on pipeline transportation of natural gas to our borders, it is difficult to imagine what share of it will be needed for transportation of hydrogen. However, this question is rather abstract, because the existing gas pipelines are in principle unsuitable for hydrogen transportation – at high pressure the interaction of hydrogen with the materials of the pipeline and the gas pipeline fittings leads to their embrittlement and destruction. And construction of special gas pipelines for hydrogen transportation will require enormous investments[5].

A separate and very serious problem is the safety of transportation and use of hydrogen and methane-hydrogen mixtures. Combustion rates and ignition limits of hydrogen are five to six times higher than those of natural gas [Makaryan et al., 2022], which requires fundamentally new and much more stringent safety rules for their wide application, especially in transportation and utilities.

Thus, the transition to hydrogen as an energy carrier will require a multiple increase in costs and consumption of primary energy sources, primarily the same fossil hydrocarbons, and will lead to the corresponding acceleration of their depletion, without guaranteeing a real reduction of global CO_2 emissions, i.e. achievement of the set climate goals. And low consumer qualities of hydrogen as an energy carrier, difficulties of its storage and transportation, safety problems [Arutyunov, 2021b; Arutyunov, 2022] will hardly contribute to its wide distribution as an energy carrier.

Economic factor

Another factor that forces Europeans not only to actively use renewable energy themselves, but also to demand it from those countries that are not experiencing problems with

[5] Hydrogen pipeline systems. Doc 121/14. European Industrial Gases Association AISBL. URL: https://www.eiga.eu/publications/eiga-documents/doc-12114-hydrogen-pipeline-systems/

energy resources and where renewable energy is not widely suitable for use because of climatic, geographical and other features, such as Russia – is their own energy problems. Experiencing an acute shortage of energy resources, Europe is forced to use expensive alternative energy sources, which seriously undermines its competitiveness and economic position in the world market. To maintain its economic position, Europeans need to force potential competitors to switch to similarly expensive energy sources, even if they have no need to do so. This is an obvious implication of the harsh "environmental" rhetoric and the imposition of corresponding economic sanctions, such as the actively discussed "carbon tax," on the world. Therefore, even without regard to the absence of realistic assumptions that the efforts being made to combat global warming will yield any results, Russia has no reason and no need to sacrifice its well-being and possibly its future profits for the sake of Western Europe's economic interests. The possibility of any additional problems for Russian exports of hydrocarbons and other products that would require taking into account the possibility of introducing such a tax in the current circumstances should hardly be taken into account. It is all the more pointless to take these requirements into account when planning the development of Russia's energy sector.

The environmental factor

In addition to the climatic factor, environmental arguments are usually cited to justify efforts to introduce RES. The mass consciousness has formed an idea of the ecological purity of these energy sources, which is far from being true. We will not discuss the environmental problems of hydropower, which have been under discussion for decades. As for solar power, it is enough to note that the production, regular replacement, and subsequent disposal of solar panels, given their entire lifecycle, leads to the release into the environment of all kinds of highly toxic compounds. Equally unfounded are claims that there is no additional consumption of natural resources associated with their operation. For example, solar power plants located in desert areas require large quantities of locally scarce clean water to regularly flush the surface of the solar panels or the mirrors that concentrate the sun's radiation.

Wind power is no less of a problem. In addition to the degradation of soil ecosystems under the influence of acoustic vibrations generated by wind turbines, changes in the volume and direction of transported precipitation, bird deaths, etc., regular replacement of blades made of non-degradable and non-combustible composite materials, which has already led to the appearance of a huge area occupied by them landfills [Ladygina, 2021] is necessary.

It is hardly necessary to discuss in detail the environmental problems of industrial production of "green" biofuels associated with soil degradation, consumption of a significant amount of fertilizers, water for irrigation and almost the same amount of traditional hydrocarbon fuel in all links of this production chain [Arutyunov, Lisichkin, 2017]. The quietly dying U.S. bioethanol production program clearly demonstrated all this.

The low energy efficiency (ratio of energy received to energy used for the process of its production – EROEI [Arutyunov, Lisichkin, 2017]) of all types of RES makes the need for huge areas and capital expenditures, many times higher than typical indicators for conventional hydrocarbon energy inevitable. Therefore, the statement about the environmental advantages of RES compared to traditional sources with an objective analysis of their full life cycle and with adequate consideration of all environmental factors associated with them is far from indisputable.

Conclusion

What is the meaning of statements about the global energy transition awaiting our world? From what and to what should the world's energy industry transition? As noted above, in real terms we can only talk about increasing the contribution of renewable energy in the world generation from the current 3–4% to the maximum possible 6–8%, and at the cost of huge and not always justified costs. It is unlikely that such a change can be given global significance.

Of course, we all want a clean environment and a comfortable, stable climate. But it is unlikely that most of the world's population is ready to give up the opportunities and benefits that modern energy, the backbone of our civilization, provides. But we have to pay for all these benefits, and the most expensive and reliable currency in the world is energy. This is why we must strike an optimal balance between two factors: prosperity and the energy that supports it, on the one hand, and ecology, on the other. We have always changed our environment and will continue to do so; this, if you will, is humanity's evolutionary mission [Arutyunov, 2021a]. This process did not begin yesterday, it has been going on for thousands of years, since the Paleolithic. Mankind is constantly changing its environment and changing itself in accordance with the changes occurring in this environment. Some of these can be regretted, but it is pointless to fight against natural evolutionary processes.

Among the many diverse spheres of human activity, energy is one of the most fundamental and materially conditioned. Adopting and implementing all the most advanced ideas and technical achievements, it remains one of the most conservative areas of the world economy due to its fantastic scale. The financial and resource costs of large-scale transformations in it are so great that even with the obvious advantages it takes decades to implement them in practice. Therefore, analyzing those energy projects that are being implemented today, and which will probably function for many more years to recoup the enormous funds invested in them, we can quite well imagine the structure of the global energy sector in the middle of the century. The overwhelming share of it, at least 70%, and most likely much higher, will still come from hydrocarbons. And so far no real arguments have been presented that can seriously shake these projections.

The question of why the campaign for "green and renewable" energy sources continues in the West, despite these arguments, lies outside the realm of science. In addition to the geopolitical and economic considerations mentioned here, we can note the low level of scientific education of the Western elite and, unfortunately, the mercantile considerations of part of the scientific community, as well as the need to adjust to what the political and financial mainstream of Western countries dictates based on their interests. In 1998, a large group of American scientists published a petition in which, based on a detailed analysis, they concluded that "there is no convincing scientific evidence that anthropogenic emissions of carbon dioxide, methane and other greenhouse gases can cause catastrophic warming of the Earth's atmosphere and destruction of its climate". [Shpolyanskaya, 2019]. However, this appeal has simply been ignored by the "mainstream" that determines the allocation of research grants and controls the vast majority of highly ranked journals.

Most specialists, of course, understand that natural systems are so complex and that the existing ideas about them are so imperfect that "the published results of modeling the influence of anthropogenic factors on climate change are nothing more than a fitting of factual material to the idea put forward" [Kondraev, 2004]. [Kondratyev, 2004]. However, there are very few people willing to be ostracized by the "mainstream", and to be cut off from funding and the opportunity to publish their work, as we are now seeing with the independent media.

In the current circumstances, it makes absolutely no sense for Russia to participate in any Western-oriented "global" projects and events that involve considerable and irrelevant costs for us. Therefore, it is necessary to develop the domestic power engineering only on the basis of national needs and conditions.

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