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Is it Possible to Stabilize the Earth Climate by Transition to Renewable Energy?

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Abstract

The evolution of the Universe proceeds through the persistent complication of the appearing objects. As the constituent objects become more complex, the intensity of their energy exchange with the environment increases, which is necessary to counteract entropic processes. Our Civilization is the most complex of the natural systems, with the development of which its energy consumption has constantly increased and will inevitably increase in the future. This will happen regardless of the sources of energy, be it fossil hydrocarbons, thermonuclear energy, or solar radiation, which is the only primary source of all renewable energy. The use of the latter on a global scale will reduce the Earth's albedo. Maintaining the thermal balance of the Earth by increasing the emission of low-potential IR radiation into space will require an increase in surface temperature. Thus, the current strategy of managing climate processes by reducing greenhouse gas emissions is in principle not capable of preventing the inevitable future global warming caused by the progressive development of Civilization, but will require enormous funds, energy, natural resources and intellectual potential. Until more realistic ideas about the ways of development of Civilization and the corresponding strategic decisions are put forward, the most rational tactic of our relationship with the environment is not to stave off inevitable changes, but to prepare for them.

1. Introduction

One of the most important problems faced by the world community at the end of the last century is the rapid increase in the average temperature of the Earth's surface. Of particular concern is the fact that the rate of temperature change is significantly higher than the rate of change observed in the pre-industrial era. According to Intergovernmental Panel on Climate Change (IPCC), by 2017 this increase has reached 1 °C compared to the pre-industrial period and continues to grow at a rate of ~0.2 °C per decade [1].

The temperature change itself is not in doubt, although the discussion about its causes continues, and there are still different points of view on its reasons. Despite solid evidence on the natural causes of the observed climate changes [2], the prevailing view on the reasons for the increase in the average temperature of the Earth's surface, reflected in the IPCC materials, is the anthropogenic impact on the composition of the atmosphere, largely through a rapid increase in the concentration of greenhouse gases, primarily CO_2, which in 2019 reached almost 410 ppm compared to 296 ppm in 1900 [3].

The critical value of temperature rise which, if exceeded, will lead to irreversible changes in the ice cover of the planet, global sea level and the pattern of the circulation flows in the atmosphere and ocean was estimated to be about 2 °C [4]. The international community's response to the current situation in an attempt to prevent the temperature rise to the critical value was the adoption of the Paris Climate Agreement by representatives of 196 countries on December 12, 2015. The purpose of the Agreement, which entered into force on November 4, 2016, is to develop and implement a strategy to reduce greenhouse gas emissions,

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primarily CO_2. Since the main source of anthropogenic CO_2 emissions into the atmosphere (more than 75%) is energy production, which from the middle of the XIX century to the present time, is more than 80% based on fossil hydrocarbons, the main goal of the effort to implement the Paris Agreement is to reduce the share of hydrocarbons in the global energy balance, mainly due to the transition to renewable energy sources.

The current situation involves a complex set of ethical, political, scientific and technical problems. On the one hand, the ever-increasing need for energy to improve the standard of living of the population of the developing countries: almost half of the world's population – 46% or 3.4 billion people – is still struggling to meet basic needs. A billion people still do not have access to electricity, and the difference in energy consumption per capita in the richest and poorest countries reaches almost two orders of magnitude [5]. Without reducing the difference in living standards, and therefore, in the energy consumption that determines this difference [9], it is difficult to expect a stabilization of the economic and political situation in the world. Therefore, despite a sharp slowdown in energy consumption growth and even stabilization of energy consumption in developed countries, a further increase of about 50% in global energy consumption is projected by 2030 compared to the beginning of the century, primarily at the expense of developing countries [6]. On the other hand, there is a very real prospect of reducing the share of hydrocarbons in the global energy balance due to their limited reserves in the Earth's crust, regardless of the possibility of replacing them with renewable energy.

However, as discussed below, the most serious objection to the proposed measures for climate stabilization is that the progressive development of Civilization is impossible without a constant increase in the energy consumed, and, consequently, its dissipation into the environment and, as a result, an increase in the temperature of the Earth's surface, regardless of the type of energy sources.

