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THE CARBON CYCLE IN THE EARTH-ATMOSPHERE SYSTEM AND THE CLIMATE CHANGE

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Összefoglalás - Az IPCC modellekkel végzett kísérletek alapján a légkör CO_2 koncentrációja 40-240 év múlva stabilizálható 450-1000 ppmv szinten a CO_2 emisszió megfelelő korlátozásával. Kérdés, hogy mennyi ideig áll rendelkezésre fosszilis tüzelőanyag. A szén körforgalma a Föld-légkör rendszerben irreverzibilisnek tűnik: nem valószínű, hogy a fanerozoikum maximális CO_2 koncentrációja megismétlődik. A földkorongra évente érkező napsugárzás energiájának néhány ezreléke, esetleg egy százaléka kémiai energia formájában raktározódik a bioszférában. Ennek egy töredéke megközelíti az emberiség évi energia fogyasztását. Az energia problémának másik megoldása a takarékosabb technológiák bevezetése. A CO_2 koncentráció növekedését a növényzet növekvő intenzitású fotoszintézissel is mérsékelheti.

Summary - According to IPCC model experiments the atmospheric CO_2 concentration could be stabilized at 450-1000 ppmv levels in 40-240 years depending on restriction measures of CO_2 emission. However the amount of available fossil fuels is rather uncertain. The carbon cycle in Earth-atmosphere system seems irreversible: it is unlikely that the maximum CO_2 concentration of Phanerozoic will return. A portion (a few thousandths or one percent) of solar energy reaching annually the Earth's surface is accumulated in biosphere as chemical energy. Its few percents may approximate the annual energy consumption of mankind. Another solution to energy problems could be found in use of more economic technologies. The response of plants to increasing CO_2 concentration in enhanced photosynthesis which may moderate CO_2 increase in the atmosphere.

Key words: consumption of carbonaceous fuels, variations of CO_2 in Phanerozoic, carbon cycle, chemical energy, biosphere

INTRODUCTION

The climate of the 21st or 22nd centuries depends largely upon the atmospheric concentration of greenhouse gases. Without atmosphere (and greenhouse effect) the mean global surface temperature would be about 255 K (-18°C). In fact the mean global surface temperature is 288 K (15°C), that is the actual surface temperature is about 33 K higher than it would be expected in case of simple radiation equilibrium. According to some estimation, 62% of greenhouse effect may be attributed to water vapour, 22% to CO_2, and 16% to other gases (e.g. CH_4, O_3, N_2O, CFC-s, etc.) (*Schönwiese*, 1995). It means that the most important greenhouse gas affected by human activity is CO_2.

The theoretical calculations concerning the possible change in climate are based on assumption of continuos increase in atmospheric CO_2. If the growth rate of CO_2 concentration will be as much as in years 1984-93, then the doubling will happen within 160 years. However, after taking into consideration some resrictions in CO_2 emissions, we may get conclusions, as follows (*Climate Change*, 1995):

if the CO_2 emissions drop to 1990 levels, respectively, cca 40, 140, 240 years from now, then

duration of restriction in years	*ppmv*	*mass of C in kg*	*mass of CO_2 in kg*
present (1995)	358	$5x10^{14}$	$1,86x10^{15}$
40	450	$6.3x10^{14}$	$2.31x10^{15}$
140	650	$10.3x10^{14}$	$3.78x10^{15}$
240	1000	$14.1x10^{14}$	$5.17x10^{15}$

IPCC (1994) carbon cycle models were used to calculate the emissions of CO_2, which would lead to stabilisation at a number of different concentration levels from 450 to 750 ppmv. If global CO_2 emmisions were maintained at near current (1994) levels, they would lead to a nearly constant rate of increase in atmospheric concentration for at least two centuries reaching about 600 ppmv by the end of the 21st century.

However the crucial point is whether the consumption of carbonaceous fuels could remain at present levels for two centuries. The assessment of traditional energy sources is uncertain, but the increase of their cost is doubtless. Thus the questions to be answered are: how long can we use traditional energies taken from fossil fuels, and how can they be replaced with other energy sources.

In order to approach the solution of problems, mentioned above, first we shall give a rough survey of variations of atmospheric CO_2 concentration during the Phanerozoic and the carbon cycle in the Earth-atmosphere system, second we try to assess the energy amounts accumulating in biosphere yearly from solar radiation and its portion available for mankind.

