Working Paper

Sustainable Biosphere (Critical Overview of the Basic Concepts of Sustainability)

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Anastasia Svirejeva-Hopkins

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Preface

This paper was prepared by the authors during their visits to IIASA in 1994-1996.

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(Critical Overview of the Basic Concepts of Sustainability)

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1. LIMITS TO GROWTH

All populations, including *Homo Sapiens*, when developed in conditions of limited resources, sooner or later reaches a maximum size, determined by the so called carrying capacity of the environment. When approaching that limit, the mechanisms responsible for slowing growth start to work and exponential (or even faster than exponential - like *Homo sapience*), growth slows and later stops. The population has occupies its new ecological niche. In natural populations, these mechanisms usually work by competition for food resources, hunger, diseases and epizootics. All this was described by T. Malthus in relation to Human populations. Since the concrete consequences of these regulation mechanisms are anti-humanitarian from the moral and spiritual point of view (hunger, wars and epidemics), then the criticism of Malthus is understandable (although how would you impose the nature out moral criteria, or understanding of good and bad).

Of course, there are other possibilities for the regulation of population processes. The first and the most obvious one - is the birth control, quite humanitarian, which is unofficially approved by Catholics. Unfortunately, in a lot of countries (in India, for example) the different programs for regulation and limitation of birth do not produce great results. I think the reasons are not only the religious and national traditions (for example the marriage age, the amount of children, the sex relation) but attributers are also to a gradual increase in the economic well being and improving quality if life of succeeding generations on certain demographic impacts.

The second method to avoid the negative consequences of approaching the population limit is to change the value of maximum size of population, in other words, to increase the carrying capacity of the environment. It could be done with the help of either more efficient use of resources, or by the expansion of resource in physical space. Until now, the human population was developing in just this way. It is clear, however, that this way of development has its limits: there are thermodynamic limits of effective use of resources, and the finiteness of our Planet determines the finiteness of our resources and the limits of expansion. These concepts were a basis for investigation by the Club of Rome and its successors. (Forrester, 1971, Meadows, etc., 1972)

There is, also the possibility of expansion into outer space, but that is not the near future and we are not going to be considering it.

2. SUSTAINABLE DEVELOPMENT

The works of the Club of Rome concluded that: in order to avoid ecological, demographic and resource (the result of natural resource exhaustion) disasters in the near future, it is necessary to stop demographic and economic growth i.e. the areas of economy, connected with resource usage. In other words, to rescue human population, the concept of zero growth has been suggested.

Naturally, this concept has caused intense criticism in both developed (with the liberal market economies, for example, USA) and developing countries of the Third World.

If in developed countries the main argument had to deal with the unlimited trust in opportunities of a liberal economy ("give business a freedom and it will solve all these problems" - N. Rockfeller), then developing countries were accusing the first ones in national egoism: "the developed countries have already solved their problems, but we are just facing them and our economy has to grow very fast in order to do it." The situation has grown tense and Brundtland Commission was formed as a compromise, which released the tension. The Commission suggested the remarkable concept of "Sustainable Development"; which looks far more attractive than the severe neo-Malthusian concept of "zero-growth". The question is : can sustainable development for the whole Earth exist in reality? Later, we are going to try to answer this question.

But, before that in order to better understand the whole concept, let us quote several sentences from the book "Our Common Future. From one Earth to one World", 1987.

Sustainable Development

Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth. The Commission believes that widespread poverty is no longer inevitable. Poverty is not only an evil in itself, but sustainable development requires meeting the basic needs of all and extending to all the opportunity to fulfill their aspirations for a better life. A world in which poverty is endemic will always be prone to ecological and other catastrophes. Meeting essential needs requires not only a new era of economic growth for nations in which the majority are poor, but an assurance that those poor get their fair share of the resources required to sustain that growth..."

"Sustainable global development requires that those who are more affluent adopt life-styles within the planet's ecological means - in their use of energy, for example. Further, rapidly growing populations can increase the pressure on resources and slow any rise in living standards; thus sustainable development can only be pursued if population size and growth are in harmony with the changing productive potential of the ecosystem.

Yet in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. We do not pretend that the process is easy or straightforward. Painful choices have to be made. Thus, in the final analysis, sustainable development must rest on political will." (More detailed discussion about sustainability - see Appendix 1).

Let us look at the last paragraph - from which it follows that a sustainable development strategy is quite realistic and there is no physical, biological or other natural and scientific limitations, and its realization depends only on corresponding political decisions. We shall try to show that the situation is far more complicated, that what exists is the myth of sustainable development but not sustainable development itself.

Let us, at first answer a very important question:

3. "HOW MANY PEOPLE CAN LIVE ON THE EARTH?"

There are quite a few estimates of the "carrying capacity" of ecological (trophic) niche for *Homo Sapiens* species. Most estimates are tied to the ability of Biosphere to provide food for growing populations. For 30 % of the planet population, hunger related to agricultural production is the main factor.

The maximum estimation assumes that all net primary production of the biosphere is used as food (Odum, E., 1983). The estimation is quite rough and idealized, but it gives an idea about growth limits.

If we consider, that net production composes a half of total gross production, then the productivity of the biosphere is $5 * 10^{17}$ kcal/year. One human individual spends about $1 * 10^{6}$ kcal per year in the form of food, and then, if we assume that all this organic production is utilized by humans then the upper limit for the human population is 500 billion. The 500 billion are located on $1.4 * 10^{14}$ m^2 of land, or 280 m^2 of surface area per person.