2. Problem

The main direction of finding solutions to the existing complex of climate and energy problems remains the improvement of global dynamics models [7]. However, models of global dynamics, providing forecasts based on long-term extrapolation of existing trends far beyond their real forecast horizon, give at best tactical recommendations. Since they are based on modern realities and trends, they do not provide an answer to fundamental strategic questions concerning the future trends of our Civilization, developing in the limited conditions of the planet Earth, which evolve with time. What is the real forecast horizon of these models? Are the proposed tactical solutions strategically optimal? Is it possible in principle to prevent temperature rise and climate change by abandoning hydrocarbon fuels? Is the attempt to preserve the existing climate conditions strategically optimal, and is it even feasible? We will try to consider these issues relying on the most general ideas about the trends of development of our Civilization and its energy needs.

Before proceeding with further analysis, it is necessary to say a few words about the social basis of the practically unanimous popular support in the developed countries for the arduous efforts of the world community aimed at stabilizing the climate and preserving existing conditions on the Earth. The comfortable living conditions provided to the population of the developed countries by modern industrial society, and the absence of the need for a constant struggle for survival, which two centuries ago was an indispensable condition for the existence of most of their population, gave rise to ideas about the ease of obtaining the benefits available today. Insufficient natural science education and understanding of the basic laws of conservation of matter and energy gave rise to the illusion of limitless possibilities of scientific and technological progress in mass consciousness. Populist demands of environmental protection movements for an increasingly high quality of life, clean air and water, complete disposal of industrial and household waste, and a ban on "genetically modified" products are constantly being raised. However, politicians do not dare to explain to the population that the full implementation of these demands will require a progressive increase in the consumption of natural resources and energy, that is, a substantial increase in the anthropogenic pressure on the environment. For example, widely discussed projects to reduce the carbon footprint of energy by sequestration of the produced CO_2 and/or switching to hydrogen fuel will inevitably lead not only to a sharp increase in the cost of energy, but also to an increase in the consumption of primary natural resources for its production (see Section 3.1).

The question of how and where the resources they consume come from, and what means are

needed for this, is of little concern to the layman, who believes that the state is obliged to provide this not only for him, but also for his distant descendants, that is, "to take care of the fate of future generations". Unfortunately, the understanding that all the comforts around us have to be paid for by the same natural resources, that is, the destruction of natural landscapes, reduction of biodiversity, pollution of air and water has not yet entered the mass consciousness. Few people realize that the demands of the "natural environment" for eternal times can turn into a return to the living conditions of our distant ancestors. It seems that, without large-scale cataclysms, the restructuring of the stereotypes of the formed global "consumer society" is hardly possible.

3. Suggested solutions

To analyze the real situation we will consider several of the most popular approaches to the reduction of CO_2 emissions: the reality of the global capture and sequestration of CO_2 from the products of hydrocarbons combustion, the energy costs of the global transition to hydrogen energy and the ability to meet current and future global energy needs through using renewable sources.

3.1. Low-carbon solution

The decarbonization of energy production, that is, reducing the share of hydrocarbons in the global energy balance, is now considered as a priority measure to reduce the concentration of greenhouse gases in the atmosphere, and therefore, to stabilize the Earth's climate. The long-term consequences of a decrease in the share of hydrocarbons in the energy balance are predicted employing large system dynamics models such as the World Energy Model (WEM) World3 and its improved versions [7]. The high level of uncertainty of the basic parameters of these models and too long time intervals of analysis exceeding a century, i.e., beyond the real horizon of modern technological forecasting, make their predictions too abstract. Note that all models predict the continuation of high rates of development of the world economy until 2100, that is, the growth of global energy consumption, although with a certain decrease in its consumption per unit of GDP. Note, however, that, over such a long period, the decarbonization of the world's energy production can occur naturally due to the depletion of hydrocarbon resources. Although it is estimated that only 50% of the available fossil hydrocarbon resources can be used to keep the temperature rise within 2 °C [8], the accuracy of this forecast is so low that the very fact that it is possible to reach the temperature threshold even at the expense of the full use of hydrocarbon resources can hardly be considered proven.

