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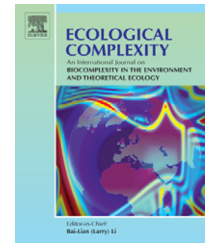

Viewpoint

Energy budget of the biosphere and civilization: Rethinking environmental security of global renewable and non-renewable resources

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ABSTRACT

How much and what kind of energy should the civilization consume, if one aims at preserving global stability of the environment and climate? Here we quantify and compare the major types of energy fluxes in the biosphere and civilization.

It is shown that the environmental impact of the civilization consists, in terms of energy, of two major components: the power of direct energy consumption (around 15×10^{12} W, mostly fossil fuel burning) and the primary productivity power of global ecosystems that are disturbed by anthropogenic activities. This second, conventionally unaccounted, power component exceeds the first one by at least several times.

It is commonly assumed that the environmental stability can be preserved if one manages to switch to ‘‘clean’’, pollution-free energy resources, with no change in, or even increasing, the total energy consumption rate of the civilization. Such an approach ignores the fact that the environmental stability is regionally and globally controlled by the functioning of natural ecosystems on land and in the ocean. This means that the climate and environment can only remain stable if the anthropogenic pressure on natural ecosystems is diminished, which is unachievable without reducing the global rate of energy consumption. If the modern rate of anthropogenic pressure on the ecosystems is sustained, it will be impossible to mitigate the degradation of climate and environment even after changing completely to ‘‘clean’’ technologies (e.g., to the ‘‘zero emissions’’ scenario).

It is shown that under the limitation of preserving environmental stability, the available renewable energy resources (river hydropower, wind power, tidal power, solar power, power of the thermohaline circulation, etc.) can in total ensure no more than one tenth of the modern energy consumption rate of the civilization, not to compromise the delivery of life-important ecosystem services by the biosphere to the humanity.

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With understanding still lacking globally that the anthropogenic impact on the biosphere must be strictly limited, the potential availability of the practically infinite stores of nuclear fusion energy (or any other infinite energy sources) poses an unprecedented threat to the existence of civilization and life on the planet.

1. Introduction

As human body cannot exist without food, the civilization, at every stage of its development, must consume energy at a certain rate. Modern civilization, with its global energy consumption rate of around 15 TW (1 TW = 10^{12} W), largely exists at the expense of fossil fuels (oil, natural gas and coal). Burning of fossil fuels leads to accumulation of carbon dioxide (CO_2) in the atmosphere.

From the second half of the 20th century the so-called global change processes have been registered on the planet. These are manifested most unequivocally as the increasing frequency of regional climatic and biospheric anomalies of all kinds, including temperature extremes, fluctuations of the atmospheric and oceanic circulation and biological productivity, etc. In parallel, it was found that the global concentration of atmospheric CO_2 (the second, after water vapor, most important greenhouse gas on Earth) is growing conspicuously, currently exceeding the preindustrial value by approximately 30%. These two observations were widely interpreted as unambiguously coupled by a cause–effect link (CO_2 accumulation as the cause, climate change as the effect). Accordingly, at the background of growing concerns about the state of the planet, the scientific and technological search for the so-called alternative (with zero or low CO_2 emissions) energy sources is steadily intensifying (Sagar and Kartha, 2007; Martinot et al., 2007; Fischer and Newell, 2008). (There is another, quite unrelated, reason for this search: the anticipated fossil fuel exhaustion.) The conceptual basis for such an approach to the energy/environment problem consists in the statement that the absence of direct anthropogenic pollution is the single – necessary and sufficient – condition for the environment to remain stable and human-friendly.

During the same period when the global climate changes started to be monitored, there were, apart from CO_2 accumulation, other global processes in action, with their decisive impact on climate and environmental stability remaining largely overlooked in the conventional paradigm (Gorshkov et al., 2002, 2004; Li et al., 2008). The conventional energy/environment paradigm does not take into account the degree to which the environment is controlled by the global biota, the latter developing power by several orders of magnitude larger than does the modern civilization. By the end of the 20th century the anthropogenic disturbance of the biota had amounted to over 60% of land area (World Resources, 1988) and the environmental controlling functioning of the biota was globally disrupted. We argue that namely this fact rather than direct anthropogenic pollution of the planet is the primary cause of the global change. In other words, the importance of the so-called regulating ecosystem services (MEA, 2005) for environmental security is dramatically underestimated by current approaches to the biota–environment interaction. Environmental stability can only be restored by reducing the anthropogenic pressure on the biota. This is impossible without reducing the global rate of energy consumption of the civilization.

In this paper we review the available, and perform several original, estimates of the major natural energy fluxes in the biosphere (Section 2). We further analyze how the energy use is structured in the modern civilization and how the energetic needs of the civilization should be re-organized to be met without compromising the global environmental safety and without losing the essential ecosystem services, like rainfall and runoff or climate stabilization (Section 3).

Note the following energy units, approximate relationships and constants that are useful for comparing numerical data from various data sources: 1 kWh year^{-1} = 0.11 W; 1 btu (British thermal unit) = 1.055 kJ; 1 barrel oil day^{-1} ≈ 70 kW; 10^5 btu year^{-1} = 3.3 W.

2. Energy budget of the biosphere

The main energy fluxes existing in the biosphere are estimated in Table 1.

2.1. *Energy of solar and thermal radiation*

All major physical and biological processes on the Earth's surface are supported by solar radiation. The power of solar energy flux reaching the planet outside the atmosphere is 1.7×10^5 TW (1 TW ≡ 10^{12} W ≡ 10^{12} J s^{-1}). The ordered, spatially and temporarily concentrated fluxes of geothermal energy (geysers, volcanoes, earthquakes) are millions of times less powerful and, globally, do not exert any noticeable impact on the biotic and physicochemical processes (Table 1). The power of tides related to the Earth's rotation around its axis is more than two hundred thousands of times less than the power of solar radiation; so tides are energetically globally negligible as well (Table 1).

About 30% of the solar radiation flux is reflected by the planet back to space, mostly by clouds. The remaining 1.2×10^5 TW of solar radiation flux is absorbed by the Earth's surface and the atmosphere and is ultimately converted into thermal radiation. Thermal radiation leaving the Earth to space corresponds to a temperature of −18 °C. About 30% of solar radiation—approximately the same amount as is reflected into space, is absorbed by the atmosphere (again clouds mostly). Thus, it is around 8×10^4 TW of solar power that ultimately reaches the surface. This power supports all ordered physical and biological processes on the Earth's surface, including the civilization.

Flux of thermal radiation emitted by the Earth's surface to the atmosphere is equal to 2×10^5 TW, i.e. it exceeds the flux