The minimum estimation is calculated by which could be called by E. Odum (1983), assuming $6.7 * 10^{15}$ kcal of food is collected all over the world. (in other words, the organics, which traditionally consumed by humans). Badly regulated distribution, large losses, low quality of crops, reduce this amount significantly. If we presuppose, that by organizing everything perfectly, we could eliminate these losses, then the modern agriculture could feed no more then 6.7 billion people.

The intermediate estimation is based on assumption, that agriculture is based on cereals, with significant consumption of artificial energy. Its productivity constitutes an average $5 * 10^{3}$ kcal /(m^2 * year). Then one person will need (in the condition of vegetarian diet) 200 m^2 of arable land. Considering, that no more then 25 % of the land territory could be used for agriculture, we estimate the population at about 170 billion.

Unfortunately, the intermediate estimation is not the mean one. There are other limitations, which reduce this number significantly. The maximal possible population, calculated with the help of the Moscow global model of biosphere processes (Krapivin, Svirezhev, Tarko, 1982) was about 16 - 17 billion people (presupposing that all major contemporary tendencies for economic development are going to be maintained during next 100 years and no revolutionary changes in food processing will be introduced).

4. TECHNOCRAT'S ILLUSIONS

Principally, it is possible to imagine algae as a food source. This will cause the artificial energy consumption to increase, because these technologies require large amounts of mineral resources and energy.

Theoretically, the maximum possible production of algae culture is on average $2,5 * 10^{4}$ kcal/m^2 per year, so only 40 m^2 is needed for supporting one person. However, at the present time using these technologies, in order to produce 1 kcal of organics 600 kcal artificial energy should be spent. The input is equal to $6 * 10^{8}$ kcal (or 400 barrels of oil) in a year per individual. In order to feed an existing population

(5 billion people) using this technology, $2 * 10^{12}$ barrels of oil must be extracted, which is 20 times higher than all the oil extracted today.

There are other sources of energy, of course. Physicists promise us an "ocean" of energy as a result of high-temperature synthesis. At first glance, it could be also used for food production, but other factors are at work here. An increase in energy consumption of 25-30 times could break the global climatic equilibrium. Because energy transforms into heat and an increase in atmospheric temperature will cause a deterioration of the current metastable climate state into one of two possible stable states. It is either going to be either going to be so warm that the polar ice begins to melt and most of civilization's centers will be flooded, or winter will take over all of the planet.

With these considerations in mind, solutions for overpopulation will not be found with extensive increases in energy production from new technologies, i.e. the technocratic solution will fail.

5. FOOD SECURITY: SUSTAINING THE POTENTIAL

Let us see how the Brundtland Commission suggests solving the problem of food production within the framework of "sustainable development".

"Growth in world cereal production has steadily outstripped world population growth. Yet, each year there are more people in the world who do not get enough food. Global agriculture has the potential to grow enough food for all, but food is often not available where it is needed.

Production in industrialized countries has usually been highly subsidized and protected from international competition. These subsidies have encouraged the overuse of soil and chemicals, the pollution of both water resources and foods with these chemicals, and the degradation of the countryside. Much of this effort has produced surpluses and their associated financial burdens. And some of this surplus has been sent at concessional rates to the developing world, where it has undermined the farming policies of recipient nations. There is, however, growing awareness in some countries of the environmental and economic consequences of such paths, and the emphasis of agricultural policies is to encourage conservation.

Many developing countries, on the other hand, have suffered the opposite problem: farmers are not sufficiently supported. In some, imported technology allied to price incentives and government services has produced a major breakthrough in food production. But elsewhere, the food-growing small farmers have been neglected. Coping with often inadequate technology and few economic incentives, many are pushed onto marginal land: too dry, too steep, lacking in nutrients. Forests are cleared and productive dry lands rendered barren.

Most developing nations need more effective incentive systems to encourage production, especially of food crops. In short, the 'terms of trade' need to be turned in favor of small farmer. Most industrialized nations, on the other hand, must alter present systems in order to cut surpluses, to reduce unfair competition with nations that may have real comparative advantages, and to promote ecologically sound farming practices.

Food security requires attention to questions of distribution, since hunger often arises from lack of purchasing power rather than lack of available food. It can be furthered by land reforms, and by policies to protect vulnerable subsistence farmers, pastoralists, and the landless - groups which by the year 2000 will include 220 million households. Their greater prosperity will depend on integrated rural development that increases work opportunities both inside and outside agriculture."

We see, that suggested strategy is a strategy of improvement of already existing technology of food production. Of course, this strategy increases the carrying capacity of the trophic niche for humans. But it does not cancel those upper limits for the size of the trophic ecological niche, which we have discussed earlier. (See#3).

Now, let us consider one more way of increase of carrying capacity of the trophic niche.

6. THE INCREASE IN FOOD PRODUCTION: ECOLOGICAL APPROACH

Usually, ecosystems consist of two chains: grazing and detritus, where a significant part of energy (sometimes more then half) goes to the detritus chain. Humans use the grazing chain for their consumption. Timofeev-Resovski (1968) has proved for the first time that humans can globally use the detritus chain. As an example he pointed out the possibility of using a "sapropel" (half decomposed and transformed organics on the bottom of the water bodies), as a food source. One more quality of the detritus chain makes it useful for this purpose: buffering capacity, the capacity allowing to accumulate and store organics for a long time. For example, there is enough sapropel only in the water reservoirs of European part of Russia for providing food for all of its population for 100 years. But sapropel accumulates again and again. The only thing needed, is a technology for its processing, but this task has been partially completed in Japan.

And what is more, the removal of parts of stored matter in detritus chain accelerates matter circulation in the whole ecosystem, which in turn, increases its productivity. But this increases the efficiency coefficient for the system. It is obvious, the food production problem should be solved with ecological means and not technocratic solutions.