On the other hand, sociologists note [9] that so far all measures aimed at decarbonizing energy production objectively lead to an increase in energy consumption. They attribute this effect mainly to the increased availability of energy resources, but also point to additional energy expenditures on the implementation of low-carbon projects [9]. In fact, all decarbonization processes require significant additional energy, which are mainly covered by increasing the consumption of the same hydrocarbon resources [10]. For example, thermodynamic estimates of the minimum additional energy spent on CO_2 extraction for various technologies of burning coal, natural gas, and petroleum fuel range from 10 to 20% [11]. According to experts of the Energy Center of the Moscow School of Management SKOLKOVO, the extraction and sequestration of CO_2 increases the capital costs of hydrogen production by steam reforming by 87% and operating costs, by 33%. At the same time, the cost of the hydrogen produced will increase by almost one and half times, whereas the price of CO_2 utilization will be up to 70 euro per ton [12]. Accordingly, due to the additional energy consumption for the extraction and sequestration of produced CO_2, the total consumption and the rate of depletion of primary energy resources, in this case natural gas, will increase significantly.

As for the currently widely discussed possibility of transition to hydrogen energy, it is necessary to recall that there are no significant sources of hydrogen in the Earth's crust. Hydrogen is a secondary energy source that can only be produced by using primary energy sources. Its industrial consumption, which has tripled since 1975, continues to grow rapidly almost entirely due to the use of fossil sources. This consumes approximately 6% of the world's natural gas production and 2% of the world's coal production, which leads to the emission of about 830 million tons of CO_2 per year [13].

The most efficient modern technology for producing hydrogen, which accounts for about 80% of its production, is Steam Reforming of Methane (SRM). Taking into account the subsequent steam conversion of the resulting carbon monoxide,

4 hydrogen molecules can be produced from one methane molecule. From the point of view of the total energy content, this is approximately equivalent to the energy of the initial methane molecule (Lower Heating Value (LHV) of hydrogen is 10.800 kJ/m^3, and that of methane is 35.840 kJ/m^3). Note, however, that, due to significant additional energy consumption, in this case of the same natural gas, for heating raw materials and producing a large volume of steam, the real consumption of natural gas in this complex capital-intensive technology is about twice as high. Thus, with the volume of global hydrogen production in 2019 of ~75 million tons (mainly for the production of ammonia and petrochemicals) the consumption of natural gas for its production was approximately 205 billion m^3.

Since the production of hydrogen by steam reforming is accompanied by the formation of CO_2, the volume of which reaches half the volume of hydrogen produced, such hydrogen is considered "grey" according to the accepted "ecological" gradation, that is, environmentally unattractive; therefore, this method does not solve the task of reducing CO_2 emissions into the atmosphere. To make hydrogen thus produced "environmentally" cleaner and to increase its attractiveness in terms of solving environmental and climate problems, it is necessary to sequester both the CO_2 contained in the flue gases formed during the heating of the reagents and production of steam, and the CO_2 formed during the steam conversion of carbon monoxide, that is, to supplement the SRM process with Carbon Capture and Storage (CCS) technologies. The hydrogen produced in such a combined process can already be qualified as "blue". However, this will require additional energy consumption and, consequently, additional consumption of natural gas. In other words, beside considerable capital expenditures and complex processing, the production of "blue" hydrogen based on SRM+CCS technologies will require more than doubling the total consumption of natural gas and the rate of depletion of its resources.

In principle, "blue" hydrogen can be produced by pyrolysis of natural gas, the products of which are hydrogen and carbon [14]. Such processes are now used to a small extent for soot production. A thermodynamic analysis of the process shows that pyrolysis requires an additional consumption of about 20% of the resulting hydrogen. To estimate the additional expenditures of natural gas to produce such hydrogen, it is necessary to assume a more realistic process efficiency, about 50%. Thus, for the pyrolysis of 1 m^3 of CH_4, 2 m^3 of CH_4 should be spent, with a total heating value of ~71.700 kJ. As a result, 2 m^3 of hydrogen, with a total heating value of 21.600 kJ are produced. The total energy efficiency of this process will be only 30%. In order to generate the same amount of energy that the use of natural gas provides, at the expense of hydrogen produced by methane pyrolysis, it will be necessary to increase global methane consumption by about threefold, from the current 4 trillion m^3/year to 12 trillion m^3/year. This is roughly equivalent to the combined global consumption of gas, oil and coal. To reach this level of gas production, the world economy will need many years and huge investments, with the gas resources being depleted 3 times faster. In addition, approximately 9 billion tons of fine carbon, which is unnecessary in such quantities, will be generated annually (the world consumption of soot is only about 40 million tons/year). Thus, for the resulting hydrogen to be considered "blue", this fine carbon should not be used as a fuel, and there will be an additional problem of its disposal.

