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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 $\text{day}^{-1} \approx$ 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 $\equiv 10^{12}$ W $\equiv 10^{12}$ 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

Table 1 – Energy budget of the Earth's surface, 1 TW ≡ 10^{12} W

Power	Nature	Source
Total earth		
Solar radiation	8×10^4	1
Evaporation	4×10^4	1,2
Sensible heat fluxes	2×10^4	1,3
Thermohaline oceanic circulation	10^3	4
Atmospheric circulation (wind power)	10^3	5
Photosynthesis	10^2	6

Power	Nature	Civilization	Source
Land			
Solar radiation	3×10^4	0.004	1 [7]
Evaporation	5×10^3	n.u.	8,9
Transpiration	3×10^3	n.u.	8,9
Atmospheric circulation (wind power)	300	0.01	5, [7]
Photosynthesis	60	6 (40)[a]	6, [10]
River hydropower	3	0.3	8, [11]
Osmotic transition river–sea	3	n.u.	12
Oceanic waves	3	0.0001[b]	13, [7]
Tides	1	0.0001[b]	14, [7]
Geothermal (concentrated)	0.3	0.01[c]	15, [16]
Anthropogenic energy consumption		15	[11]

Sources of data (sources in square brackets refer to civilization): 1—Ramanathan (1987), Schneider (1989); 2—Makarieva and Gorshkov (2007); 3—Palmen and Newton (1969); Makarieva and Gorshkov (2006); 4—Section 2.2; 5—Section 2.3; 6—Whittaker and Likens (1975); 7—International Energy Agency (www.iea.org) Statistics for Renewables in 2004; 8—L'vovitch (1979); 9—Brutsaert (1982); 10—Gorshkov (1995); 11—Energy Information Administration, Official Energy Statistics from the U.S. Government (www.eia.doe.gov), data for 2005; 12—Section 2.4; 13—Akulichev (2006); 14—Hubbert (1971); 15—Starr (1971); 16—Hammons (2007).

[a] 6 TW is direct consumption of primary productivity (food of people and cattle and wood consumption); ~40 TW is the photosynthetic power of the biota on territories disturbed by anthropogenic activities (~60% of land area).

[b] Oceanic waves and tides combined.

[c] Civilization can only use concentrated sources of geothermal energy, like, e.g., geysers; total geothermal power on Earth is of the order of 15–30 TW (Berman, 1975; Hammons, 2007). n.u. not used.

of solar radiation absorbed by the planet by 40%. This difference arises due to the so-called greenhouse effect of the atmosphere. The atmosphere (or, more precisely, its certain greenhouse components like water vapor, cloudiness and CO_2) plays the role of a planetary "coat", which returns 40% of surface thermal radiation back to the surface. This elevates the mean global surface temperature to +15 °C from −18 °C that would have been observed in the absence of greenhouse effect.

Temperature difference between the surface and thermal radiation emitted into space from the absorption bands of greenhouse gas molecules, is equal to 33 °C. This difference does not coincide with the temperature difference between the surface and the upper troposphere. As everybody knows from everyday life, the latter difference is two-three times greater and is, therefore, unrelated to the magnitude of the planetary greenhouse effect (Makarieva and Gorshkov, 2007). (Greenhouse effect can exist at zero value of the vertical gradient of air temperature). The magnitude of the greenhouse effect is determined by the relative width of thermal spectrum that is covered by the absorption bands of the greenhouse substances. The absorption bands of water vapor and clouds cover practically the entire thermal spectrum, thus largely determining the magnitude of the planetary greenhouse effect. The absorption bands of CO_2 correspond to only 19% of the thermal spectrum width. Therefore, the increase of CO_2 in the atmosphere exerts only a minor influence on the greenhouse effect compared to water vapor, but it can considerably decrease air temperature in the upper atmosphere (Makarieva and Gorshkov, 2007). The cumulative thermal radiation into space will remain to be largely determined by the absorption bands of water vapor and clouds and will correspond to the temperature difference of the same 33 °C between the surface and thermal radiation emitted into space. This fact is ignored in many studies (Makarieva et al., 2004) and leads to an incorrect evaluation of the impact of atmospheric CO_2 accumulation on global mean surface temperature.