7. ONE MORE TECHNOCRATIC ILLUSION. THE LIMITS TO AGRICULTURE INTENSIFICATION

It is known that intensification of agriculture (the increase of crop production) correlates with increase of artificial energy flow in the ecosystem. Indeed, the increase of fertilizers input, usage of complex infrastructure, pesticides, herbicides etc., i.e. all that is called a "modern agriculture technology", results in greater crop production. This is a typical pattern of development agriculture in industrial countries.

However, there are limits, determined by physical laws. In other words, we pay the price for increasing of the productivity of agriculture, which is a degradation of the environment (including soil degradation).

It is obvious from the analysis of maize production in Hungary in 80-es (Svirezhev et al., 1990).

Let the gross agroecosystem production be P_l, the net production be $(1 - r)\,P_l$, where r is the *respiration coefficient*, so that rP_l are the *respiration losses*. For maize crop in the temperate zone $r \doteq 0.4$. The k^{th} part of the net production is being extracted from the system with the yield, so that the *crop yield*

$$y = k(1-r)P_1 \quad (1)$$

Let σ be the annual entropy production (overproduction) by one area unit of agroecosystem and T be the mean temperature of vegetation period in this site (in K).
Then the entropy balance of this system is:

$$\sigma T = (1-k)(1-r)P_1 + rP_1 + W - P_0 \quad (2)$$

where W is the *artificial energy inflow* and P_0 is the *gross production of successionally closed ecosystem.* In the Hungarian case it is a middle - European steppe.

There is an empirical relation between P_1 *(*and *y)* and W *(*let us remember, even if the ecological-energetic analysis by D.Pimentel et al. was very popular in 1970s - 1980s). Results of this popularity is that we know the coefficients of energy efficiency ($\eta = y / W$) for different agroecosystems of many countries and various regions.

The average yield of maize was 4.9 t/ha (in dry matter), which makes 0.735 * 10 ^{11} J/ha. For maize production in Hungary η = 2.7 and k = 0.5. Since the steppe community is a successionally close ecosystem for a corn field after cultivation is stopped (grassland of the temperate zone), then the gross production

$$P_0 = 2800 \text{ kcal/m}^2 = 1.18 * 10^{11} \text{ J/ha.}$$

Substituting these values into (2) , we get:

$$\sigma T = 0.8 * 10^{11} \text{ J/ha.}$$

On the other hand, artificial energy input to the system is

$$W = 0.27 * 10^{11} \text{ J/ha.}$$

Therefore, *compensation for environmental degradation requires the 300% increment in energy input with all the additional energy spent only for soil reclamation, pollution control, etc. with no increase in the crop production.*

From the condition $\sigma = 0$ we have $W_{crit.}$ = 16 GJ/ha. (1GJ = 10^9J). Let us compare this value with the value of "the limit energy load", which has been got by M.Simmons by means of very concrete and detailed calculation. This value is equal to 15 GJ/ha. It is a very curious coincidence, is not it?

Calculating $y_{crit.}$ (from (2) at $\sigma = 0$), we get $y_{crit.}$ = 2.9 t/ha. This is the estimation of maximal crop production (in dry matter) for "sustainable" or "ecological" agriculture.

Let us suppose, that the primary degradation process, which accumulates all the degradation processes, is soil erosion. If we have the thermodynamic model of soil erosion, we can estimate the annual erosion losses resulting from the intensive agriculture. In accordance with (Svirezhev, 1990), the erosion loss of 1t of soil from one hectare corresponds to the production of entropy σ_S: Then $\sigma_S * T = 0.31 * 10^{10}$ J/ha. Consequently, high crop production will cost us 26 tons of soil loss annually. By the

USA standards, no more than 10t of soil may be lost from a hectare. Obviously, 26 tons per hectare is the extreme estimate: the actual losses are less, since there are other degradation processes, like environmental pollution, soil acidification (this factor is very important for Hungary), etc.

Within the framework of the thermodynamic approach we can calculate the entropy of these processes as well. For example, the entropy contribution to the acidification of soil can be calculated in terms of appropriate chemical potentials. However, (and this is the principal constraint of thermodynamic approach), we can not predict the way of realisation the degradation of the environment: the strong mechanical degradation of soil and weak chemical pollution, the high acidification of soil, the strong chemical contamination by pesticides and fertilisers, or some intermediate ways. Every way is equiprobable. For the solution of this problem some additional information is needed.

On the other hand, this approach gives as the possibility to estimate the "entropy fee", which the mankind pays for high crop yield, for intensification of agriculture. Overproduction of entropy can be compensated by processes of environmental degradation , in particularly, by soil degradation. It is known that the loss about 40% of soil tends to fast fall of crop yield to 5-7 times (G. Dobrovolsky The Soil Geography, Moscow Univ. Press, Moscow, 1974). This is a typical agricultural disaster. But it is a disaster from anthropocentric point of view, from point of view of physics laws, a fall of crop yield by the reason of soil degradation is a natural reaction of physical system, tending to decrease an internal production of entropy and to minimise its overproduction. It is the consequences of the Prigogine theorem. The corresponding estimations for Hungary shows that if the intensive production of maize would be continued, it would be finished by agricultural disaster through 30-40 years.

8. COMPARATIVE ANALYSIS FOR ENERGETICS OF THE BIOSPHERE AND TECHNOSPHERE

In order to do the correct analysis of sustainabiliry concept we must analyse the main dynamic factor of evolution for biosphere and techosphere (anthroposphere), i.e. to compare their energy flows patterns.