As for the global industrial use of alternative energy sources, the technological unreality of this was discussed in detail in [10]. The low density of energy flow of these sources requires huge areas with the inevitable violation of natural ecological cycles in them. They require a huge consumption of water, rare metals and structural materials in the volume that exceeds their content in the earth's crust. And the subsequent dispersion of these materials in the environment after the end of the life cycle can lead to global environmental problems. Due to the inconstancy of energy flow, their industrial use is impossible without a huge investment and high losses associated with the operation of energy networks, which make up a significant share of the transmitted energy, and without energy storage systems, which are virtually absent for industrial capacities.

The production of "green" hydrogen by electrolysis based on renewable energy remains the most expensive technology for its production. The cost of such hydrogen is three times higher than the cost of hydrogen produced by methane steam reforming; therefore, despite all efforts, the share of "green" hydrogen in its global production is less than 1%. So far, there are no large-scale projects in the world to produce hydrogen using renewable energy. The most realistic plans for obtaining "carbon-free" hydrogen are currently offered only by

nuclear power with an electrolysis efficiency of about 40%. Note, however, that the share of nuclear power in the global energy balance is only slightly higher than 4% [5] and because of limited resource, it cannot significantly exceed this value. Therefore, this source cannot meet the global demand for hydrogen.

3.2. Renewable energy solution

In view of the problems associated with CO_2 sequestration and the significant entailing costs [11, 12], the principal role in the decarbonization of energy and the stabilization of climate processes in all scenarios of global dynamics is assigned to renewable energy. The impressive growth rates of the world's renewable energy capacities, the rapid technological progress in the creation of renewable energy sources and the quite noticeable decline in the cost of energy produced by them in recent years cause understandable enthusiasm of their proponents. Global energy investment in 2019 amounted to about $1.9 trillion, $311 billion of which (approximately 16.5%) was made up of investments in renewable energy production, i.e., almost 2.4 times more than investments ($130 billion) in fossil fuel-based energy production [15].

The growing role of renewable sources is confirmed by the fact that in 2020 their share in global electricity production reached 27% [13]. But, firstly, electricity accounts for only about 20% of primary energy production, and secondly, more than half of renewable electricity production (approximately 57%) is accounted for by hydropower [5], whose capabilities are limited by natural conditions and are already close to the limit [10]. Therefore, the widespread belief in the ability of renewable energy to become the main source of energy for the growing world economy, not supported by serious energy, economic, and environmental analysis, raises the most serious questions [10, 16–18].

First of all, when analyzing the prospects of various types of renewable energy sources, it is necessary to clearly realize that all of them, with the exception of extremely insignificant in their potential geothermal energy, have their primary source falling on the Earth solar radiation. Solar energy is the only real primary source of renewable energy on the Earth. All the others: hydropower, tidal, wind and biomass energy are its derivatives. Therefore, to assess the potential of renewable energy in general, it is enough to limit ourselves to an analysis of solar energy. The solar energy resource is huge: the uppermost Earth's atmosphere is irradiated by a solar energy flux of ~$5.6 \cdot 10^{24}$ Joules per year, i.e., 5,000 times the current energy consumption of mankind. Approximately 35% of this energy is reflected back into space by the Earth's atmosphere, whereas the remaining energy is spent on heating the Earth's surface, the evaporation-sedimentary cycle in the atmosphere, the formation of waves in the seas and oceans, air and ocean currents and wind, as well as photosynthesis. In all these processes, the high-potential energy of solar radiation of the UV and visible regions are converted into low-potential energy of infrared radiation emitted back into space by the heated surface of the Earth, whose average temperature is about 20 °C.