2.2. *Estimating the power of thermohaline circulation*

Thermohaline circulation is the global overturning of the ocean, with water masses sinking in the polar regions and upwelling elsewhere at lower latitudes.

Global mean temperature of the oceanic surface is 15 °C. Oceanic waters below 1 km have constant temperature of 4 °C world over. In the absence of thermohaline circulation, oceanic waters would have had uniform temperature at all depths. The reason for the constant low oceanic temperatures at depths below 1 km consists in the unique physical properties of water. Water has maximum density, i.e. it is the heaviest, at 4 °C. In the result, the cold polar waters sink to the depth of the ocean. The power of this downward flux, which occurs around the poles, is $F \approx 10^{15}\ \mathrm{m^3\ year^{-1}} = 3 \times 10^7\ \mathrm{m^3\ s^{-1}}$ (Stuiver and Quay, 1983). To compensate for this flux, water masses undergo upwelling over the remaining area of the world ocean, $S = 3.6 \times 10^{14}\ \mathrm{m^2}$. The water masses ascend and heat up to the surface temperature. The mean upwelling velocity is $u = F/S \approx 2\ \mathrm{m\ year^{-1}} = 5 \times 10^{-8}\ \mathrm{m\ s^{-1}}$. The waters are warmed from 4 to 15 °C, i.e. $\Delta T = 11$ K, during their upwelling from depth to the surface, at the expense of solar radiation. The energy flux of this heating is $\rho c \Delta T u$, where $\rho = 10^3\ \mathrm{kg\ m^{-3}}$ is water density, $c = 4.2\ \mathrm{kJ\ (kg\ K)^{-1}}$ is water heat capacity. The total global power of thermohaline circulation is thus $\rho c \Delta T u S = \rho c \Delta T F = 1.4 \times 10^{15}\ \mathrm{W} \approx 1 \times 10^3$ TW (Table 1).

2.3. *Estimating the power of atmospheric circulation*

Power of the wind atmospheric circulation is supported by solar energy. It creates upwelling vertical air fluxes that are compensated by the opposite horizontal flows of air at the surface and in the upper atmosphere. The upwelling water vapor fluxes lead to condensation of water vapor in the upper atmosphere and precipitation of the condensed moisture. In the result, the upwelling air fluxes move at the same velocity w. The global mean value of w is determined by the known value of global precipitation $\bar{P} = 10^3\,\mathrm{kg\,H_2O\,m^{-2}\,year^{-1}} = 1.7\,\mathrm{mmol\,H_2O\,m^{-2}\,s^{-1}}$. At global mean surface temperature of 15 °C concentration of water vapor near the surface is $N_{H_2O} = 0.7\,\mathrm{mol\,H_2O\,m^{-3}}$. Therefore the mean velocity of the upwelling water vapor and air is $\bar{E}/N_{H_2O} = 1\,\mathrm{mm\,s^{-1}}$. The force dictating upwelling of air masses arises due to the observed compression of the vertical distribution of water vapor, which is due to water vapor condensation in the upper atmosphere (Tverskoi, 1951; Weaver and Ramanathan, 1995; Makarieva et al., 2004, 2006; Makarieva and Gorshkov, 2007). This force is equal to $f_E = \beta\gamma\rho g$, where $\beta \approx 3$ is the compression coefficient, $\gamma = 2 \times 10^{-2}$ is the relative content of saturated water vapor near the surface at global mean surface temperature of 15 °C, $\rho \approx 1\,\mathrm{kg\,m^{-3}}$ is air density, $g = 9.8\,\mathrm{ms^{-2}}$ is the acceleration of gravity. The power of upwelling air masses is equal to $f_E w h_{H_2O} S \sim 10^3\,\mathrm{TW}$, where $h_{H_2O} = 2.4\,\mathrm{km}$ is the scale height of water vapor vertical distribution in the atmosphere, $S = 5 \times 10^{14}\,\mathrm{m}^2$ is the Earth's surface area.