The Biosphere, as an open thermodynamic system, exists with a permanent flow of solar energy. Earth receives $1.2*10^{22}$ kcal of solar energy per year (which maintains the work of climatic machine). Vegetation is the main concentrator and transformator of solar energy in the Biosphere, but uses only $2.5*10^{20}$ kcal/year (Krapivin, Svirezhev, Tarko, 1982). This energy is spent on the evaporation through the leaves, providing water and nutrient transport, and creating new biomass.

The function of the "green cover" results in $1.3*10^{18}$ kcal/year of the new biomass. Approximately 60% of it is immediately used for respiration and the rest 40 % is the *annual global production,* which is equal to $5.4*10^{17}$ kcal/year.

The energetic characteristics of the Biosphere have not significantly changed since the beginning of photosynthesis (0.5 - $1*10^{9}$ years ago). The functioning of autotrophic component of the Biosphere provides the energetic basis for evolution of animals ("biological evolution"). Since, the efficiency coefficient of this autotrophic component is equal to:

$$\eta = 5.4*10^{17} / 2.5*10^{20} \approx 0.2\ \%.$$

Then, the Biosphere stability is maintained by the continuous dissipation of energy. In other words, the Biosphere is a typical *dissipative system.* This energy flow provides the steady state for $1.84*10^{18}$ grams of living biomass (or $8.3*10^{18}$ kcal), and the animal biomass is only 0.8%, i.e. $1.46*10^{16}$ grams. Only 3% of annual net-production ($1.75*10^{16}$ kcal/year) of plants is consumed by animals (Smil, 1991). This energy flow supports both a metabolism of living matter and its diversity, i. e. the *information basis of evolution.*

At the present time, the Technosphere of Earth (technological civilisation) spends about $6.9*10^{16}$ *kcal/year* (Krapivin, Svirezhev, Tarko, 1982) for its functioning and evolution. This is mainly the energy of fossil fuels and nuclear energy. The part of pure biosphere energy (water energy, wood) in this balance is small ($\approx$5 %).

Obviously, *Homo Sapiens* is a component both of the Biosphere and the Technosphere.

If we consider humans as animals, then all human energetic requirements are satisfied through food, and the annual energy demand per individual is 10^6 kcal. For the current population size of *Homo Sapiens* ($\approx 5*10^9$ individuals) annual energy demand is equal to $5*10^{15}$ kcal/year. When we compare these variables, one can see that *the energy demand of mankind as a biological species is currently equal to 1/3 of the total biological energy of the Biosphere.* The Figure 1 represents the dynamics of food energy demand for mankind, using the reconstruction of human population growth from Neolithic era.

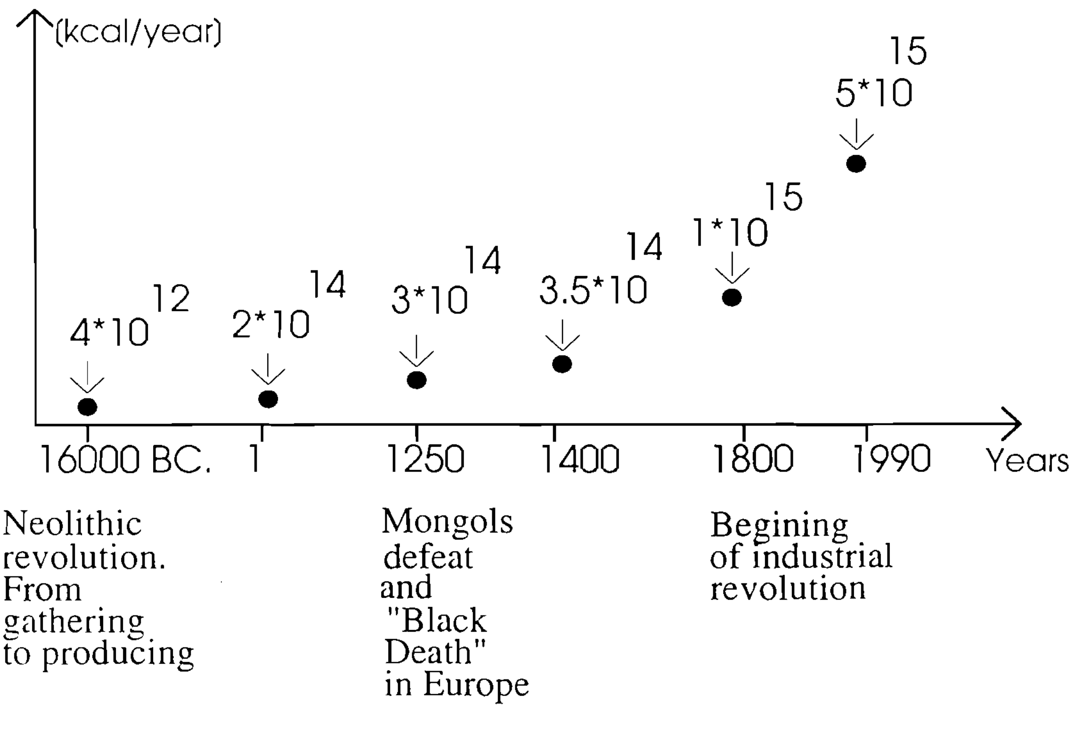

Fig.1 Energy food demand for mankind. Source: (Krapivin, Svirezhev, Tarko, 1982)

Until Neolithic revolution, when a man had changed his behaviour from gathering to producing food, he was a part of the Biosphere, no different from other animals. The human population was $4*10^6$ individuals, and required an energy supply of $4*10^{12}$ kcal/year, which was 0.023 % of the energy flow for all animals.

