Thermal Pollution and Anthropogenic Carbon Dioxide Emissions as Factors of Global Warming

Valery V. Snakin	Darya V. Gavrikova
Institute of Fundamental Problems of Biology, Russian Academy of Sciences	Institute of Fundamental Problems of Biology, Russian Academy of Sciences
Lomonosov Moscow State University, Russia	Lomonosov Moscow State University, Russia
Dr. Sci (Biol.), Professor ORCID: 0000-0002-9389-752	laboratory ass, ORCID: 0009-0000-6236-1889

Abstract – This study analyzes data from the literature and presents our original quantitative assessments of the anthropogenic contribution to global warming. The contribution of water vapor – the principle greenhouse gas – to warming is practically independent of human activity. The share of anthropogenic carbon dioxide and methane emissions in the overall greenhouse effect is estimated to be no more than 1–3%. Furthermore, global warming itself is the primary driver of the observed increase in atmospheric greenhouse gas concentrations, including water vapor, carbon dioxide, and methane. The main anthropogenic contribution to contemporary climate warming is thermal pollution, which occurs at virtually all stages of industrial and domestic human activity. However, for today, thermal pollution does not make a reliably detectable contribution to global warming, manifesting significantly only at the regional level. The global warming observed in recent decades primarily represents another peak in the cyclical dynamics of the Earth's climate system. Both positive and negative consequences of global warming are considered. It is noted that carbon-free energy cannot be an effective instrument of combating warming because, firstly, the increase in atmospheric carbon dioxide is predominantly driven by warming itself, and secondly, warming stimulates photosynthesis, the principal biospheric process for creating organic matter.

***Keywords**: anthropogenic factor, greenhouse effect, carbon dioxide, methane, water vapor in the atmosphere, specific energy consumption, bioproduction process, carbon-free energy, climatic optimum.*

I. INTRODUCTION

The issue of global climate change is one of the most widely discussed environmental topics. The trend of global warming observed in recent decades has raised concerns within the international community regarding potential adverse consequences. These include, notably, the aridization of regions and, as a result, a threat to agriculture, the melting of glaciers and permafrost, a rise in the mean sea level, and other phenomena of a potentially catastrophic nature. However, to what extent are these concerns justified? Is humanity capable of preventing a negative trajectory in natural processes? Or are human actions exacerbating the environmental situation?

It is widely recognized that climatic parameters have constantly and cyclically changed throughout Earth's long history, in the absence of any influence from human activity. Data from ice core studies at the Russian inland Vostok station in Antarctica [1] clearly demonstrate interconnected variations in atmospheric dust content, temperature, atmospheric carbon dioxide and methane concentrations, insolation, and sea level over the past 420,000 years. However, it remains unclear which of these parameters are causes of climate change and which are consequences. Modern changes in climatic parameters fall within the range of fluctuations observed over this period. It should be noted, however, that with a much higher frequency of measurements, contemporary data on climate dynamics exhibit sharper fluctuations compared to the more smoothed data obtained from analyses of past eras.

The study of climate history shows that the primary driver of the cyclical pattern of periodic cold (glacial) and warm periods, as follows from [2 et al.], is the variation in Earth's orbital inclination. From a historical perspective, the current period (the Holocene) represents an interglacial period, which began approximately twelve thousand years ago, marking a transition from a cooling phase to warming. The Holocene Climatic Optimum (Atlantic period), with temperatures 1–3°C higher than present-day ones, lasted roughly from nine to five thousand years ago [3, 4 et al.]. Thus, from a long-term forecasting viewpoint, our era represents a progression towards the next glacial period, i.e., cooling. However, this overarching trend is superimposed by oscillations in climatic conditions, resulting in both cooling and warming periods within the general trajectory.

Consequently, many researchers consider natural factors—related to the dynamics of insolation and geothermal processes, which are undoubtedly still far more powerful than human activity—to be the primary cause of the warming observed in the current period [1, 5–9 et al.]. V.I. Vernadsky also wrote about the natural causes of observed climatic changes: "We live in an interglacial period – the warming is still continuing – but man has adapted so well to these conditions that he does not notice the glacial period..." [10, p. 34].

Nevertheless, considering the ever-increasing human impact on natural processes, the majority of researchers lean towards the opinion that humans, specifically their contribution to the greenhouse effect, are the main cause of the observed warming. For instance, unfounded claims are often found in the literature, such as "anthropogenically forced warming in the central-western Tibetan Plateau from 1980 to 2018 exceeded 1.2 °C, with the anthropogenic contribution reaching ~60% of the observed warming (1.8–2.0 °C)" [11]. Although the "culpability" of carbon dioxide and methane emissions in global climate warming has not yet been scientifically proven, some researchers (e.g., [12]) already accuse specific states and population groups of having a disproportionately large influence on warming. Moreover, as [13] write, ecologists often use patterns observed in spatial climate gradients to predict the consequences of climate change (space-for-time substitution); the authors argue that this can be misleading not only in terms of scale but also regarding the nature and direction of the impacts.

This study attempts to *quantify the human contribution to global climate warming*, drawing upon both original and published data. Primary attention is focused on the *anthropogenic contribution to the greenhouse effect*, as well as the most obvious human contribution to warming: *thermal pollution*. Essentially, these two factors are closely interconnected, as the emission of carbon dioxide very often occurs concurrently with heat release. However, thermal pollution represents a more universal warming factor, as it also occurs in carbon-free processes (for example, in the expanding nuclear power industry).

At the same time, we largely do not consider the anthropogenic impact on *changes in the Earth's surface reflectivity* (albedo) and *atmospheric transparency*, nor the influence of these factors on climate. On one hand, a decrease in albedo due to land plowing, asphalt road surfacing, deforestation, contamination of snow surfaces with dust, etc., leads to increased absorption of solar heat by the Earth. On the other hand, anthropogenic dust loading of the atmosphere reduces the influx of solar energy. Therefore, the contribution of these factors is multidirectional, contradictory, and its assessment remains limited by the short observation period. For instance, the authors of [14] found no correlation between changes in terrestrial albedo and insolation indicators.

II. CONTRIBUTION OF ANTHROPOGENIC GREENHOUSE GAS EMISSIONS

For a variety of reasons – including the importance of climate for human development, a sense of human responsibility for one's activities, environmental alarmism, and political-economic considerations – the majority of international environmental and socio-political documents, notably the Paris Climate Agreement signed by most countries of the world, cite the anthropogenic contribution to the greenhouse effect as the primary cause of contemporary global warming. This premise forms the basis for the efforts undertaken by the international community towards so-called decarbonization of the economy, which involves discriminating against industries whose operation results in the emission of carbon dioxide into the atmosphere.