2.4. *Estimating hydropower and the power of the osmotic transition river–sea*

Gross global hydropower is estimated as the power of global river runoff, which is, on average, 300 mm year^{-1} over all land or $R = 1.5 \times 10^6\,\mathrm{m^3\,s^{-1}}$, falling down from the mean height H of the continents, $H = 200$ m. The resulting power is equal to $R\rho g H = 3$ TW, where g is acceleration of gravity (L'vovitch, 1979). The economically available hydropower is estimated as 20% of the gross physical power, i.e. at 0.6 TW (Asarin and Danilov-Daniljan, 2006). At present the civilization already claims half of the economically available hydropower (Table 1).

Theoretical possibility of using power of the river–ocean transition is based on the salinity difference between river and oceanic water. One needs a semi-permeable membrane, which separates river and oceanic water and prevents the dissolved ions from penetrating to fresh water. In the meantime, the solvent (water) diffuses unimpeded through the membrane from the area of its higher concentration (fresh water) to the area of its lower concentration (oceanic water), which is the essence of osmosis. In the result, pressure and level of the oceanic water increases. The magnitude of this increase depends on the amount of dissolved ions, i.e. on the salinity of seawater.

The osmotic pressure of seawater dissolved ions (mean salinity 3.5%) equals 28 atmospheres. In terms of water column height, atmospheric pressure equals 10 m. Thus, the osmotic pressure of seawater can raise the level of seawater in a reservoir separated from river water by a semi-permeable membrane to up to 280 m. This is somewhat higher, but of the same order of magnitude, as the mean height of the continental river runoff. The theoretical power of using the osmotic transition river–ocean is therefore of the same order of magnitude as the global hydropower (Table 1). However, technical difficulties in creating the semi-permeable membranes firmly preclude the energetic use of the osmotic river–ocean transition.

3. Energy consumption and the environmental problems of our civilization

World total energy production and consumption is about 15 TW = 1.5×10^{13} W (Table 2). Energy consumption is partitioned between the non-renewable energy sources like oil (37%), coal (27%), natural gas (23%), and nuclear power (6%) and renewable energy sources, of which the most important is hydropower (Table 2). All the other sources of renewable energy are negligibly small on a global scale.

Global production of net electric power constitutes 13% of total energy production power. Deviations from this mean figure in particular countries are insignificant (Table 3). The main global energy source for production of electric power is fossil fuel burning (thermal electric power plants). Only in a few countries (France) a greater portion of electric power is produced from nuclear power.

Total energy consumption in France is equal to 4×10^2 GW, of which nuclear power makes up 36%, which is the largest relative amount in the world (Table 2). Nuclear power stations generate 79% of net electric power (Table 3) the latter accounting for 16% of total energy consumption (Table 3).

Table 2 – Distribution of global energy consumption, TW (1 TW ≡ 10^{12} W), over energy sources in 2005

Region	Total TW	Total (%)					
		Oil	Coal	Gas	Nuclear	Hydro	Other
World	15.4	37	27	23	6 (2)	6 (2)	1
USA	3.4	42	22	23	9 (3)	3 (1)	1
China	2.2	22	68	3	1 (0.3)	6 (2)	≪1
Russia	1.0	19	16	55	5 (1)	5 (2)	≪1
Japan	0.8	51	18	15	12 (4)	3 (1)	1
France	0.4	40	4	16	36 (14)	4 (1)	≪1

Data of the U.S. Energy Information Agency (www.eia.doe.gov, assessed 29 April 2008). The first four countries listed account for over half of the world's energy consumption.