According to the physical theory of fluctuations (Landau, Lifshitz, 1964) the probability of fluctuation which could cause the elimination of *Homo Sapiens* is equal to:

$$P_e = exp\{- \frac{energy\ demand\ for\ human\ population}{energy\ supply\ for\ all\ animals}\}$$

$$= exp\ \{ -4*10^{12} / 1.75*10^{16} \} = 99.9\% .$$

During the time period from Neolit until the origin of the Technosphere (XVIII century) with its own source of energy (fossil fuels), Humans were the part of the Biosphere only. They were competing with other species, and had increased their energy demand up to $6*10^{14}$ kcal/year and the probability of their elimination diminished:

$$P_e' = exp\ \{ -6*10^{14} / 1.75*10^{16} \} = 96.6\ \%.$$

Looking at these numbers one can say that as a biological species, *Homo Sapiens* were very fortunate that they were not eliminated before the origin of the Technosphere.

The primary biosphere net production ($5.4*10^{17}$ kcal/year), is the energy flow which supports the diversity of biota. Even now, the energy flow, used by the Technosphere ($6.9*10^{16}$ kcal/year), is about 10% of the total primary production of the Biosphere. The conclusion is: At the present moment, the Biosphere and Technosphere are in a state of strong competition for common resources, such as land area and fresh water. Pollution of the environment and reduction of biota diversity are the consequences of this competition.

Since, the Biosphere (considered as an open thermodynamic system) is in the state of dynamic equilibrium, then all entropy flows must be balanced too. Therefore, the entropy excess, which is produced by the Technosphere, must be compensated by means of two processes:

1. Biosphere degradation;
2. Change in the work of the Earth climate machine (in particular, increasing of the Earth's average temperature).

Let us assume that all energy, consumed by the Technosphere, is transformed into heat Q. Then the annual entropy produced by the Technosphere, is equal to :

$$S_t = Q/T = 6.9*10^{16} \text{ kcal/287 K*year} = 2.4*10^{14} \text{ kcal/K*year}$$

(The annual average temperature of Earth (T) is equal to 14°C or 273+14=287 K.)

The full destruction of biota , which, we assume, is equivalent to its full combustion, gives us the following value of entropy:

$$S_d = 8.3*10^{18} / 287 \text{ K} = 2.9*10^{16} \text{ kcal/K}.$$

If we assume that the energy consumption of the Technosphere will not be increased, then this "anti-entropy storage" of biota is enough for compensation of the technosphere entropy production during 100 years. If this technogenic entropy is used for soil destruction, then the agony would take 300-400 years more, since the organic matter storage in soil is 3-4 times larger than in biota.

9. INDUSTRY, ENERGY AND ENVIRONMENT. THE MYTH OF SUSTAINABLE DEVELOPMENT

In this section we would like to formulate several theses, which could provoke an interesting discussion.

* Sustainable Development for the world community is the Brundtland Commission's main idea.

* Sustainable Development means:
- the development of the world's industry and technology while saving its natural environment;

* Sustainable Development is an old idea. Let us remember that still V. Vernadsky (see Appendix 3) spoke of the new global system called him the "Noosphere", which is the result of the evolution of the Biosphere under the influence of human technological civilisation.

* Unfortunately this very attractive idea of Sustainable Development runs counter to the basic laws of physics (the Second Law of Thermodynamics).

What arguments can be used for proof of this last thesis? Let us consider the entropy balance of one area unit of the Biosphere, occupied some natural ecosystem (in detail see Appendix 2). From the viewpoint of thermodynamics, any ecosystem is an open thermodynamic system. Climax of the ecosystem corresponds to the dynamic equilibrium (steady - state), when the entropy production in a system is balanced with the entropy flow from the system to the environment. This work is being done by the "entropy pump".
In other words, *the climatic, hydrological, soil and other environmental conditions are organised in such a way, that only natural ecosystem, which is specific for these conditions is at the equilibrium state.*
Let us suppose that the considered area is influenced by anthropogenic pressure, i.e.
a) The direct flow of artificial energy takes place (energy load).
b)There is the inflow of chemical elements inside the system (chemical load).
It is a typical impact of industry (and in broad sense, technological civilisation) on the environment.

* If we consider the main characters of technological civilisation, we can see that they create the energy and chemical loads. These characters are:

a) the use of non-biosphere sources of energy (fossil fuels - are the traces of past biospheres, not replenishable by the current biosphere; nuclear energy);

b) technological processes increase concentrations of chemical elements in the Biosphere (metallurgy, chemical industry, etc.);

c) dispersion of chemical elements in comparison with their "biotic" concentrations.

* All the above processes produce entropy which can not be "sucked" away by the Biosphere's "entropy pump".

Since the ecosystem should also remain in dynamic equilibrium with its environment, the entropy production (overproduction) of ecosystem should be compensated by the outflow of entropy to the environment. This compensation can occur only at the expense of environmental degradation in this, and , may be other location, resulted, for instance, from heat and chemical pollution, from mechanical impact on the system. The value of this overproduction *can be used as the criterion for environmental degradation or as the "entropy fee" which has to be paid by society (really, suffering from the degradation of environment) for modern industrial technologies. Thus*

* Degradation of the environment is a unique way to compensate for the overproduction of entropy.

* The process of overproduction can be non-homogenous in space - there is the spatial transportation of entropy. This transportation can be either natural or artificial. The natural process of entropy transportation connects to the wide spreading of different pollution by natural agents (wind, rivers, etc.). The artificial process is either purposeful export of industrial waste into other regions, or the import of low - entropy matters (for example, fossil fuels) from other regions. Thus,

* *Sustainable Development is possible only locally, in selective areas of the planet and only as a result of creating "entropy dumps" elsewhere.*

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APPENDIX 1. SUSTAINABILITY

What does the term "sustainability" mean? Despite of its wide spreading, there is no rigorous, mathematically correct definition of this concept. (Note, the same situation takes place with term "stability", with one exclusion: there is the mathematical theory of stability with Lyapunov definition.). Here we try to specify these concepts.

