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Contribution of Energy Produced by Humanity to Global Warming

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Abstract

Civilization has reached such a level of development when the energy produced by humanity (the energy of civilization) begins to become a noticeable addition to the energy of incoming solar radiation. The energy of civilization accumulates in the surface layer, where human activity is concentrated, and dissipates in the form of heat, causing a rise in temperature. An equation is derived to calculate the contribution of civilization's energy to global warming, which prove to be directly proportional to the accumulated energy of civilization and inversely proportional to the energy of solar radiation on the earth's surface to the power of three-fourths. The coefficient of proportionality is expressed in terms of fundamental physical constants: Planck's constant, the speed of light and the Boltzmann constant. It is shown that the contribution of energy of civilization is comparable with the role of increasing concentration of carbon dioxide over the past decades. To mitigate the negative effect, it is necessary to reduce the energy production and partially revise the environmental policy.

Keywords

Stephan-Boltzmann Law, Energy Of Civilization, Global Warming

1. Introduction

In recent decades, events in the world around us have been changing at breakneck speed. The problems associated with climate change and global warming have become particularly acute. Thousands of researchers around the world are involved in finding solutions. An overview of these numerous works is not given here and can be easily found on the Internet. Respected scientists warn mankind about the approaching threat and call for urgent measures to prevent a catastrophe [1] [2] [3] [4] [5].

There is an almost unanimous opinion that it is human activity that destroys the environment. The most common view is that global warming is caused by the burning of organic fuels, which increases the concentration of CO_2 in the atmosphere. The additional carbon dioxide enhances the greenhouse effect, which returns some of the infrared radiation absorbed by carbon dioxide, and increases the temperature of the planet [6] [7].

On the Earth's scale, the greenhouse effect lasts for billions of years, and its contribution to the planet's climate is undeniable. Experimental data on an increase in the concentration of CO_2 from 280 ppm to 400 ppm and an increase in the temperature of the Earth over the past 150 - 200 years by about 1˚C are also indisputable. The graphs of temperature rise and carbon dioxide concentration over time are very similar to each other. However, all these cannot be regarded as a proof of a one-to-one correspondence between the phenomena: there is no evidence that the greenhouse effect is the sole cause of the current global warming [8].

The purpose of this work is to show that the energy produced by humanity for its own consumption (the energy of civilization), as well as the greenhouse effect, cause heating of the planet's surface and contribute to global warming.

2. The Impact of Human Activity on Global Warming

2.1. Uninhabited Planet

The average temperature of the Earth is determined by the thermal balance, that is, how much energy the planet receives and how much it radiates back into space. When drawing up a balance sheet, energy power values are usually used. Of ~340 W/m^2 of solar radiation received by the Earth, an average of ~100 W/m^2 is reflected into space and the remaining ~240 W/m^2 of solar energy goes to the Earth's energy budget. The energy budget of the planet is considered in detail in the special literature [9] [10] [11].

The total radiation power per unit of the surface of a completely black solid, P (W/m^2), is related to its temperature T by the fundamental Stefan–Boltzmann law [12] [13]:

$$P = \sigma T^4, \tag{1}$$

where σ is the Stefan-Boltzmann constant:

$$\sigma = \frac{2\pi^5 k^4}{15c^2 h^3} = 5.6704 \times 10^{-8}\ \text{J} \cdot \text{s}^{-1} \cdot \text{m}^{-2} \cdot \text{K}^{-4} \tag{2}$$

Here k is Boltzmann's constant, h is Planck's constant, and c is the speed of light.

The surface of the Earth is usually approximately regarded as a completely black body. According to this assumption, in order to maintain heat balance, each square meter of the planet's surface emits an average of 239 W/m^2 of incoming radiation at a temperature, T_r:

$$T_r = \sqrt[4]{239/\sigma} = 255\ \text{K} \tag{3}$$

However, the average temperature of the Earth's surface, T_e, is higher and equal to 288 K. The temperature difference, $T_e - T_r = 33$ K, is explained by the contribution of the greenhouse effect [6] [7]. Thus, the average temperature of the earth's surface is equal to the sum of temperatures

$$T_e = T_r + 33\ \text{K} \tag{4}$$

This increase in temperature due to the greenhouse effect, 33 K, determines the suitability for life and the modern climate of the earth. It should be noted that we distinguish between two stages of the greenhouse effect: the main stage, which lasted for billions of years and determined the Earth's climate, and the current short (several decades) warming period, which is presumably associated with an increase in carbon dioxide due to the burning of organic fuels.