Civilian nuclear energy is exclusively used for generation of electricity. The efficiency of electric power production from nuclear power and hydropower (it is equal to the ratio between net electricity generation power (Table 3) and gross electricity generation power) does not exceed 35%. Therefore, the usable share of nuclear power and hydropower (figures in braces) constitutes less than one third of total nuclear power and hydropower.

Table 3 – Distribution of net electric power production over different energy sources (same data source as in Table 2 data for 2005)

Region	Total electric power (TW)	Thermal (Oil, coal, gas) (%)	Nuclear (%)	Hydro (%)	Other (%)	Share of electric power in total energy consumption (%)
World	1.98	66	15	17	2	13
USA	0.46	72	19	7	3	14
China	0.27	81	2	17	≪1	12
Russia	0.10	65	16	19	≪1	10
Japan	0.12	63	27	8	2	15
France	0.06	11	79	9	1	16

This is about one third of all power delivered by nuclear power stations. The remaining two thirds are spent on heat production (Table 2). Predominantly, it is waste heat, because, due to its high radioactivity, it is very difficult to use it in livelihoods and industries. As is well known, for safety reasons nuclear power plants are built outside densely populated cities, which poses additional difficulty for utilizing nuclear heat. (The same ratio of usable to waste power is characteristic of all nuclear reactors functioning in Japan, USA and Russia). In the result, nuclear power contributes only 14% ($0.79 \times 0.16/(1 - 0.36 \times 1/3) \times 100\%$) to the consumption of usable energy in France, not 36% and by far not 80%, as one is periodically misinformed by the mass-media. Similarly, the global share of usable nuclear power in the total energy consumption of the world is only 2% (Table 2) which coincides with the contribution of usable hydropower.

To summarize, modern civilization practically exclusively relies on fossil fuels, which account for about nine tenths of global energy consumption (Table 2). Fossil fuels are considered dangerous because of greenhouse gas (CO_2) emissions associated with their burning, hence the modern hunt for environmentally friendly renewables. Generally, there are two widespread, mutually exclusive attitudes towards global climatic change. According to the first one, climate change does exist, it is of anthropogenic origin AND it is caused by CO_2 emissions. According to the second one, the existence of directional climatic change is reasonably questionable; but even if it does exist, it is not of anthropogenic origin and, in particular, is unrelated to CO_2 emissions. However, as already noted, although CO_2 is a greenhouse gas, it is not the major one in the atmosphere of Earth. All greenhouse substances – water vapor, cloudiness and CO_2 – are involved into biogeochemical cycles and controlled by the natural biota of Earth (Makar'eva and Gorshkov, 2001; Gorshkov and Makarieva, 2002). This control is mainly implemented through regulation of the atmospheric amounts of water vapor and clouds, which represent the major greenhouse substances of Earth's atmosphere. Therefore, namely the anthropogenic disturbance of this controlling mechanism, natural ecosystems, by deforestation on land in the first place, is responsible for the climate anomalies that are being observed with increasing frequency. In other words, global scale stabilization of life-compatible surface temperature is an essential regulating ecosystem service provided by the biota, which is currently largely neglected and which remains practically unstudied. We argue, breaking the conventional dichotomy of approaches to climate change, that, although climate change does exist and is of anthropogenic origin, its primary cause IS NOT the build-up of atmospheric CO_2.

The second widely appreciated disadvantage of using fossil fuels as the main energy source is their clearly foreseeable exhaustion. Easily accessible stores of oil, gas and uranium are to be depleted within a few coming decades, of coal—within one century. Here, again, search for alternative energy sources to replace the fossils appears to be an obvious strategy to pursue. It is commonly perceived as self-evident and hardly demanding any logical analysis. A fundamentally different strategy of solving the energetic and environmental problems of civilization follows, however, from the consideration of the biotic regulation mechanism. Let us quantify the amount by which the humanity has reduced the power of this mechanism. Total power of the global biota is of the order of 100 TW, of which land biota accounts for approximately two thirds. Humans have destroyed natural biota on 60% of land, which means the global regulatory biotic power has been reduced by approximately 40 TW. This figure comprises about 6 TW of the primary productivity of the biota consumed by the civilization in the form of food for people, cattle fodder and wood. The remaining power pertains to disturbed ecosystems incapable of performing environmental control.