Even 40 years ago, a fundamental insufficiency of solar energy for industrial use was clearly understood: because of its low density of energy fluxes [19], huge areas are required to collect solar radiation for industrial purposes. According to some estimates, even for the engineering equipment of such facilities, there may simply not be enough raw materials in the Earth's crust to produce not only rare elements used in the manufacture of solar panels, but even ordinary structural materials. Serious environmental problems are also inevitable due to the dispersion of various elements in the biosphere during the production and subsequent disposal of panels. Unfortunately, the problem of the availability of raw materials for the production of renewable sources themselves [20] and the environmental problems associated with their production, operation, and disposal [10] has not yet been given due attention.

A serious problem of all types of renewable energy is the variability of the energy produced by them, which requires the peak capacity of installations several times higher than the nominal average, and the cost of energy storage systems commensurate with the cost of its generation [10]. It was estimated that, in order to meet certain energy demands only from renewable sources, their installed capacity should be 4–7 times higher than the installed capacity of traditional sources that solve exactly the same task [18, 21]. Another serious problem of solar energy is its low energy efficiency EROEI (the ratio of Energy Return on Energy Invested). Estimates of this value are rather uncertain due to differences in the methodology of accounting for different factors, and therefore, they vary widely from 0.8 [22] to 8 [23]. Taking into account the necessary auxiliary systems, the real value is probably not higher than 6, which is almost

on the verge of the minimum acceptable value for industrial energy and maintaining high economic activity EROEI=3–4 [18].

Taking into account the projected growth in energy consumption to meet at least the minimum needs of almost 4 billion inhabitants of the most backward countries, these estimates do not look very optimistic. Therefore, in contrast to the optimistic forecasts of enthusiasts about the imminent and almost complete transition to renewable sources, serious forecasts predict their share in global energy at a level of no more than a few percent in the foreseeable period [6].

4. Discussion

Energy is not just the lifeblood of modern society and a central issue of today's global political economy [24]. Energy is a fundamental concept in our Universe, the driving force of all processes occurring in it. Without understanding its global role, it is impossible to analyze neither the evolution of our Universe nor the processes of evolution of the Biosphere, an integral part of which is our Civilization. Therefore, the main question that needs to be answered is whether our Civilization can develop progressively without a constant increase in energy consumption? The second related question: if we assume that it is possible to implement the Paris Climate Agreement and completely exclude hydrocarbons from the world energy balance, switching exclusively to renewable energy, will this stop the Earth's climate change?

4.1. Can reducing the concentration of greenhouse gases stop the increase in the temperature of the Earth's surface?

First of all, it is necessary to understand whether the increase in the concentration of greenhouse gases in the atmosphere is the only and eliminable cause of the temperature rise on the planet on which Civilization originated and develops. Is it possible, in principle, to stabilize the temperature of the Earth if the existing Civilization on it gives up carbon energy sources?

According to the ideas formulated in the first half of the last century by V. Vernadsky, life is not a random phenomenon on the Earth's surface, its appearance on our planet is a natural result of the evolution of our Universe [25–27]. Indeed, during the period of its existence accessible to our analysis, there has been a constant complication of the forms of matter. Elementary particles were followed by the appearance of atoms and molecules, then chemical compounds, biological objects, complex forms of life, intelligence and, finally, Civilization, which, apparently, can also be considered a natural stage in the evolution of the Biosphere, and therefore the Universe. At all stages, the complexity of systems was accompanied by an increase in the intensity of their energy exchange with the environment, which is necessary to counteract entropy processes. Therefore, an increase in the intensity of energy flows within complex systems and the intensity of their energy exchange with the external environment as they become more complex can be considered a necessary condition for progressive evolution. This is confirmed by the surrounding Biosphere and the Civilization that has emerged within it. Therefore, it is necessary to recognize that the progressive development of Civilization is impossible without a constant increase in the intensity of the energy flows caused by it, that is, the intensity of its energy consumption and, accordingly, the intensity of the dissipation of this energy into the environment.