At the core of the modern interpretation of this hypothesis lies climate computer modeling conducted by Syukuro Manabe (Japan, USA), which was recognized with the Nobel Prize in Physics (jointly with Klaus Hasselmann and Giorgio Parisi, 2021) [15], along with two unproven assumptions: 1) the main contribution to modern warming is made by the greenhouse effect due to so-called greenhouse gases, primarily carbon dioxide; and 2) the observed increase in atmospheric carbon dioxide concentration is caused by an anthropogenic factor – humanity's use of carbon-containing energy sources.

As already noted above, numerous facts contradict the hypothesis of an anthropogenic enhancement of the greenhouse effect.

Our analysis [7] of data from various authors, the results of which are presented in Table 1, shows that the maximum possible contribution of anthropogenic carbon dioxide and methane emissions to the increase in the greenhouse effect is less than 1% and 3%, respectively. Thus, even if the greenhouse effect is significant in modern climate warming, the anthropogenic contribution from carbon dioxide emissions, as well as methane, is not the determining factor in this process.

Table 1. Approximate estimate of the possible anthropogenic contribution to the greenhouse effect [7]

Factor	Water vapor (H_2O)	Carbon dioxide (CO_2)	Methane (CH_4)
Approximate atmospheric content	0,5–4 %	0,04–0,05 %	0,00017 %
Assessment of the contribution to the greenhouse effect	40–90 %	10–20 %	4–9 %
Anthropogenic proportion of atmospheric concentration growth	~0	~5 %	25–33 %
Anthropogenic contribution to the greenhouse effect	~0	<1 %	<3 %

As is well known, among all greenhouse gases, **water vapor** makes the largest contribution to the greenhouse effect (up to 90%). Its atmospheric concentration is directly dependent on atmospheric temperature and, in this sense, is independent of human activity.

The second most significant greenhouse gas is **carbon dioxide** (CO_2), whose contribution to the greenhouse effect is estimated at 10–20%. It is known that the World Ocean is the primary reservoir of carbon dioxide in the biosphere (according to available estimates, approximately 140 trillion tons are dissolved in ocean waters, which is 60 times greater than the amount in the atmosphere). At the same time, the concentration of carbon dioxide and a number of other greenhouse gases in natural waters depends on temperature. As a result of changing natural processes, these gases are both absorbed by ocean waters and released into the atmosphere, significantly influencing the Earth's climate.

According to the fundamentals of physical chemistry, the solubility of carbon dioxide in water decreases substantially with increasing temperature. Therefore, during climate warming (including warming of oceanic waters, whose rate of warming, according to [16], is faster than that of the atmosphere), a vast amount of carbon dioxide must be released into the atmosphere. A basic calculation of the physicochemical equilibrium in the World Ocean–atmosphere system shows that when the temperature increases by 2°C (e.g., from 14°C to 16°C), the solubility of carbon dioxide in water decreases by more than 6% (see physicochemical reference books, e.g., [17]). This means that *with a warming of only two degrees, an enormous quantity of carbon dioxide would be released from natural waters, capable of almost doubling its atmospheric concentration!*

This relationship is confirmed by observational data. For instance, the study by [18] notes that with rising sea surface temperatures, anomalous CO_2 outgassing is observed in subtropical and subpolar regions, particularly in the Northern Hemisphere, precisely due to the temperature increase reducing the solubility of carbon dioxide.

Consequently, the increase in atmospheric carbon dioxide concentration observed in recent decades is primarily a consequence, but not a cause, of global warming! This is further confirmed by the fact that the winter of 2025/26 was exceptionally severe across Eurasia and North America, despite total carbon dioxide emissions in 2024 having increased by 0.9% compared to the previous year, reaching 36.3 Gt CO_2 [19].

An analogous situation is observed for another greenhouse gas – methane. The current rise in its atmospheric concentration is also primarily a result of increasing temperatures. For instance, according to predictive modeling [20], total CH_4 emissions from lakes and reservoirs are projected to increase by 24–91% under IPCC climate change scenarios by 2080–2100, driven mainly by warming. As temperatures rise, greater quantities of methane are released from wetland systems and gas hydrate deposits, whose vast reserves have yet to be fully quantified. Notably, the rate of atmospheric methane increase is 2–4 times higher than that of CO_2 [21].

A potentially greater contribution of anthropogenic methane emissions to the atmosphere compared to carbon dioxide is noted (see Table 1), as available data indicate significant natural gas losses during exploration, extraction, and storage [22, 23].

III. NATURAL MECHANISMS OF RESILIENCE TO CLIMATE WARMING

Given the increase in atmospheric concentrations of the major greenhouse gases (water vapor, carbon dioxide, and methane) with rising temperatures, it might appear that warming represents an autocatalytic process (a positive feedback loop), threatening to accelerate global warming. As atmospheric temperature increases, one might expect to observe an explosive, self-amplifying rise due to the greenhouse effect. However, this does not occur. Two noticeable reasons account for this: the non-decisive role of the greenhouse effect within the climate system, and, more importantly, a well-established natural feedback mechanism: rising temperature → increasing humidity → increased cloud cover → reduced insolation → slowing of warming.

Another mechanism of biospheric resistance to warming is the absorption of atmospheric carbon dioxide through increased photosynthetic activity in both the World Ocean and terrestrial ecosystems. It has been noted that, as a result, both the duration and rate of carbon uptake have increased in recent decades, enhancing ecosystem productivity [24]. A reduction in atmospheric methane concentration is facilitated by the activation of methanotrophic microorganisms, for which methane serves as the primary energy source [22, 23].

This convincingly demonstrates that the planet's climate system possesses compensatory mechanisms that avert critical situations and, consequently, ensure the sustainable functioning of the biosphere.

At the biological level, mechanisms for adaptation to climatic changes also exist. Organisms adjust to these changes, exhibiting resistance in a shifting environment. Notably, marine diatoms – which form the base of oceanic food webs – adapt to warming through genome duplication (polyploidization) [25, 26].

Thus, over billions of years of evolution, the Earth's biosphere has developed various mechanisms for maintaining equilibrium during climatic changes, which are typically cyclical in nature.

IV. THERMAL POLLUTION

The most obvious and probably the most significant contribution humanity makes to climate warming results from direct thermal pollution of the biosphere. This occurs through the human harnessing of energy from diverse sources (fossil fuels, nuclear power, etc.) and the ultimate conversion of this energy into heat. Additional environmental heating arises even from indoor air conditioning. Consequently, atmospheric temperatures in large population centers are substantially (by 1–3°C) higher than those in surrounding areas, which are themselves subject to anthropogenic "heating" (from highways, aviation, product pipelines, heated water bodies, etc.). It is largely due to this persistent "warming" of the environment by settlements, industrial enterprises, and infrastructure that meteorological stations continually record new temperature records.