The value of 40 TW characterizes the destabilizing environmental impact of the humanity. It is determined by the scope of anthropogenic activities on the planet that are supported by direct energy consumption of 15 TW (Table 1). Thus, irrespective of whether anthropogenic energy consumption is accompanied by environmental pollution (e.g., CO_2 emissions) or not, as long as its magnitude remains unchanged, the destabilizing environmental impact of humans will persist as well. Notably, 40 TW is more than twice a higher power than the direct anthropogenic energy consumption. Global environmental stability can only be regained if one restores the biotic mechanism of climate control, which is possible if the energetic impact on the biota is reduced by at least one order of magnitude (Gorshkov et al., 2000).

Increasing energy efficiency is widely discussed as one of possible measures towards solution of both the energetic and environmental problems of the civilization. The destabilizing impact the humanity imposes on the biosphere is determined, however, by the useful power of energy consumption P_u, which fuels all anthropogenic activities. The efficiency of energy conversion, s, is defined as the ratio of useful power P_u to the total consumed power P_t, $\varepsilon = P_u/P_t$. If energy efficiency s is increased at fixed total power P_t, this means that the useful power available for anthropogenic transformation of the biosphere, increases as well. This will only stimulate further degradation of environmental stability. If energy efficiency s is increased at fixed useful power P_u, this means that the total consumed power P_t decreases. This allows one to diminish the rate at which the resources are depleted and the environment is polluted by fossil fuel burning. However, this will not diminish the rate at which natural ecosystems are destroyed, because this rate is determined by the value of P_u. To decelerate degradation of the biotic regulation mechanism and to re-gain environmental stability one needs to reduce the global value of P_u, irrespective of whether energy efficiency is high or low. Therefore, although widely discussed in the environmental context, the problem of energy efficiency is logically unrelated to the problem of climate and environment stabilization.

Growth of energy consumption opens a possibility for acceleration of population growth up to the maximum possible rate determined by the biological reproductive capacity of the woman. In its turn, population growth demands increased energy consumption. Until fossil fuels are depleted, the power of energy consumption can grow arbitrarily rapidly, as dictated by the rate of demographic and economic growth. There is no logic in substituting fossil fuels by some pollution-free renewable energy sources. It is necessary to reduce the very magnitude of energy consumption and the related magnitude of the anthropogenic pressure on the biosphere. Growing population numbers, the associated growth of energy consumption and scope of human activities, degradation of the remaining natural ecosystems, can lead to an irreversible loss of climate and environmental stability well before the fossil fuels stores are depleted.

4. Discussion: renewable energy sources and the sustainability of life-important ecosystem services

Early in the history of the industrial burning of fossil fuels, their share in the global energy consumption was negligibly small. The environmental danger associated with fossil fuel burning started to be discussed only after its apparent consequences (CO_2 build-up in the atmosphere) became globally significant. At present the share of renewable energy sources in the energy consumption budget of the civilization is approximately as small as was the share of fossil fuels a century ago (Table 2). And again, as with respect to fossil fuels, there is a wide-spread and scientifically unverified opinion that the consumption rate of renewables can be safely increased to ultimately fully substitute fossil fuels, with global energy consumption rate remaining the same or even growing. This strategy is justified by the single environmental argument that the use of renewable energy sources is not accompanied by CO_2 emissions (“clean” energy sources). However, the available, although largely disregarded, scientific knowledge is already sufficient for this strategy to be rendered as directly facilitating environmental degradation.

Among the renewable energy sources currently used by the humanity, river hydropower is the most significant one (Table 2). However, all the available hydropower is one order of magnitude smaller than the modern global power of energy consumption (Table 1). At present, about half of the technologically available and economically relevant hydropower is already used up (L’vovitch, 1979; Asarin and Danilov-Daniljan, 2006). Use of hydropower by the civilization cannot be significantly increased.