2.2. The Energy of Civilization

It is worth emphasizing that the thermal balance is compiled for an uninhabited planet [9]. To quantify the impact of humanity on climate change, one can use the idea of Kardashev, who proposed to evaluate the development of civilization by the amount of energy, E, that it is able to use [14] [15].

Let's call the total energy produced by humanity the energy of civilization. The second law of thermodynamics states that the efficiency of any real process is less than 100%: part of the energy is dissipated in the environment in the form of heat, the rest, free energy, can be used for the needs of humanity. According to the first law of thermodynamics, free energy cannot disappear, and in the process of producing useful work, it is also dissipated as heat in the atmosphere of the planet. Thus, on the scale of the Earth, all the energy of civilization is inevitably converted into the heat of civilization, which is dissipated in the atmosphere.

Since single- and diatomic air molecules do not absorb or emit electromagnetic radiation in the real temperature range, the heat of civilization is dissipated by increasing the kinetic energy of air molecules (mainly N_2, O_2 and Ar) when colliding with more heated objects. Air molecules are held by gravity and remain on Earth; thus, the energy of civilization accumulates on the planet in the form of kinetic energy of molecules, and its total value, E_t, is summed up over a time interval:

$$E_t = \sum_{i_1}^{i_2} E_i \tag{5}$$

where, E_i is the annual energy output; i_1 and i_2 are the beginning and end of the interval, respectively. Therefore, the influence of civilization's energy on temperature is constantly increasing; this is the *additional energy* (*compared to the pre-industrial era*) that the planet receives from a developing civilization. Although only free energy is used for the development of civilization, thermal pollution is caused by the total energy generated by humanity.

The sources of this energy, fossil fuels, radioactive substances, winds, rivers, and tides, exist in nature regardless of whether the earth is inhabited or not.

Questions arise: "Why does the energy from these resources affect the thermal balance of a planet with a developed civilization? And why are these resources actually neglected in the case of an uninhabited planet?" The main reason is the speed of energy release. In nature, these sources slowly dissipate their energy, while humanity forces them to release free energy for a short time. The ratio of speeds can reach the order of a million and a billion. Below are two illustrations. In nature, the energy of rivers is slowly dispersed over thousands of kilometers of riverbeds, whereas on hydroelectric dams it is released within seconds. Fossil fuels and radioactive substances have existed for millions and billions of years, but their internal energy is quickly released in the corresponding chain reactions. Obviously, if the speed of natural processes is millions of times slower, then the contribution of these sources to the heat balance of an uninhabited planet per second, that is, the power of these sources, is negligible. The same reasoning can be carried out with respect to the energy density per m^2: in technology, it can be millions of times higher.

2.3. Contribution of Civilization's Energy to Global Warming

In order to assess the impact of the energy of civilization on global warming, let's assume that the warming is caused only by the energy of civilization, and the influence of all other factors does not change during the period under consideration. Then it follows from Equation (4) that the difference in earth temperatures ΔT_e for the studied period is equal to the difference in radiation temperatures ΔT_r for the same period:

$$\Delta T_e = \Delta T_r \tag{6}$$

Equation (6) makes it possible to estimate ΔT_e proceeding from the Stefan-Boltzmann equation, since the increment of the temperature of the surface layer ΔT_e turns out to be equal to the change in the temperature of radiation ΔT_r. As a result of the calculation, we will get the contribution of the energy of civilization to the temperature increase, which is less than the observed global warming; the difference between the latter and calculated values is determined by the effect of increasing concentration of carbon dioxide in the atmosphere.

To calculate, it is necessary to convert the annual energy production E_i into an increase in the average power of civilization per m^2 of the planet's surface, ε_i. Obviously, $\varepsilon_i = E_i \Big/ \left(\left(5.616\times10^6\right)\times\left(5.1\times10^{14}\right) \right)$, where 5.616×10^6 is the number of seconds per a year, and 5.1×10^{14} is the surface area of the Earth (m^2). Then it follows from Equation (6) that the energy of civilization for the i-th year will cause the following increase in temperature:

$$\Delta T_i = \sqrt[4]{\frac{P_s + \sum_i \varepsilon_i}{\sigma}} - \sqrt[4]{\frac{P_s + \sum_{i-1} \varepsilon_i}{\sigma}}, \tag{7}$$

where $\sum_i \varepsilon_i$ and $\sum_{i-1} \varepsilon_i$ are the sums of the energies of civilization (SEC), for i и ($i - 1$) years, respectively.

