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The Impact of Energy Produced by Civilization on Global Warming

Vladimir Kh. Dobruskin

Independent Researcher, Beer Yacov, Israel
Email: dobruskn@gmail.com

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Abstract

The thermodynamic approach to the evolution of human society shows that the energy generated by civilization disrupts the thermal balance of the Earth. This energy did not exist before the advent of civilization; it practically does not affect the thermal radiation of the planet and dissipates in the atmosphere in the form of heat, increasing the kinetic energy of gas molecules and, consequently, their temperature. Since air molecules cannot leave the Earth due to gravity, excess heat accumulates on the planet and contributes to global warming. A quantitative assessment of the effect is given. An analogy can be made: the energy generated by humanity heats the atmosphere, as a furnace heats a dwelling.

Keywords

Thermodynamics, Global Warming, Energy of Civilization, Climate

1. Introduction

In recent decades, events in the world around us have changed at breakneck speed. This applies to all aspects of life: climate, the number of natural disasters, outbreaks of new diseases and the coronavirus pandemic, changes in morality and demography, fierce political struggle, wars and the crisis of the world economy, conflicts of interest between the greens and industry, etc. Global climate change is widely recognized as a reaction of the planet to human activity and the main threat to our civilization; many other risks are associated with climate change, such as increased natural disasters, deforestation, the emergence of new deserts, lack of drinking water and etc. Respected scientists warn humanity about the approaching threat and call for urgent measures to prevent dangers [1] [2] [3] [4] [5].

Climate change and global warming are studied by physicists, chemists, biologists, paleontologists, oceanologists, agronomists, soil scientists and many other scientists. There is a wide range of ideas about the causes and consequences of the observed changes; it seems quite normal for such an extremely complex, multifactorial system [6]-[13]. In our opinion, a universal approach to the study of these phenomena could be provided in the framework of thermodynamics [14] [15]. Albert Einstein wrote about classical thermodynamics [16]: "This is the only physical theory of universal content, which, I am convinced, will never be refuted within the framework of the applicability of its basic concepts." Due to such universality and indisputability of the laws of thermodynamics [17] [18], one could hope to get indisputable conclusions and predict ways to mitigate the undesirable consequences of events, whereas any attempts to "circumvent" thermodynamics or "deceive nature" would be doomed to failure. The rationale for the applicability of classical thermodynamics to phenomena under discussion was given in earlier publications [14] [15].

The purpose of this study is to consider climate change in the framework of thermodynamics and to assess the impact of energy produced by civilization on global warming. The paper is organized as follows. After introduction section, the concept of the energy of civilization is introduced (Section 2), which is used in Section 3 to consider the impact of civilization on global warming. An analogy is drawn between the heating of an ordinary dwelling and the heating of the Earth. In conclusion, some of the obstacles to climate change mitigation are outlined.

2. Energy of Civilization

The application of thermodynamics is based on the postulate of Kardashev, who suggested that the level of development of civilization is determined by the amount of energy it is able to use [19]. This postulate allows us to use energy values to quantify the development of civilization, that is, to translate the problem into the language of physics (thermodynamics).

It is important to note that on the scale of the Earth, all the energy produced by civilization is used for consumption, and no reserves are made for the future. Consequently, in this case the energy produced by a civilization and the energy consumed by it are equal to each other. Because of the quantitative equality, these values can be used interchangeable on the Earth scale; as a rule, they will be called "the energy of civilization". Note that in the case of individual countries, the quantities of energy consumed and energy produced do not coincide with each other, since countries can be either energy exporters or energy importers.

The energy of civilization (fossil fuel energy or nuclear energy) was not used before the advent of civilization. Fossil fuel energy is non-renewable energy accumulated over hundreds of millions of years by a desert planet and released by humans as a result of rapid combustion. It is a source of carbon dioxide and other chemical pollutants in the atmosphere. Atomic energy is also generated from converted natural radioactive substances. The key feature of these processes is that fossil fuels and radioactive substances undergo very slow changes in nature, while humanity forces them to quickly release energy. Our planet copes with very slow changes, but the rapid release of energy disrupts the thermal balance.

Renewable energy sources, wind generation and hydrogenation, are based on the energy of solar irradiance, which does not depend on whether the planet is inhabited or not. Humanity has not invented winds, tides and rivers, but only converts their free energy to perform useful work. These energy sources are implicitly included in the thermal balance of the planet as derivatives of solar radiation; they cannot be counted twice, the second time as the energy of civilization. However, being concentrated at local points, they disrupt the natural energy dissipation along extended air and river flows and have at least a local effect.