The power of atmospheric circulation on land (wind power) is twenty times larger than the modern global power of energy consumption (Table 1). However, wind on land is controlled by the natural vegetative cover (forest) (Makarieva et al., 2006; Makarieva and Gorshkov, 2007). Natural forests act as pumps of atmospheric moisture, with the forest-induced atmospheric circulation delivering moisture from the ocean to land. This process compensates the gravitational river runoff and supports soil moisture and biological productivity on land. Maintenance of water cycle on land emerges as one of the most important ecosystem services (classifiable as both provisioning and regulating, see MEA, 2005) delivered by the biosphere to our civilization. Sustainability of this service is critical for the well being of the humanity.

In the meantime, when the moisture-laden ocean-to-land winds are, on their way to land, impeded by windmills, this steals moisture from the continent and undermines the water cycle on land; the more so, the greater the extent of the anthropogenic consumption of wind power. In its effect, the use of wind power is equivalent to deforestation. Not to threaten the terrestrial water cycle, wind power stations can thus be allowed to exempt less than one per cent of the total wind power, which means no more than 5% of the modern rate of global energy consumption. Even this low figure is difficult to achieve due to the various technical limitations. To conclude, windmills will never be able to compete in power with the existing hydrological dams.

Thermohaline circulation plays a most important role in the maintenance of the stability of the Earth’s climate. The use of thermodynamic machine producing power at the expense of the difference between sea temperatures at the surface and at depths can dramatically aggravate the environmental problems of the humanity.

Solar power constitutes the basis of the energetic budget of the biosphere. Natural ecological communities of the biota maintain particular atmospheric concentrations of greenhouse substances with relatively narrow absorption bands but large optical depth (product of atmospheric height, absorption cross-section and concentration). Such greenhouse substances do not significantly influence the planetary greenhouse effect, see Section 2.1, but create a negative vertical temperature gradient in the terrestrial atmosphere. This brings about the observed non-equilibrium state of atmospheric water vapor, upwelling air fluxes and atmospheric circulation. Due to the large value of this gradient, 3/4 of solar power on the Earth’s surface is transformed into the power of sensible and latent (evaporation) heat fluxes (Table 1, Makarieva et al., 2006). On land, natural forest cover maintains optimal soil moistening and compensates river runoff by pumping atmospheric moisture evaporated from the ocean (Makarieva and Gorshkov, 2007). Thus, photosynthesis performed by green plants consuming solar energy is the main controlling process for this life-supporting circulation (this process is already disrupted by human activities on two thirds of land area (Table 1).

In several billion years, life has evolved maximum efficiency in the use of solar energy for generation of all these life-important ecosystem services. Any large-scale consumption of solar energy, currently almost invariably perceived as harmless and environmentally friendly, will have a catastrophic impact on the resilience of these critically important life-supporting processes.

The main danger for the life-compatible environment and climate on Earth consists in the excessively high absolute magnitude of global anthropogenic energy consumption. This danger persists irrespective of whether this consumption is accompanied by direct environmental pollution like CO_2 emissions or not. Modern or, even more so, growing energy consumption will totally destroy Earth's environment within the coming decades. Within the nearest century it is necessary to reduce global energy consumption by one order of magnitude, when it can be met by the existing renewable energy sources without causing environmental and climatic problems. This demands a detailed scientific analysis of the biotic nature of environmental stability on Earth and of possible ways of how the imperative of reducing global energy consumption could be constructively faced. In the absence of such an analysis, the attempts to find alternative energy sources (including thermonuclear power) to sustain modern or growing energy consumption of the civilization represent a logical dead-end, which will result in but further aggravation of the dangerous situation the civilization today finds itself in, with clearly foreseeable loss of the most important ecosystem services on which the humanity is critically dependent.

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