The civilization's energy began to increase noticeably only after the beginning of the industrial era, *i.e.* after ~1800 year, whereas before it was close to zero. Strictly speaking, both expressions on the right side of the equation (7) should include not P_s, but the value ($P_s + \alpha$), where α is the additional energy of civilization before the beginning of the period of interest to us. However, since $\alpha \ll P_s$ and due to the subtraction operation, the contribution of α is insignificant and can be neglected. Adding up the annual temperature rises, after some algebra, we get that the total energy of civilization for the period from i_1 to i_2 year will cause the following warming, ΔT:

$$\Delta T = \sqrt[4]{\frac{P_s + \sum_i \varepsilon_i}{\sigma}} - \sqrt[4]{\frac{P_s}{\sigma}} \tag{8}$$

Here $\sum_i \varepsilon_i$ is SEC from i_1 to i_2. Since the energy of civilization is much less than the power of solar radiation, $\sum_i \varepsilon_i \ll P_s$, we can generate a power series expansion for Equation (8) about the point $\sum_i \varepsilon_i$ and limit ourself to the first term:

$$\Delta T = \frac{1}{\sqrt[4]{\sigma}} \frac{\sum_i \varepsilon_i}{(P_s + \omega)^{3/4}} \tag{9}$$

If we (a) determine the proportionality coefficient, $\gamma = \frac{1}{\sqrt[4]{\sigma}}$, and (b) substitute Equation (2) into it, we obtain an expression for γ in terms of basic physical constants:

$$\gamma = \frac{1}{4\pi^{5/4}} \left(\frac{15}{2}\right)^{1/4} \left(\frac{c^2 h^3}{k^4}\right)^{1/4} = 16.2008\ \mathrm{K} \cdot \mathrm{m}^{0.5} \cdot \mathrm{W}^{-0.25} \tag{10}$$

and come to the final expression:

$$\Delta T \approx 16.2008 \frac{\sum_i \varepsilon_i}{P_s^{3/4}} \tag{11}$$

Equation (11) is a very good approximation to the exact expression.

Table 1 presents (a) the values of the SEC based on the annually published data on energy production and (b) the calculated contributions of the energy of civilization to the overall warming. The data is presented for three arbitrary time periods.

The radiation surface coincides with the thin surface layer of the biosphere, in

Table 1. Contribution of civilization's energy to global warming.

Time interval, years	Sum of the energy of civilization[a]		Global warming, ΔT_{exp} °C	Contribution of the SEC, (Equation (11))	
	E_t, TWh	$\sum_i \varepsilon_i$, W/m^2		ΔT °C	$\Delta T/\Delta T_{exp}$, %
1985-1994	1.04×10^6	0.23	0.12[b]	0.06	50%
2013-2022	1.71×10^6	0.38	0.20[c]	0.10	50%
1950-2020	6.25×10^6	1.40	0.82[b]	0.37	45%

[a][16]; [b][17]; [c][18].

which human activity is concentrated. Comparison of calculated values of ΔT (Equation (11)) and experimental values of global warming, ΔT_{exp}, shows that the energy generated by humanity can cause up to half the magnitude of global warming. In the future, with the growth of energy production, this share may increase even more. Therefore, coordinated measures to limit energy consumption are required to mitigate the effects of warming. The table also reveals that the SEC power, 1.40 W/m^2, for 70 years from 1950 to 2020 is equivalent to more than 0.5% of the solar radiation power on the earth's surface.

If to use a metaphor, the contribution of civilization to global warming can be compared to the action of a heater that heats a closed room as people living in it acquire the necessary knowledge and begin to use energy sources stored in the same room.

It should be noted some important points in assessing the contribution of the energy of civilization. The latter is the sum of all types of energy produced by mankind regardless of sources, *i.e.*, it includes renewable and non-renewable, carbon-free and organic energy sources, that is, all sources without exception. This means, for example, that one kilowatt of energy received from a wind turbine, coal or nuclear power plant, etc. cause the same thermal pollution. Here we compare the energy sources only from the point of view of their impact on thermal pollution, leaving aside other environmental effects. Even if it were possible to switch to carbon-free energy and stop the temperature rise due to the greenhouse effect, the heating of atmosphere due to the energy of civilization will continue and even increase if measures are not taken to limit energy production.

3. Conclusion

The energy generated by humanity is the additional energy (compared to the pre-industrial era) that the planet receives from a developing civilization. It accumulates in the surface layer, where human activity is concentrated, and dissipates as heat, causing an increase in temperature. An equation is derived to calculate the contribution of civilization's energy to global warming. Currently, its contribution is comparable to that from an increase in the concentration of carbon dioxide over the last decades. However, with the progress of civilization, the role of this energy will increase, and uncontrolled development of civilization can lead to serious consequences that justify gloomy forecasts. In order to mitigate the consequences, it is necessary to review environmental policy and, along with the measures already taken, take additional steps to reduce energy production and increase the efficiency of its use.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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