Despite the evident direct impact of anthropogenic thermal input on the planet's climate, the role of this factor in warming has yet to be quantified. For reasons that remain unclear, this obvious factor is entirely unaccounted for in the documents of the Intergovernmental Panel on Climate Change [27] and the Paris Agreement, where all efforts to combat climate warming are focused on energy decarbonization – an approach that has yet to demonstrate its effectiveness.

As early as 1962, academician M.I. Budyko noted that in the most industrially developed countries, human economic activity generates additional heat, the magnitude of which was already non-negligible compared to the radiation balance of the Earth's surface. He argued that an increase in energy production of 4 to 10% per year would lead, within no more than 100–200 years, to a situation where the amount of heat generated by humans would become comparable to the radiation balance of the entire continental surface. In such a scenario, he posited, enormous changes in climate across the entire planet would be inevitable [28].

Although some estimates suggest that anthropogenically generated heat is currently negligibly small compared to the heat received from the Sun and the Earth's interior – constituting approximately 0.005% of that amount – thermal pollution has a quite perceptible effect specifically on the temperature of the human environment.

According to available estimates, the global average impact is only +0.028 W/m^2, but over the continental United States and Western Europe, it reaches +0.39 W/m^2 and +0.68 W/m^2, respectively [29]. Nevertheless, powerful sources of anthropogenic heat emissions, given their high concentration precisely within the human environment, exert a noticeable influence on the thermal regime of that environment.

According to statistical data, from 1860 to 2015, energy consumption increased approximately 40-fold and continues to rise. All this energy, after performing useful work, is converted into heat and warms the atmosphere. An assessment of the impact of alternative (hydrogen, solar, and wind) energy on planetary thermal pollution compared to traditional carbon-based energy revealed that they sometimes lead to even greater thermal pollution and possess a number of other significant drawbacks that preclude considering alternative energy as fully "green" [7, 8].

A striking illustration of thermal pollution's impact on climate is the presence of urban heat islands (UHI) over settlements and industrial facilities, particularly pronounced over large cities. Air temperatures in the latter are typically several degrees higher than in nearby small towns. It should be noted that the ambient temperature of cities has formed under the influence of constant heating from megacities, and that the actual temperature difference between a city and its surroundings in the absence of this constant heating would be substantially greater. In reality, thermal pollution occurs along all transportation routes, both on land and in the air. Heat is released by all product pipelines (into the atmosphere, soils, and natural waters). Power plants, especially nuclear power plants, discharge colossal amounts of heated water into rivers. This significantly affects the living conditions of aquatic organisms and the structure of ecological systems in such water bodies.

Thus, the impact of powerful anthropogenic heat sources on the biosphere is quite perceptible. This is particularly evident during the winter season. Model simulations [30] have indicated that cities in the United States, the Middle East, northern Central Asia, northeastern China, as well as interior regions of South America and Africa, will face substantial warming by the end of the century, exceeding global warming by more than four degrees.

Temperature increases are recorded precisely in the air medium, which possesses the lowest heat capacity compared to the aquatic environment and soil, and therefore responds more distinctly to thermal pollution. Thermal pollution occurs precisely in that part of the biosphere where changes in surface temperature are recorded – the very data upon which conclusions about global warming are based. Per unit volume, the heat capacity of water is 2970 times greater than that of air: $C_{water}/C_{air} = 2970$. Consequently, the ocean serves as the planet's primary thermoregulator. The heat capacity of a mere 10-meter layer of water is four times greater than that of the entire atmosphere. Therefore, even small changes in the thermal state of the ocean can have a profound impact on the atmosphere.

V. ASSESSMENT OF THERMAL POLLUTION BY WORLD REGION

Since virtually all energy consumed by humanity is ultimately converted into heat, data on specific energy consumption – i.e., the total energy consumption of a country per unit area – can be taken, as a first approximation, as an estimate of thermal pollution across different territories.

To this end, we divided the total energy consumption data for 47 countries, sourced from the World Energy & Climate Statistics – Yearbook 2025[1], by the respective areas of these countries (Fig. 1). The leading positions in specific energy consumption, significantly ahead of other nations, are occupied by Taiwan, South Korea, Kuwait, Belgium, and the Netherlands. Overall, the greatest energy consumption – and consequently the largest contribution to planetary climate warming – is made by the countries of Western Europe, China, and India. According to these estimates, Australia, Algeria, Kazakhstan, Argentina, and Canada make the smallest contribution to global thermal pollution. Russia's contribution is also relatively low.

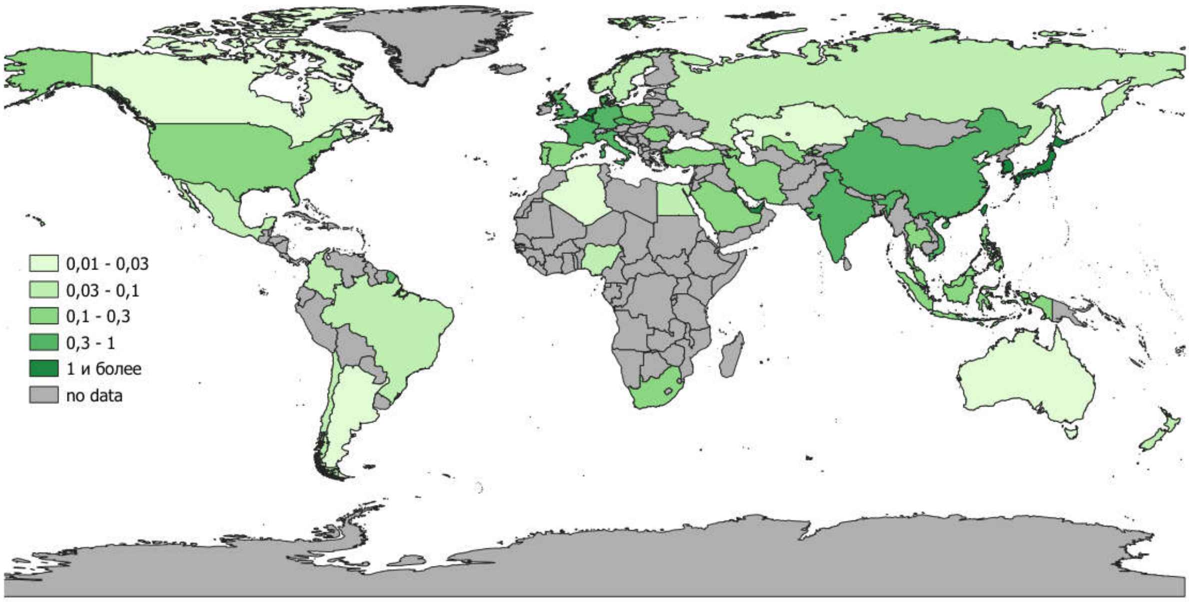

Figure 1. Specific energy consumption by countries in 2024 (megatons of equivalent fuel per 1000 km²)

A similar pattern emerged when calculating specific oil consumption by various countries (Fig. 2). Here, the leading positions were occupied by Taiwan, Kuwait, South Korea, Belgium, the Netherlands, and Japan, respectively. Among the countries with the lowest oil consumption per unit area were Kazakhstan, Australia, Uzbekistan, Algeria, and Russia.