Thus, even if it is possible to stabilize the population of the Earth and not consider its inevitable expansion into space in the future, a constant increase in energy consumption is a necessary precondition for the development of Civilization. Any attempt to artificially limit energy consumption by curbing the pace of technological development (which does not contradict its more rational use) will inevitably lead to a halt in the development of society, stagnation and subsequent degradation. In the history of Civilization, there were many examples of this, including the fate of the so-called "primitive communities" that still exist in remote corners of the planet, "perfectly fit" into the surrounding environment. In fact, they implemented the scenario of the Concept of Sustainable Development in their specific conditions, "perfectly" fitting into their environment and achieving "complete harmony" with Nature, paying for it, however, with a halt in development and even degradation. However, this is hardly the future that Humanity is striving for.

There is no doubt that an attempt to implement such a scenario on a global scale will lead to similar consequences. Humanity has no choice: either to continue progressive development (and, accordingly, increase the consumption of energy and other resources and their dispersion into the environment) or to "preserve" our relationship with the environment and to "fit" into it with the inevitable

subsequent degradation and primitivization of the society. Attempts to find an "intermediate trajectory" with a huge number of connections that provide a relative (not absolute!) stability of the Biosphere, which continues to develop and therefore change, and even more presumptuously rely on the ability to control such a complex system in "manual mode" is absolutely groundless.

Thus, the first and fundamental conclusion that must be drawn from an analysis of the most general trends of the evolution of our Universe is that the energy consumption of our Civilization will constantly grow, and therefore, its dissipation into the environment will grow. This should occur regardless of the type of energy source used, be it hydrocarbon fuels, thermonuclear energy, the most likely energy source of the future [28], biofuels, or solar radiation [10, 29].

The second fundamental conclusion, which follows directly from the previous one, is that the average temperature of the Earth's surface will also inevitably rise. For example, the global use of solar radiation, as alternative energy enthusiasts plan, is equivalent to the absorption of an appropriate amount of solar radiation by the surface of the planet, that is, a change in its albedo. According to the Stefan–Boltzmann law, the establishment of a new thermal balance by dissipating this additional incoming energy into space in the form of infrared radiation of the heated surface of the planet will automatically lead to an increase in its average temperature. And while the energy consumption of Civilization increases, that is, as long as its development continues, the temperature of the Earth's surface (in accordance with the Stefan–Boltzmann law) will constantly increase, regardless of any efforts to stabilize it. Even a complete refusal to use hydrocarbon fuels and the subsequent reduction of the concentrations of greenhouse gases in the atmosphere to the preindustrial level will not be able to stop the increase in surface temperature caused by the growing energy consumption of Civilization [29].

This conclusion makes it meaningless to set the preservation of the planet's climate as a strategic task of Civilization, and requires the formulation of more realistic goals. Note also that the idea of the possibility of a long-term and comfortable existence of the world's population in the currently existing climatic conditions due to the transition to renewable energy is also illusory and leads to a loss of time instead of solving genuinely important strategic problems.

4.2. Controlled development or self-development?

The challenges facing Civilization require a system response. The authors of [7] believe that more advanced models of world dynamics (World Energy Models) and their continuous improvement on the basis of scientific monitoring and analysis of information flows will allow us to find a way out of this situation. At the same time, the organization of strategic risk management, forecast and prevention of crisis phenomena should become a super-task for science, since they can only be compensated by a targeted intervention in the social organization of society. These ideas reflect the ideas of the Concept of Sustainable Development about the need to forecast and prevent crisis phenomena and strategic risk management, which, according to its developers, can ensure crisis-free development.

Indeed, experience shows that the costs of forecasting and preparing for natural emergencies are about 15 times lower than the damage prevented. However, it is still unclear whether the idea of managed development is even viable. One of the most prominent economists of our time, Friedrich Hayek, considered spontaneous evolution as a necessary condition for progress and the opinion that we can do more than we actually do as the main mistake. He believes that the market mechanism makes it possible to use such a volume of information that is not available to any governing body. Instead of specific goals imposed from above, more abstract norms of behavior should be adopted. It is precisely because of this that the possibilities for the peaceful coexistence of people have been expanded beyond the initial small groups because in doing so everyone has been able to benefit from the knowledge and skills of other people acting with completely different goals of their own [30].