We start from the implicate citation of the Brundtland Commission book "Our common Future. From one Earth to one World". (Oxford Univ. Press, Oxford - New York, 1987).

Sustainable development is not a fixed state of harmony, but a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, the institutional change are made consistent with future as well as present needs. Humans are able to make a development sustainable, to see that it meets our needs without compromising the future generation needs. There are limits of course, based on the state of technology and social organisation and by the ability of the Biosphere to neutralise the human impacts. Brundtland Commission believes that both technology and biosphere can be both managed and improved, and lead to a new era of economic growth.

"Development is growth", that is how sometimes it is perceived, but they are not the same, of course. Sustainable development and sustainable growth are related.

The challenge of sustainable development is to find new products, processes and technologies which are environmentally friendly, while satisfying our needs. In other words, it must be insured that every economic and social decision takes into account the physical world. On the other hand, there is the concept of "zero growth" (Club of Rome concept), called also "stability concept" (not completely correct). Shortly this concept can be presented in following words: to stop all pollution, population etc. at the current level, hoping that the impacts on the environment are going to be diminished with some time. But as we know now, the desired effect is not going to happen, because of the complexity and uncertainty involved. Plus, the evolution process (of the technosphere, in this case) is irreversible.

In order to explain the term "sustainability", some standard method is used: the definition is expended, so that three forms of sustainability are considered: sustainable use, sustainable growth and sustainable development.

If humans use living components of ecosystem (renewable resources) in ways that allow natural processes to replace what is used, the system will renew itself indefinitely and human use will be "sustainable". The examples are the use of resources for a long periods of time without degradation (western Amazonia, coastal north-western North America, northern Australia) and such practices are often tied up to strong cultural beliefs. There are few, if any examples of long-term sustainable use by modern industrialised societies and even non-industrial societies have not always been successful in sustaining exploitation of a resource, particularly when new area have been colonised. The question "how modern societies can live and prosper sustainability" is the great challenge, facing our generation.

Next, let us consider the term "sustainable growth", particularly its implications to the limits of resources. Growth in human population and growth in per capita resource consumption and the associated habitat degradation often happens without recognition of the finite nature of Earth resources. A basic question, concerning sustainable growth is whether economic growth could be sustained without population growth, growth in consumption of resources, or continued destruction of habitat.

Sustainable development can be defined in a variety if ways and usually undefined. It can mean sustainable use, in which case it is imperative, it can mean sustainable growth of population and resource consumption, in which case it is impossible. The main problem is, that unregulated growth in quest of sustainable development can be potential for real economic and social improvement and could be fostered by sustainable use of renewable resources.

APPENDIX 2. THERMODYNAMIC CRITERION FOR ENVIRONMENTAL DEGRADATION: ANTHROPOGENIC IMPACT ASSESSMENT

"... nobody knows, what is the entropy in reality, that is why in the debate you will always have an advantage"
John von Neumann

There are no principal constraints for the application of thermodynamic concepts to such physical-chemical systems as ecological systems. The problem is the following:

there is not a direct homeomorphism between the models (in a broad sense) in thermodynamics and the models in ecology.

But despite all of this, if we would be able to formulate correctly the concept of a thermodynamic system in relation to the ecosystem, it could be very useful (Svirezhev et al., 1990). From the viewpoint of thermodynamics, any ecosystem is an open thermodynamic system. Climax of the ecosystem corresponds to a dynamic equilibrium, when the entropy production inside the system is balanced with the entropy outflow to the environment. This work is being done by the "entropy pump". What does this term mean?

1. Let us consider one unit of the Earth surface, which is occupied by some natural ecosystem (i.e. meadow, steppe, forest, etc.) and is maintained in the climax state. Natural periodicity in such a system is 1 year.
2. Internal energy of ecosystem is increased by a value of gross primary production (which can be expressed in caloric units).
3. One part of this production is used for respiration (with the further transformation into a heat).
4. Another part, on the one hand, turns into litter and other forms of soil organic matter, and, on the other hand, is being taken by consumers.
5. But, since the system is in the equilibrium, an appropriate part of dead organic matter in litter and soil has to be decomposed (releasing a place for a "new " dead organic matter form annual net primary production). The "old"

dead organic matter has "to be burned" , so that the chemical energy of it is transformed into the heat.

Consequently, the heat production dQ in a stable (climax) ecosystem at the state of thermodynamic equilibrium with its environment (temperatures in ecosystem and its environment are equal) is equal to the gross production P_0:

$$dQ = P_0 . \tag{1}$$

In fact,

total heat production =
heat emission of plant metabolism (heat emitted during the process of respiration + heat emission of consumers metabolism + heat emission of the decompostion of "old" organic matter (which is equal to caloric equivalent of appropriate part of the net primary production)
= gross (total) primary production.

The annual entropy production produced by ecosystem (internal production) is equal to

$$S_0 = dQ/T = P_0/T, \tag{2}$$

where T is the mean "active" temperature (in K) at given point of the Earth , i.e. the mean temperature of season, when the ecosystem functions. According to our assumption, this production is compensated (in accordance with the equilibrium condition) by the flow of the entropy due to the solar "entropy pump" with the power at some point of the Earth is equal to $S_0 = P_0/T$.

"Entropy pump" hypothesis:
the climatic, hydrological, soil and other environmental conditions are organized at given point in such a way, that only natural ecosystem, which is specific for these local conditions, is at the equilibrium.