[1] https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

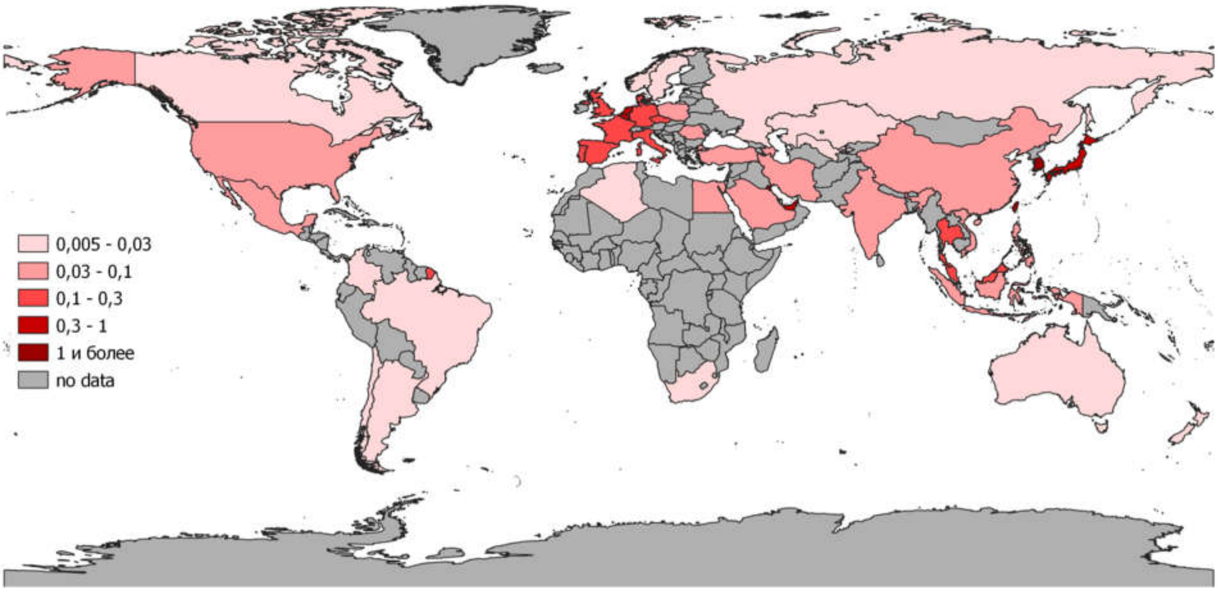

Figure 2. Specific oil consumption by countries in 2024 (million tons per 1000 km²)

It is important to note that the release of carbon dioxide during the human economic activity most often occurs simultaneously with the release of heat into the environment.

Since carbon-containing sources still account for the majority of energy production, the extent of thermal pollution can also be inferred from available estimates of atmospheric carbon dioxide emissions by different countries. This is likely why climate studies demonstrate a near-linear relationship between global warming and cumulative CO_2 emissions since the onset of industrialization [27, Fig. 6.12, p. 438].

Thus, carbon dioxide emissions can largely be considered a marker of thermal pollution. In this context, sources of thermal pollution from nuclear power plants and alternative energy sources would fall outside this consideration, but they do not yet occupy a leading position in the energy sector. The vast majority of energy is still obtained from fossil fuels, which are primarily responsible for carbon dioxide emissions.

Figure 3, utilizing data from the World Energy & Climate Statistics – Yearbook 2025[2], presents specific (per unit area) carbon dioxide emissions by country. The figure demonstrates that, according to these estimates as well, the leaders in thermal pollution are Taiwan, Kuwait, South Korea, the Netherlands, and Japan. The countries with the lowest specific CO_2 emissions include Australia, Brazil, Canada, Argentina, Kazakhstan, and Russia.

[2] https://yearbook.enerdata.net/co2/emissions-co2-data-from-fuel-combustion.html

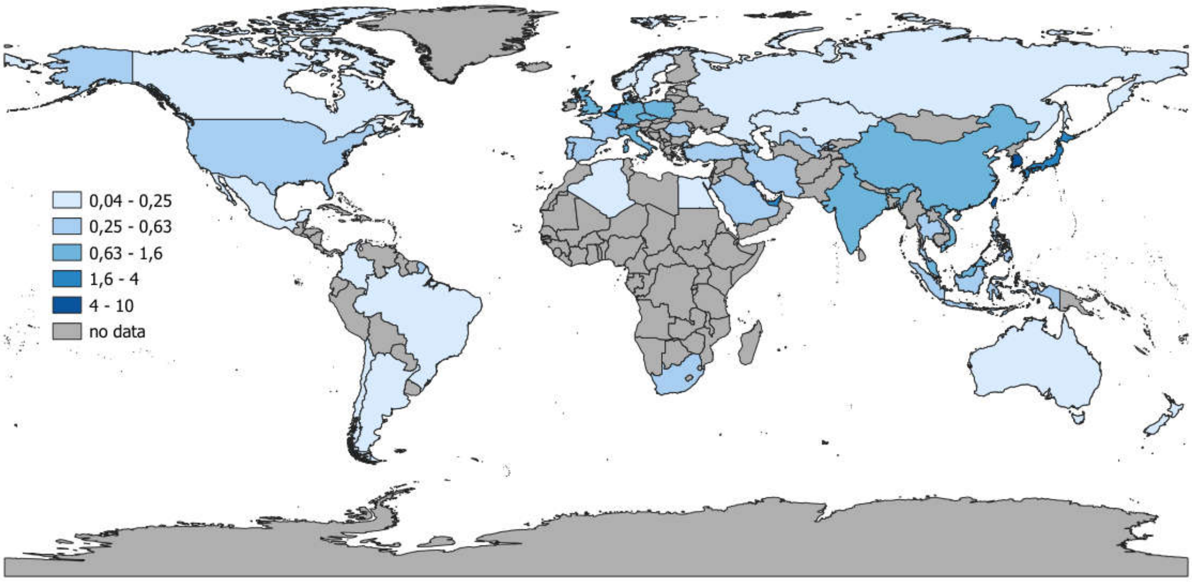

Figure 3. Specific CO_2 emissions by countries in 2024 (million tons of CO_2 equivalent per 1000 km²)

VI. ASSESSMENT OF THE RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND GLOBAL WARMING

Comparing the patterns of global warming distribution with the geographical distribution of humanity's energy consumption reveals that the areas of maximum energy consumption by country differ from the "geography" of global warming (Fig. 4). The lesser warming observed in the Southern Hemisphere can be attributed both to natural factors (such as the circumpolar upwelling and transport of material toward the equator [31]) and, potentially, to the location of the majority of thermal pollution hotspots in the Northern Hemisphere.