Hayek emphasized that unified values and goals are the main obstacle to achieving any goals. The meaning of the market is that all people use their own knowledge to achieve their own goals, obeying the rules of the game, which are the norms of human behavior developed by society. Therefore, he believes that our social institutions mature as part of an unconscious process of structural self-organization. Morality is not a creation of intelligence, it forms a separate tradition "between instinct and intelligence." The significance of this tradition is that it provides us with a mechanism for adapting to problems and circumstances that are inaccessible to reasoning. Our moral traditions, like many

other aspects of culture, developed simultaneously with our reason, but not as a product of it. Hayek believed [30], and it is difficult to disagree with this, that our moral traditions exceed our intellectual abilities, on which rational management of our behavior can be based.

In addition to the restriction on the constant growth of energy consumption and basic resources, which is incompatible with sustainable development, another tacit assumption of global dynamics models is that the basic behavioral patterns of the world's population will remain unchanged in the future. Although the pace of scientific and technological progress in the field of genetics, bioengineering, and artificial intelligence is so high that drastic changes are not only inevitable, but also unlikely to take long to occur.

A realistic approach to the problem of sustainable progressive development of Civilization in the inevitably changing world should not set as its task the preservation of the environment familiar to us, and even more so, should not be reduced to this problem. Its goal should be to search for optimal ways of mutual evolution (coevolution) of Civilization and the world in which it exists (in the first approximation, the Biosphere), as Vernadsky was one of the first to point out [25–27]. Unfortunately, the current discussion of the strategy of interaction between Nature and Civilization is practically reduced to the need to mitigate the impact of Humanity on the environment, which is not a solution to the problem, but only an attempt to delay the onset of the crisis.

The concept of sustainable development can be considered as a natural spontaneous reaction to the explosive expansion of Humanity into the Biosphere because of the rapid scientific and technological progress of the XIX and XX centuries and the resulting mentality of "conquerors of Nature". As we approached the natural limit of the period of active exploration of the planet and its resources, such a "nature protection" reaction would inevitably arise. However, it is already necessary to move from such a primitive reaction, ensuing from the Concept of Sustainable Development, to the development of a fundamentally new strategy for the development of Civilization in new technological and environmental conditions. Such a strategy must proceed from the inevitability of mutual evolution of Civilization and Nature, including the planet's climate, and to rely not only on current but also on projected achievements of Humanity, including the possibility of new forms of social organization and a new type of its subjects, even if it sounds fantastic now.

5. Conclusions

Based on the above analysis, we can draw some conclusions that should be taken into account when formulating a strategy for the interaction of Civilization with the environment and analyzing possible ways of its further development. According to the observations of the known Universe, its evolution proceeds by the constant complication of the objects arising in it. As the objects become more complex, the intensity of energy fluxes circulating in them and the intensity of their energy exchange with the environment, which is necessary for the counteraction to entropic processes, increases. This is true for inorganic systems, for all forms of life and all ecosystems, the Biosphere as a whole and the Civilization that has emerged within it. Our Civilization is the most complex natural system known to us, and we have no reason to believe that there are any fundamental differences in the laws of its development from other natural objects. Therefore, with the development and complexity of Civilization, its energy consumption has constantly increased, and inevitably and naturally will grow in the future. This will happen regardless of the sources of energy used by Civilization, whether it is fossil hydrocarbons, thermonuclear energy, or solar radiation, with the increase in energy consumption leading to an increase in its dissipation into the environment. The use of solar radiation on a global scale, which is the only primary source of all renewable energy, will increase its absorption by the Earth's surface, that is, reduce the albedo of the Earth's surface. This will be accompanied by an Earth's surface temperature rise and, consequently, by an increase in the scattering of low-potential IR radiation into space.

Thus, the current tactic of managing climate processes by reducing greenhouse gas emissions is in principle not capable of preventing the inevitable future global warming caused by the progressive development of Civilization, but will require the expenditure of enormous funds, energy, natural resources, and intellectual potential. Therefore, until more realistic ideas about the ways of development of Civilization and the corresponding strategic decisions are developed, the most rational tactic in our relationship with the environment is not to fight the inevitable changes, but to prepare for them.

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