If this area is under anthropogenic pressure, i.e. there are:
a) direct inflow of artificial energy (energy load). We suppose that this inflow is dissipated inside the system and transformed into the heat.
b) inflow of chemical elements with molar concentration C_i (i = 1,...,n) (*chemical load*) is being also dissipated inside the system .

Let the gross production of ecosystem under the anthropogenic pressure be P_1, the *energy load* be W and the concentrations of chemical elements in natural ("wild") ecosystem be C_{i0} .

We assume that "natural" and "anthropogenic" ecosystems are connected by the *relation of succession*.

A few words about the *relation of succession*.

Let us assume that the anthropogenic pressure has been removed. The succession from the anthropogenic ecosystem towards the natural one has started. The next stage of this succession would be "natural" ecosystem in our sense. Really, if the anthropogenic pressure has been weak, the "natural" ecosystem (in our sense) is typical for this locality "wild" ecosystem.

On the other hand, if the anthropogenic ecosystem is an agroecosystem, surrounded by forest, successionaly close to its "natural" ecosystem is a grass-shrubs ecosystem (not a forest).

The following "*Gedankenexperiment*" testify in the favour of this hypothesis. Let us stop the energy and chemical fluxes into the ecosystem. As a result a succession would take place at the site which tends towards the natural ecosystem type, specific for the territory (grassland, steppe, etc.).

Under severe degradation a succession would take place also, but towards the another type of ecosystem.

This is quite natural, since the environmental conditions has been perturbed (for instance, as a result of soil degradation). So, if there is no input of artificial energy, the equilibrium state for a given site (locality) will be presented by the natural ecosystem, as the local characteristics of the "*enthropy pump*" correspond exactly to the natural type of ecosystem.

Nevertheless, there is a small incorrectness. When we discussed successionally closed system above, we assumed implicitly that any stage of the succession is a dynamic equilibrium. Since a succession is a transition process between two stationary states, this statement is incorrect, but as far as we can suggest that the time-scale of ecological succession is much more than the time-scale of anthropogenic processes, we can consider a succession as the thermodynamically quasi-stationar process (simulatanously, we remain inside the model of equilibrium thermodynamics). However, if we suppose to construct a thermodynamic model of succession, we should release the hypothesis on quasi-stationary transition.

The equation of the balance of entropy production (σ) at the given site:

$$\sigma T = W + RT\,\Sigma(C_i \ln(C/C_{i0}) - (C_i - C_{i0})) + P_I - P_0\,, \qquad (3)$$

where R is the gas constant and C_{i0} are some basic concentrations.

The values in (3) are not independent. For instance, P_I depends on W and C_i. Since we are not able to estimate this correlation in a framework of theory of thermodynamics, we have to use the empirical correlation.

Since the ecosystem should also remain at a dynamic equilibrium with its environment, the entropy production of ecosystem should be compensated by the outflow of entropy to the environment. This compensation can occur only at the expence of environmental degradation ($\sigma > 0$), resulted, for instance, from heat and chemical pollution, from mechanical impact on the system. Therefore, the value σ can be used as the criterion for environmental degradation or as the "enthropy fee" which has to be paid by society (really, suffering from the degradation of environment) for modern industrial technologies.

APPENDIX 3. VERNADSKY's CONCEPT OF THE BIOSPHERE

We must remember that the "new" concept of the Biosphere has the long-time history. At the beginning of XIX century J.-B. Lamarque had introduced the term "Biosphere". He considered it as the "Scope of Life" and some external Earth cover.

In 1875 the same term had been introduced in geology by E. Suss, who distinguished the Biosphere as one of the Earth covers. But V. Vernadsky was the first person, who had created the modern concept of the Biosphere. This concept was stated in two lectures, issued in 1926. This concept seemed very new and incomprehensible at that time, and started to be fully understood only recently.

While Vernadsky has formulated the so-called conceptual model of the biosphere, its further development and formalization were provided by his disciple V.A. Kostitzin (1935). Vernadsky specified the important role of global cycles of oxygen, carbon, and nitrogen in the geological history of the planet, and, particularly, in the evolution of the atmosphere and climate. A mathematical model describing these global cycles was first formulated by Kostitsyn (1935). Based on the balance equations, it allowed to evaluate global cycles in relation to periodical climate change.

While the concept of Vernadsky can be considered as maximally aggregated (it is like a view on the biosphere from the outside), the concept of the biogeocoenosis (BGC) developed by V.N.Sukachev (1967), related to the elementary units of the biosphere, is basically atomistic in nature.

In accordance with *definition* of N.V.Timofeev-Ressovsky (1961), *BGC is the part of the Biosphere, having no any essential ecological, geomorphologic, hydrological, microclimatic or any other boundary inside itself.* By this the whole biosphere of the Earth is divided into elementary systems, naturally separated from one another. Due to the reality of existence of these boundaries, BGCs can be considered as semi-isolated subsystems, function of averaging inside of BGC is quite natural. So, the BGC dynamics can be described by comparatively few number of variables.

According to N. Basilevich (personal communication), there are about 50 000 BGCs on the Earth.

From the other side, BGC is the elementary unit of biogeochemical cycles in the biosphere. Indeed, nitrogen and phosphorus cycles inside the BGC are practically isolated (excluding denitriphication). If we consider only horizontal migration of biogeochemical elements (without river transport), then the carbon cycle is also isolated. We understand this isolation so, that all carbon (and partly nitrogen) cycles of the BGC are connected with one another through the atmosphere and hydrosphere, and their direct relationships or the intensity of their internal connections are developed much weaker. It is significant that all the BGCs are dynamically similar - for every BGC we have the same structure of local biogeochemical cycles. Therefore, if we describe the BGC dynamics as the dynamics of local biogeochemical cycles, then the differences between the BGCs are the differences in parameters of the same dynamic systems.