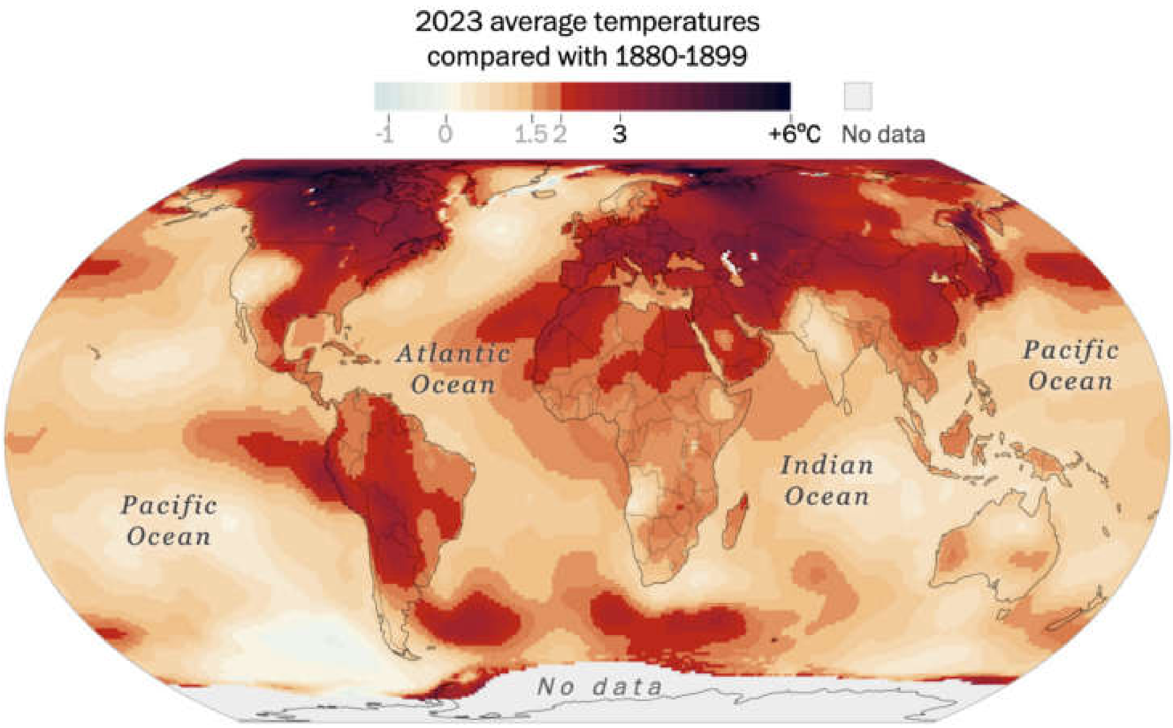

Figure 4. Average temperature increases in regions of the planet in 2023 relative to 1880–1899, according to FlowingData[3]

Based on the data presented above, Pearson correlation coefficients were calculated for the indicators under consideration, along with an assessment of their statistical significance (p-value) for the territories of the 47 countries examined (Table 2). A significance level of $p < 0.05$ indicates a significant correlation, while $p \geq 0.05$ suggests a weak correlation that does not reject the null hypothesis (i.e., it is statistically insignificant).

Table 2. Correlation coefficients between the indicators characterizing thermal pollution and the actual temperature increase over countries [32].

Parameter	Pearson correlation coefficients (the boundary of the significance level), calculated p-value			
	Specific energy consumption	Specific oil consumption	Specific CO_2 emission	Temperature increase over the past 140 years
Specific energy consumption	1,00	0,97 ($p < 0,05$) p-value: $1,63 \times 10^{-29}$	0,98 ($p < 0,05$) p-value: $3,97 \times 10^{-34}$	0,18 ($p \geq 0,05$) p-value: 0,2181
Specific oil consumption	0,97 ($p < 0.05$)	1,00	0,94 ($p < 0,05$) p-value: $2,30 \times 10^{-22}$	0,18 ($p \geq 0,05$) p-value: 0,2174
Specific CO_2 emission	0,98 ($p < 0,05$)	0,94 ($p < 0.05$)	1,00	0,13 ($p \geq 0,05$) p-value: 0.3708

[3] Where it warmed the most in the world – FlowingData (https://flowingdata.com/2024/01/17/where-it-warmed-the-most-in-the-world/).

Temperature increase over the past 140 years	0,18 ($p \geq 0,05$)	0,18 ($p \geq 0,05$)	0,13 ($p \geq 0,05$)	1,00

The obtained results, firstly, unequivocally demonstrate strong interrelationships between specific energy consumption, specific oil consumption, and CO_2 emissions (correlation coefficients of 0.94–0.98). This is entirely expected, as oil consumption constitutes a substantial part of energy consumption, and carbon dioxide emissions accompany the majority of processes associated with energy generation across a wide range of technological applications.

Secondly, the absence of a significant correlation between indicators characterizing thermal pollution and the temperature anomaly is noted at the given level of statistical significance (correlation coefficient 0.18). This may indicate that climate warming is predominantly determined by other factors, and that a larger data volume might be required to identify the presumed relationship, which could be non-linear or indirect.

Consequently, despite the evident contribution of thermal pollution to the planet's heat balance, it is not yet a determining factor in global climate warming. Notably, specific energy consumption (as well as oil consumption) showed a slightly stronger correlation with global warming compared to carbon dioxide emissions (correlation coefficients of 0.18 and 0.13, respectively).

VII. CONSEQUENCES OF GLOBAL WARMING

Like virtually all natural phenomena, global warming has not only negative impacts on our civilization but also a number of positive ones, which must undoubtedly be taken into account in environmental policy and practice.

Among the negative aspects, it can be noted that in northern Canada, the economically important and busiest winter ice road in the world – the Tibbitt to Contwoyto Winter Road (TCWR), stretching 400 km across frozen lakes – is losing its viability as a result of climate warming [33]. Warming in the Arctic often leads to infrastructure damage and other adverse consequences.

Attention is frequently drawn to the fact that climate change increases the frequency and intensity of heatwaves worldwide, which is particularly alarming for countries of the Global South. At the same time, warming makes winters more comfortable, which is highly significant for regions with temperate climates.