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 humanity needs. According to the first law, the free energy also cannot disappear, and in the process of producing useful work, it is spent on overcoming resistance and also turns into heat. For example, when a truck carries a load, useful work is spent on overcoming friction and air resistance and eventually also turn into heat. Thus, on the scale of the Earth, all the energy produced is inevitably converted into heat.

3. Impact of Energy Produced by Civilization on Global Warming

3.1. Ideal and Real Thermodynamic States of the Earth

For a long period of our history, until about 1800 year, the influence of civilization on the climate was insignificant, and humanity existed in harmony with nature - with clean air and drinking water, green forests, clean rivers and oceans, and so on. This state of the planet will be called the ideal state; it practically does not differ from the state of the uninhabited Earth. Obviously, everyone would prefer to live in such an environment, among the pristine nature. It can be argued that in the absence of a developed civilization, such a state would remain virtually unchanged up to the present days and even in the near future.

The average annual temperature, averaged also over the Earth's surface, has maintained at about 15˚C for 1000 years. It is determined by the Earth's thermal balance, that is, how much energy receives the planet and how much it radiates back into space - quantities that change very little. The thermal balance of the planet and the physics of this phenomenon are discussed in detail in the specialized literature [20] and are not touched upon here, except for the radiation of the Earth's surface. Note that, although this is not explicitly emphasized, the thermal balance of the Earth is considered in relation to an ideal, uninhabited planet, and the energy produced by civilization is not included in the balance.

Due to the presence of greenhouse gases in the atmosphere (mostly carbon dioxide), only part of the Earth's infrared radiation is emitted into space. These gases absorb and then re-emit the Earth's radiation, partly back to the surface and partly into space through an atmosphere transparent to long-wave radiation. The returned radiation heats up the planet; the greenhouse effect is lasting over billions of years. Without it, the Earth's surface would be about 33˚C colder [21], and life on a frozen icy planet would be impossible.

Over the past 150 - 200 years, the concentration of CO_2 in the atmosphere has increased from 280 ppm to 400 ppm. A widespread theory explains global warming by the intensification of the greenhouse effect due to the appearance of additional carbon dioxide molecules [21] [22]. In this article, we intend to draw attention to another probable cause of global warming, related to the scientific and technological revolution.

Unlike an ideal planet, on our real planet, anthropogenic evolution continues and accelerates, civilization continuously produces energy, and this energy inevitably upsets the thermal balance that existed on an ideal Earth. Due to the thermal inertia of the oceans and the slow reaction of other elements of the climate system, it takes centuries for the climate to reach an equilibrium state [23]. For this reason, the real planet is not in equilibrium: its current state can only be considered as an indicator of what the displacement of the equilibrium of an ideal planet leads to.

Let's compare these two states: 1) the ideal state of the Earth, when human activity is either insignificant or non-existent, and 2) the real state of the planet with an evolving civilization. According to thermodynamics (Le Chatelier's principle) [17], the dynamic equilibrium in the system is maintained until the conditions to which it corresponds are violated. If the latter occurs, the equilibrium position shifts to counteract the change; the process continues until a new equilibrium is reached. Now let's apply Le Chatelier's principle to an ideal system that has been in equilibrium for 1000 years. What will happen to an ideal equilibrium system if it is affected by an amount of energy equal to the energy of civilization? We expect the equilibrium position to shift and in fact we observe shifting towards the state of the real system. Since the energy of civilization upsets the thermal balance of the Earth, the reaction of the planet should be aimed at countering and mitigating the destructive impact. The only way available to nature is to change the environment in such a way as to slow down the progress of civilization. Climate change and global warming on Earth are just a manifestation of such a reaction of the planet, which worsens human living conditions and, therefore, could reduce economic activity in the future.

3.2. Contribution of Civilization's Energy to Global Warming

Consider quantitively how civilization effects on temperature. The total power emitted per unit area of the surface of a perfectly black body (P) is given by the Stefan-Boltzmann law [24]:

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

where $\sigma = 5.6704 \times 10^{-8}$ J·s^{-1}·m^{-2}·K^{-4} is the Stefan-Boltzmann constant and T is the absolute temperature. It is generally accepted to consider the Earth as approximately a black body, whereas real industrial objects are gray bodies that emit less radiation than a black body at the same temperature. The technical structures as a whole occupy only a very small part of the planet's area. Thus, the total thermal radiation of the Earth is practically not affected by the energy of civilization. Since the latter is not radiated into space, it is transmitted to environmental molecules (mainly atmospheric molecules), increasing their kinetic energy and temperature. Air molecules (N_2, O_2 and Ar) remain on Earth due to gravity, and the energy of civilization is accumulated on the planet. Therefore, the total thermal energy, ΔE, for the time interval is summed up:

$$\Delta E = \sum_{i_1}^{i_2} E_i \text{ ,} \tag{2}$$

where E_i is the annual energy production; i_1 and i_2 are the beginning and end of the interval, respectively.