Finally, if, on the one hand the biosphere is a system of global biogeochemical cycles, interacting with each other, then, on the other hand, the biosphere can be considered as the system of loosely interacting elementary subsystems, subjected to the same dynamic laws and regulations. So, we have the biosphere system as a statistical ensemble.

In the sequel the Biosphere concept was developed by both Vernadsky himself, and V. Kostitzin V. Sukhachev (1967), N. Timofeev-Resovsky and other Russian scientists. The concept allows us to speak about the Russian classical school in Globalistics. It is characteristic for this school, on the one hand, the tendency to the conceptual generalisation of accumulated empirical data, and, on the other hand, maximally delicate relation to speculative constructions and hypotheses. (Note, many of contemporary global models suffer from it).

In accordance to Vernadsky, the Biosphere is an external Earth cover, the Scope of Life (let us remember Lamarque). But he notes also that this definition (as just the Scope of Life) is not complete. The Vernadsky's Biosphere includes:

a) "*Living matter*".

b) "*Bio-genic* matter", i.e. organic and mineral substances, created by living matter (for instance, coal, peat, litter, humus, etc.).

c)"Bio-inert matter", created by living organisms with inorganic Nature together (water, atmosphere, sediment rocks).

There are two components in the Vernadsky concept of the Biosphere. The first is the properly biosphere concept, which can be called some verbal model of the Biosphere. The second component is the method of study of such complex system as the Biosphere, called the "Empirical Generalisation Method" (EGM) by him. Certainly, the EGM is essentially wider than some method for study of biosphere processes, it is some general scientific method. Let us remember "Science is a method" by Cartesius. Speaking modern language, the EGM is a typical method of the systems analysis.

The empirical generalisation is based on real facts collected by inductive way, not to leave the domain of these facts. On this first stage all possible scientifically established facts about studied phenomenon must be collected. The next stage, speaking modern language, is the aggregation of collected facts into some more general categories called empirical generalisations. It gives us the possibility to move from huge number of accumulated facts to considerably lesser number of statements, that, in turn, allows to speak about the possibility to describe the studied large (complex) system quantitatively.

Really, an empirical generalisation is a system of axioms, reflecting our level of empirical knowledge, which could be used as a basis for any developed in the future, formal theory.

Hence, having the system of empirical generalisations, we can follow two ways, when constructing models. Either we remain in the frameworks of this system, constructing models called "phenomenological" ones, or, complementing some hypotheses to the existing empirical generalisations, we shall get some new models. In accordance to Vernadsky's opinion, the choice on set of these models - hypotheses must be produced by the coincidence of predicted and observed again facts. If this coincidence takes place then the hypothesis becomes an empirical generalisation of higher level. From this point of view, for example, the practical astronomy of Ancient World was a typical empirical generalisation, and ancient astronomers were successfully using the phenomenological model created on its basement. The same empirical generalisation underlain in the basis of two principally different cosmogonies hypotheses by Ptolemeo and Copernicus. If and only if new facts had appeared, the Copernicus cosmogony became a new empirical generalisation. Therefore the same empirical generalisations can be a basis of different models.

But the reciprocal picture can be possible, when an empirical generalisation exists separately, without some kind of hypotheses and explanations from viewpoint of contemporary science. For example, the radioactivity phenomenon could not be explained in frameworks of the Physics of XIX century.

What kind of empirical generalisations lays at the base of the Vernadsky's Biosphere? (In this case we will call this system of axioms "Vernadsky Biosphere"; however, these axioms will be presented in a more formal form than in Vernadsky's original work.)

1. During all geological periods on Earth, living organisms have never been created directly from inorganic matter.

This is the homogeneity axiom. Note, in mathematics, the operators, which transforms a zero to zero, are called by homogeneous, too. There is the analogue of this axiom in biology, called by the Redi Law ("alive only from alive").

2. The existing facts cannot answer on the question about the origin of life on Earth.

To get an answer, we must leave the frames of the Empirical Generalisation Method and use different speculations. There is only one way to resolve this contradiction, namely, to postulate the following: whatever was pre-biosphere history of Earth, evolution of the Biosphere during all geological periods must give the contemporary Biosphere as a result. This is the ergodicity axiom. It postulates that in large degree the process of the Biosphere evolution is deterministic and stable in respect to initial periods of its history.

3. There were no lifeless geological epochs.

This means that the contemporary living matter is genetically connected with living matter of all the previous epochs. It is natural to call this axiom by the continuity axiom .

The following empirical generalisations are, actually, some conservation laws. On the other hand, since they generalise some equilibrium properties, of the Biosphere, we can call them the axioms of stationary state).

4. The chemical composition of living matter was, in average, the same as it is now.

5. The amount of living matter, in average, was the same for all geological time.

These Vernadsky's generalisations cause a lot of objections at present times. However, there are not enough new facts to formulate new empirical generalisations. Therefore it is quite possible to consider the changes of the total amount of living matter, observed in different geological epochs, as fluctuations around some constant average level. (The same can be also said about chemical composition of living matter and terrestrial core.)

And, at last, generalisations, which determined the principles of functioning for biosphere mechanisms.

6. Energy, stored and emitted by living organisms, is Solar energy. Through them (living organisms) this energy is controlling chemical processes in Earth core (in particularly, global biogeochemical cycles).

7. Vegetation plays the main role in assimilation and allocation of the Solar energy.

If we agree with the axiom about constancy of the total amount of living matter during the whole time of the Biosphere Life, then we have to assume that its evolution went only on the way of structural complication of living matter, either by increasing the number of species (there are $3*10^6$ species on Earth), or by complication of the structure of biological communities.