On the other hand, warming in the Eurasian Arctic region has enabled increased activity along the Northern Sea Route. Warming also provides an opportunity to substantially increase agricultural productivity. Even so-called urban heat islands, typically viewed as a phenomenon increasing heat-related mortality, actually reduce cold-related mortality. A global analysis of over 3000 cities shows that urban heat islands significantly reduce cold-related mortality, outweighing the increase in heat-related mortality by more than four times on a global scale [34, 35]. The negative aspects of cooling are vividly illustrated by the unexpectedly severe winter of 2025/26, which led to dozens of fatalities even in developed regions of the USA, Japan, and Russia.

Climate change alters both the duration and rate of carbon uptake by plants, thereby affecting terrestrial gross primary productivity (GPP). The duration and average daily rate of carbon uptake (GPPrate) have increased over recent decades, increasing total GPP at a rate of ~0.56% per year during the growing season across the Northern Hemisphere [36].

Current climate warming and the corresponding increase in atmospheric carbon dioxide concentration – a crucial factor for photosynthesis – inavoidably lead, in regions with sufficient moisture, to increased landscape bioproductivity and a corresponding rise in agricultural crop yields. The increase in atmospheric carbon dioxide concentration affects vegetation cover, not only accelerating the rate of plant biomass growth but also intensifying plant water transpiration, i.e., increasing air humidity. This could significantly impact environmental conditions, regional climate, and human economic activity.

Empirical evidence of the increase in agricultural crop yields in Russia is presented in the work of V.N. Kudeyarov [37], demonstrating that despite a significant reduction (almost by half) in sown areas in the 2000s compared to 1960–1990, and a decrease in fertilizer application in the Russian Federation, gross grain harvests more than doubled by 2022. One of the factors contributing to this yield increase is evidently warming and the elevated atmospheric carbon dioxide concentration.

In 2024, a record level of global vegetation greening (the global greening trend) was observed worldwide, significantly exceeding the previous maximum set in 2020. In total, greening was observed on 67.7% of vegetated land surfaces, particularly on Eurasian and tropical grasslands, as well as on global croplands. However, despite the prevalence of greening signals, approximately one-third of vegetated land surfaces exhibited browning, largely attributable to hot and dry conditions. The most pronounced browning anomalies were observed in southern Africa, Ukraine, the tropical forests of the Congo, and parts of the Amazon [38].

In this context, one cannot help but consider that combating the increase in atmospheric carbon dioxide concentration is effectively directed against a crucial biospheric process – landscape bioproductivity. Moreover, the so-called low-carbon, "green" economy cannot serve as a means of combating global climate warming, not only because the rise in atmospheric carbon dioxide content is predominantly a consequence, rather than a cause, of warming, but also because low-carbon energy is typically associated with an increased global burden on the biosphere, particularly the increase in thermal pollution discussed above. We should not emulate Don Quixote's "tilting at windmills" by attempting to erect various obstacles to entirely natural processes involving carbon dioxide emissions. Nor should we forget that we humans, like virtually all living organisms, emit carbon dioxide through respiration.

As demonstrated in studies [39, 40 et al.], addressing environmental problems (in practice, so far very inconsistently and, most importantly, ineffectively) by disrupting natural carbon cycles and through financial manipulations with carbon dioxide emission quotas, without scientific justification, is highly unwise and costly. The same opinion is expressed in the work [41]: many pathways for decarbonizing the economy appear to be largely ineffective in combating global warming. For instance, the environmental benefits of rooftop solar panels in terms of climate change mitigation appear to be overestimated by 41–98% compared to previous analyses conducted in the United States. As R. Evans [6] writes, "*an attempt to decarbonize the global economy will lead to serious economic upheaval.*"

The increase in photosynthetic intensity resulting from warming should be regarded not only as a mechanism for regulating atmospheric carbon dioxide concentration but also as a mechanism for regulating oxygen concentration – oxygen that is essential for the biosphere (including humanity) and is being consumed by industry on an ever-increasing scale. This is significant, as studies of ice cores have revealed that over the past 800,000 years, the atmosphere has lost approximately 0.7% of its oxygen content [42, 43].

Regarding past periods of warming and cooling, historians have already drawn their conclusions, characterizing warming periods as times of climatic optimum for human civilization, while cooling periods with low agricultural yields are designated as climatic pessimums. For instance, the Roman Climatic Optimum – a period from approximately 250 BCE to around 400 CE – contributed to the rise of large empires, including the Roman Empire. The Roman Climatic Optimum was followed by the climatic minimum of the Early Middle Ages, which lasted several centuries and was associated with the Great Migration Period, during which various peoples migrated actively in search of new territories with favorable living conditions, including more productive ecosystems.

VIII. DISCUSSION

The analysis presented in this study of the interrelationships among parameters characterizing anthropogenic impact on the climate system indicates that the contribution of human activity to global climate, despite its direct nature, remains relatively minor on a global scale, manifesting primarily at the regional level. This provides further evidence supporting the mainly natural causes of contemporary global climate change.

It is also important to note that the correlation between actual climate warming in different countries and the increase in anthropogenic carbon dioxide emissions proved to be even lower than the correlation with thermal pollution characteristics. This likely demonstrates the absence of a direct impact of anthropogenic carbon dioxide emissions on climate warming. The presence of a weak correlation with warming (correlation coefficient 0.13) can be explained by the close association between carbon dioxide emissions and thermal pollution, since heat release processes are largely linked to CO_2 emissions.

Nevertheless, thermal pollution of the biosphere – a direct anthropogenic impact on climate – is ubiquitously manifested at the regional level in the form of "urban heat islands" over large settlements, ground warming, and increased watercourse temperatures due to heated water discharge. This poses a threat to the functioning of natural ecosystems, particularly endangering thermosensitive biological species. To a significant extent, thermal pollution underlies the increasingly frequent recording of temperature maxima by meteorological stations.

It should be noted that thermal pollution is a manageable factor. Combating it could yield rapid and measurable local effects, directly improving urban quality of life and ecosystem health during the current period of global warming.

Reducing the negative environmental impact of thermal pollution requires an integrated approach at various levels. At the regional level, energy policy should be modernized to enhancing energy efficiency – specifically, utilizing "waste" heat from electricity generation for building heating, implementing closed-loop cooling systems for thermal and nuclear power plants, promoting so-called "cool" urban planning (using light-colored and reflective materials for roofs and facades), among other measures. At the city level, mass greening initiatives, creation of reflective surfaces, development of public transportation, and composting of organic waste rather than incineration should be encouraged. At the household level, the use of energy-efficient appliances, home insulation to reduce heating and cooling costs, and conscious energy consumption are important.