According to an ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), a warming rate since 1975 is approximately 0.15˚C - 0.20˚C per decade [25]. Another assessment of the planet warming is approximately 0.14˚C per decade [26]. World energy production was 14.421 gigatons of oil equivalent in 2018 [27]. Assuming that this is the average annual value for decade from 2013 till 2023 years (2018 ± 5 years), total energy production is ΔE = 144.21 Gtoe per decade (6.04 × 10^{18} kJ/decade). What can generate this amount of energy on the scale of the Earth?

The boundary between outer space and the atmosphere is the Karman line at a distance of 100 km, but the human activity, including jet flights, is concentrated within 11 km, mass of which is about $m_a = 3.86 \times 10^{18}$ kg [28]. It is easy to estimate what temperature rise, ΔT, could cause such an amount of energy in an imaginary closed atmosphere:

$$\Delta T = \Delta E / m_a c_a = 1.56^\circ\text{C} \cdot \text{decade}^{-1} \text{ ,} \tag{3}$$

where c_a = 1.0035 kJ/Kg^{-1} grad^{-1} is the specific heat capacity of air. Of course, energy is spent not only on heating the atmosphere, but also on heating the surface layers of Earth. The ocean absorbs excess heat from Earth's system, acting to balance the excess heat from rising global temperatures. Evaporation and condensation of water play a crucial role in this process. Scientists have determined that the ocean absorbs more than 90 percent of the excess heat [29] [30]. In the case of this super-complex problem of heat- and mass-transfer, an analytical calculation of changes of the average temperature is extremely difficult. For example, in order to accurately determine the change by 0.15˚/decade at T = 288˚K, the calculation error should be less than about 0.03˚, that is 1 × 10^{-4} of the average temperature. Obviously, any simplification and approximation are impossible because they devalue the accuracy. In addition, it should be a time-dependent solution, since it takes centuries, not 10 years, to achieve an equilibrium state of the climate.

Due to the lack of an exact solution, let's also assume that only 10% of the energy of civilization is spent on heating the atmosphere, while about 90% is spent on heating the surface layers. In this case equation (3) would lead to $\Delta T = 0.1\Delta E/m_a c_a = 0.156^\circ C$, which is consistent with experimental data, allowing us to conclude that the energy of civilization is an important factor in global warming.

The destructive impact of the energy of civilization leads to an increase in the entropy of the planet as follows

$$\Delta S = \Delta E/T , \quad (4)$$

where T is the average temperature of the Earth. Over the specified decade, the growth of the entropy of the Earth is equal to $\Delta S = 21 \times 10^{15}$ kJ/K˚. According to the statistical interpretation of entropy, this value can be considered as a measure of increasing disorder, that is, a measure of the destruction of nature.

Just to illustrate, the following an analogy can be drawn: the energy of civilization heats the atmosphere of the planet, as an oven heats a dwelling. In this analogy, the Earth is presented as an imaginary dwelling of humanity, the energy generated by humanity serves as fuel for the furnace that heats the planet. Consequently, civilization acts as an imaginary furnace heating the Earth. Of course, this is just an analogy that helps to understand the alleged mechanism of global warming.

To avoid possible contradictions, it is worth recalling famous article [31] on the physics of heating an ordinary house, which gave rise to several important scientific ideas [32]. There is a fundamental difference between the systems being compared: The Earth is a closed system that gas molecules cannot leave, whereas an ordinary dwelling is an open system, that is, the air inside it moves into the environment when heated and expanded.

4. Conclusions

Thermodynamic analysis of the situation led to the conclusion that the energy generated by civilization heats the Earth and contributes to global warming. To prevent further threats to humanity, it is necessary to reduce the total energy production. There are no simple solutions to the problem, the discussion of possible actions has been going on for decades, but a binding global agreement has not yet been reached, although time is running out. The lack of political consensus, which is perhaps the most difficult problem that humanity has ever faced, hinders the adoption of urgent measures. For example, limiting energy consumption per capita is not suitable for the "golden billion", and reducing the birth rate and population is not applicable in a number of countries and contradict their cultural and religious traditions. The huge list of problems can be continued. Nevertheless, it would be preferable for humanity to prevent global warming with the help of a political agreement, rather than passively waiting for the inexorable reaction of nature, which could lead to a catastrophe.

Conflicts of Interest

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

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