The recent increase in atmospheric carbon dioxide and methane concentrations is primarily driven by rising temperatures and the corresponding release of carbon dioxide from natural waters, predominantly from the World Ocean. Since atmospheric carbon dioxide is a crucial factor for photosynthesis, combating it effectively targets the reduction of the biosphere's productive potential. All this calls into question the success of measures undertaken within the framework of economic decarbonization/

The scientific literature notes a multitude of negative consequences arising from the adoption of the unsubstantiated hypothesis of anthropogenic warming as a practical guide for action. This fosters inadequate perceptions regarding the possibilities of reorienting national and regional energy systems, while natural constraints are overlooked. The anthropogenic warming hypothesis, unconfirmed by critical experiments and lacking consistency with established physical and geographical facts, has been accepted as an indisputable truth—a situation that discredits science [44].

In this context, the fight against anthropogenic CO_2 emissions appears entirely unfounded, futile, and even harmful, as it essentially constitutes a battle against photosynthesis – a fundamental biosphere-forming process. Therefore, the proposal at the UN Climate Change Conference (COP29) in Baku (2024) to consider not only mitigation (reducing greenhouse gas emissions) but also adaptation to climate change – i.e., promoting measures for impact mitigation, adaptation, and research in the climate sphere [45] – was significant. Unfortunately, this initiative was frozen at the Conference.

IX. CONCLUSIONS

The analysis of original data and literature materials presented here allows for the following conclusions to be formulated:

1. Thermal pollution constitutes the primary anthropogenic contribution to the planet's climate system. At the current stage, thermal pollution influences regional climate but is not the determining factor in global climate warming.

2. The apparent relationship between the increase in carbon dioxide concentration and global warming is due to the fact that thermal pollution is in most cases accompanied by its release into the atmosphere.

3. The increase in greenhouse gas concentrations (water vapor, carbon dioxide, methane) is primarily a consequence, rather than a cause, of the currently observed climate warming.

4. Contemporary global warming fundamentally represents another peak in the cyclical dynamics of the Earth's climate system.

5. Global warming has both negative and numerous positive consequences. In particular, the rising atmospheric carbon dioxide concentration stimulates photosynthesis – the most important biospheric process.

6. Carbon-free energy cannot be an effective countermeasure to global warming, since carbon dioxide is not a determining factor in modern warming, and the fight against it is aimed at countering the bioproduction process.

7. Given the undeniable role of anthropogenic heat in regional climate change, measures to reduce thermal pollution should be intensified in order to prevent its negative manifestations.

REFERENCES

[1] Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V. M., Legrand, M., Lipenkov, V. Y., Lorius, C., Pépin, L., Ritz, C., Saltzman, E., Stievenard, M., “Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica”, *Nature* **399** (6735), 429–436 (1999). DOI: 10.1038/20859

[2] Bajo, P., Drysdale, R.N., Woodhead, J.D., Hellstrom, J.C., Hodell, D., Ferretti, P., Voelker, A.H.L., Zanchetta, G., Rodrigues, T., Wolff, E., Tyler, J., Frisia, S., Spötl, G., Fallick, A.E., “Persistent influence of obliquity on ice age terminations since the Middle Pleistocene transition”, *Science* **367** (6483), 1235 (2020). DOI: 10.1126/science.aaw1114

[3] Walker, M., Johnsen, S., Rasmussen, S. O., Popp, T., Steffensen, J.-P., Gibbard, P., Hoek, W., Lowe, J., Andrews, J., Björck, S., Cwynar, L. C., Hughen, K., Kershaw, P., Kromer, B., Litt, T., Lowe, D. J., Nakagawa, T., Newnham, R., and Schwander, J., “Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records”, *J. Quaternary Sci*. **24** (1), 3–17 (2009)

[4] Kotlyakov, V., “Global warming and surging glaciers”, *UN Chronicle* **46** (4), 74–79 (2012). https://doi.org/10.18356/c8b4a3f4-en

[5] Friis-Christensen, E. and Lassen, K., "Length of the Solar Cycle: An Indicator of Solar Activity Closely Associated with Climate", *Science* **254** (5032), 698–700 (1991). DOI: 10.1126/science.254.5032.698

[6] Evans, R., "Nine Facts About Climate Change", *The Lavoisier Group* (2006) (https://lavoisier.com.au/articles/greenhouse-science/climate-change/longversionfinal.pdf).

[7] Snakin, V. V., "Low-carbon power and global climate warming", *Zhizn Zemli* [Life of the Earth] **46** (1), 4–19 (2024) (in Russian). DOI:10.29003/m3770.0514-7468.2024_46_1/4-19

[8] Tsegelskiy, V.G., "Myths of the Paris agreement", *Zhizn Zemli* [Life of the Earth] **45**, no 4, 540–555 (2023) (in Russian). DOI: 10.29003/m3535.0514-7468.2019_45_4/540-555

[9] Fedorov, V. M., Chukov, V. S., Frolov, D. M., "Causes of modern climate changes in the Arctic", *Zhizn Zemli* [Life of the Earth] **47** (2), 203–214 (2025) (in Russian). DOI: 10.29003/m4689.0514-7468.2020_47_2/203-214

[10] Vernadsky, V. I., *Scientific Thought as a Planetary Phenomenon* (Moscow: Nongovernmental Ecological Foundation V. I. Vernadsky, 1997. 265 p.)

[11] Wang, Y., Yan, P., Ji, F. et al., "Anthropogenic Contribution to the Rapid Warming over the Tibetan Plateau", Clim. Dyn. **61**, 329–339 (2023). https://doi.org/10.1007/s00382-022-06576-8

[12] Mahdavi, P., Ross, M. L. & Simoni, E., "Government efforts to reduce fossil fuel subsidies have failed at a very high rate", *Nat. Clim. Change* **15**, 471–472 (2025). DOI: 10.1038/s41558-025-02304-2.

[13] Evans, M. E. K., Adler, P. B., Angert, A. L. et al., "Reconsidering space-for-time substitution in climate change ecology", *Nat. Clim. Change* **15**, 809–812 (2025). https://doi.org/10.1038/s41558-025-02392-0

[14] Goode, P. R., Palle, E., Shoumko, A. et al., "Earth's Albedo 1998–2017 as Measured from Earthshine", *Geophysical Research Letters* **48** (17) (2021). https://doi.org/10.1029/2021GL094888.

[15] Tyutyunnik, V. M., "Physical modelling of Earth's climate: 2021 Nobel Prize winners in Physics Syukuro Manabe and Klaus Hasselmann", *J. of Advanced Materials and Technologies* **7** (1), 8–12 (2022). DOI: 10.17277/jamt.2022.01.pp.008–012.

[16] "Climate Change: Ocean Heat Content", *NOAA Climate.gov.,2023*.

[17] *Brief Handbook of Physical and Chemical Quantities* / Ed. by A. A. Ravdel and A. M. Ponomareva. 8th ed. (Leningrad: Chemistry, 1983. P. 25).

[18] Müller, J. D., Gruber, N., Schneuwly, A. et al., "Unexpected decline in the ocean carbon sink under record-high sea surface temperatures in 2023", Nat. Clim. Change **15**, 978–985 (2025). https://doi.org/10.1038/s41558-025-02380-4/

[19] Deng, Z., Zhu, B., Davis, S. J. et al., "Global carbon emissions and decarbonization in 2024", *Nat Rev Earth Environ.* **6**, 231–233 (2025). https://doi.org/10.1038/s43017-025-00658-x

[20] Bastviken, D., Johnson, M. S., "Future methane emissions from lakes and reservoirs", *Nat Water* **3**, 1397–1410 (2025). https://doi.org/10.1038/s44221-025-00532-6

[21] Kershengolts, B. M., Lifshits S. K., Spector V. B.,Spector V. V., "The role of the decomposition of arctic methane hydrates in changes in the global climate, and the need to take these risks into account in economic activities in the Arctic", *Arktika 2035* **1** (5) (2021) (in Russian) (https://arctic2035.ru/n5-p33?ysclid=maqwjs3ssk878961007)

[22] Snakin, V. V., Vlasov, S. V., Doronin, A. V. et al., "Atmospheric methane: Natural and anthropogenic sources", *Scholars J. of Research in Agriculture and Biol.* **4** (1), 262–274 (2019) (https://www.scischolars.com/journals/index.php/sjrab)

[23] Vlasov S. V. et al., *Methane in the atmosphere, methanotrophs and development of oil and gas industry* (Moscow: MAKS Press, 2021. 140 p.). https://doi.org/10.29003/m1986.978-5-317-06580-5

[24] "Carbon uptake rate dominates changes in vegetation productivity over time", *Nat. Clim. Change* **15**, 477–478 (2025). https://doi.org/10.1038/s41558-025-02316-y

[25] Jin, P., "Duplicating genomes to survive the heat", *Nat. Clim. Chang*. **15**, 1146–1147 (2025). https://doi.org/10.1038/s41558-025-02454-3

[26] Li, Z., Zhang, Y., Irwin, A. J. et al., "Polyploidization in diatoms accelerates adaptation to warming", *Nat. Clim. Change* **15**, 1241–1248 (2025). https://doi.org/10.1038/s41558-025-02464-1

[27] *IPCC Fifth Assessment Report, 2014* (https://archive.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter6.pdf)

[28] Budyko, M. I., "Some ways of influencing climate", *Meteorology and hydrology* **2**, 3–8 (1962) (in Russian)

[29] Flanner, M. G., "Integrating anthropogenic heat flux with global climate models", *Geophysical Research Letters* **36** (2) (2009). DOI: 10.1029/2008GL036465

[30] Zhao, L., Oleson, K., Bou-Zeid, E. et al., "Global multi-model projections of local urban climates", *Nat. Clim. Change* **11**, 152–157 (2021). DOI: 10.1038/s41558-020-00958-8

[31] Armour, K., Marshall, J., Scott, J. et al., "Southern Ocean warming delayed by circumpolar upwelling and equatorward transport", *Nature Geosci* **9**, 549–554 (2016). https://doi.org/10.1038/ngeo2731

[32] Snakin, V. V., Mitenko, G. V., Gavrikova, D. V., "Thermal pollution as a significant anthropogenic contribution to global warming", *Zhizn Zemli* [Life of the Earth] **47** (4), 503–513 (in Russian). DOI: 10.29003/m4984.0514-7468.2025_47_4/503-513

[33] Mullan, D., Swindles, G., Patterson, T. et al., "Climate change and the long-term viability of the World's busiest heavy haul ice road", *Theoretical and Applied Climatology* **129** (3/4) (2017). ISSN 0177-798X

[34] "Urban heat islands increase or reduce mortality in different cities", *Nat. Clim. Change* **15**, 473–474 (2025). https://doi.org/10.1038/s41558-025-02310-4

[35] Wang, S., Zhan, W., Zhou, B. et al., “Dual impact of global urban overheating on mortality”, *Nat. Clim. Change* **15**, 497–504 (2025). https://doi.org/10.1038/s41558-025-02303-3

[36] Liu, Z. et al., “Enhanced vegetation productivity driven primarily by rate not duration of carbon uptake”, *Nat. Clim. Change* **15**, 560–568 (2025) https://doi.org/10.1038/s41558-025-02311-3.

[37] Kudeyarov, V. N., “Sixty-year climate change and carbon balance in agriculture in the Russian Federation”, *Soil as a component of the biosphere: Current issues in the context of climate change. Proc. of the All-Russian scientific conference dedicated to the 120th anniversary of V. A. Kovda* (Pushchino: 2024. P. 12–15) (in Russian) (https://issp.pbcras.ru/docs/conference/Kovda/Konf_Kovda_2024.pdf).

[38] Gui, Y., Wang, K., Huntingford, C. et al., “Vegetation greenness in 2024”, *Nat Rev Earth Environ* **6**, 255–257 (2025). https://doi.org/10.1038/s43017-025-00656-z

[39] Grachev, V. A., “Creative heritage of V. I.Vernadskyм and global challenges of sustainable development”, Bull. of Moscow University. Ser. 27. Global Studies and Geopolitics **2**, 3–20 (2018) (in Russian).

[40] Snakin, V. V., “Science, Technology and Geopolitics: Global Environmental Aspects”, *Use and protection of natural resources of Russia* **3** (179), 3–9 (2024) (in Russian). EDN BSTTCB

[41] Bistline, J. E. T., Watten, A., “Emissions reductions of rooftop solar are overstated by approaches that inadequately capture substitution effects”, *Nat. Clim. Change* **15**, 1173–1175 (2025). https://doi.org/10.1038/s41558-025-02459-y

[42] Stolper, D. A., Bender M. L., Dreyfus, G. B., Yan, Y., Higgins, J. A., “A Pleistocene ice core record of atmospheric O_2 concentrations”, *Science* **353**, 1427–1430 (2016)

[43] Yan, Yu., Brook, E. J., Kurbatov, A. V., Severinghaus, J. P., Higgins, J. A., “Ice core evidence for atmospheric oxygen decline since the Mid-Pleistocene transition”, *Science Advances* **7** (51) (2021). DOI: 10.1126/sciadv.abj9341

[44] Reteum, A. Y., “Dangerous myth of anthropogenic warming” (2020) (https://regnum.ru/news/polit/3101660.html) (in Russian)

[45] Voronkova L. P., “The Formation of Global Geography”, *Vek globalizatsii* [Age of Globalization] **4**, 149–157 (2024) (in Russian). DOI: 10.30884/vglob/2024.04.12