It is noteworthy to mention that the largest environment change in Earth-atmosphere system took place about 700 million years ago after appearance of free oxygen in the atmosphere (*Lukács*, 1994)

VARIATIONS OF ATMOSPHERIC CO_2 CONCENTRATION AND GLOBAL TEMPERATURE IN PHANEROZOIC

The composition of terrestrial atmosphere and the global mean temperature can be reconstructed relatively well, making use of paleoclimatogal, mineralogical, paleontological data from the last 570 million year period (*Budyko*, 1982; *Budyko et al.*, 1987, 1988). Temporally weighted mean mass of the atmospheric CO_2 in Phanerozoic has been as much as

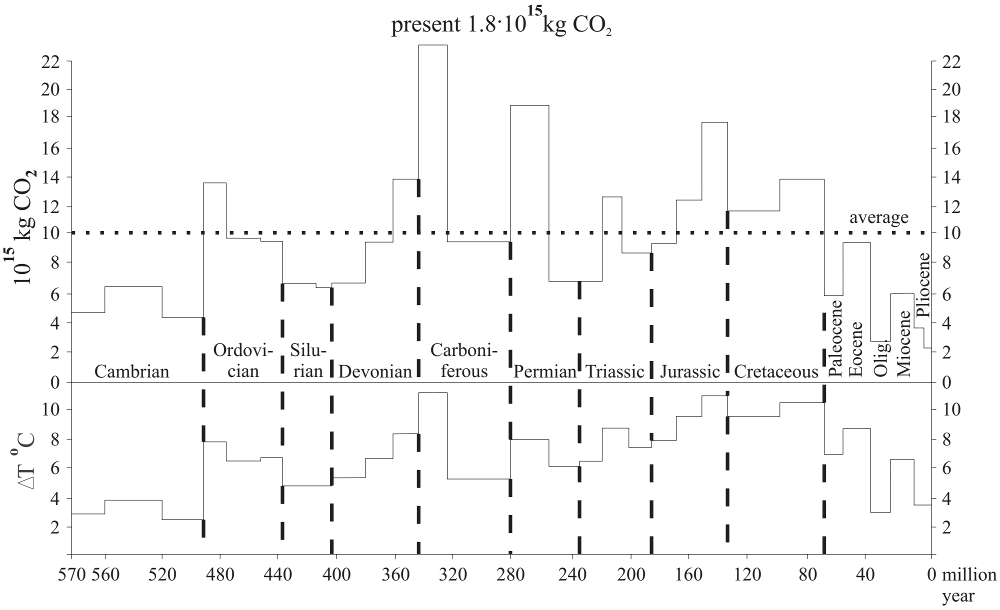

Fig. 1 Variations in mass of atmospheric carbon-dioxide (above) and global surface temprature deviation from presents value (below) during Phanerozoic

10^{16} kg, i.e. 5.5 times more than present value (PAL = Present Atmospheric Level: $1.8 \text{x} 10^{14}$ kg). In early Carboniferous it reached the maximum concentration which is about 12 times larger than PAL. Other maxima were found in early Permian, late Jurassic and late Cretaceous (*Fig. 1*). However in the last 70 million years the atmospheric CO_2 amount did never exceed the average value (10^{16} kg), moreover it has been gradually decreasing until the Holocene time.

It is noteworthy that the estimated mean global temperature varies more or less parallel with CO_2 concentration. An approximative relationship can be established between the atmospheric CO_2 mass and global mean temperature, namely:

$$\Delta T = 2.5 \text{ x } b \qquad (K) \qquad (1)$$

here b = log k/log2, if k > 1, and denotes the ratio between past and present CO_2 amounts in the atmosphere, so "b" is the number of doubling in CO_2 mass: $\triangle T > 0$ stands for increase of global mean temperature in comparison with the present value (e.g. in *Table 1*).

Table 1 Temperature deviations in several earth historical periods (legends see in the text)

	k	***b***	***△T gained from (1)***	***△T estimated (see Fig. 1. below)***
early Carboniferous	12.7	3.67	9.2 K	11 K
early Permian	11.1	3.47	8.6 K	8 K
late Jurassic	9.9	3.3	8.2 K	10.9 K
late Cretaceous	7.6	2.93	7.3 K	10.4 K
early Cambrian	2.7	1.44	3.6 K	2.9 K
early Ordovician	7.5	2.9	7.3 K	7.7 K
late Silurian	3.67	1.87	4.7 K	4.8 K

The decrease of atmospheric CO_2 has been accompanied by dropping in global temperature in the last epoch of Earth's history (*Fig. 1,* below). The temporally weighted average of global temperature during the Phanerozoic was about by 6°C higher than at present.

Consequently it may be stated that the present CO_2 concentration and global mean temperature exhibit peculiar stage of the atmosphere*. So we shall investigate the possible causes of this extreme atmospheric stage, namely the low CO_2 concentration, and we shall thoroughly discuss the problem: whether human activity is able to release as much CO_2 into the atmosphere to reach the mean value of Phanerozoic?

Recently a great number of papers is concerned with the carbon cycle in the Earth-atmosphere system (*Bernáth et al*., 1981; *Houghton*, 1996; *Lassey et al.*, 1996). For the sake of a good survey, here a very simplified sketch is presented on the carbon cycle (*Fig. 2*), e.g. no

* The data involved in *Fig. 1* are valid only in 10 million year periods and exclude those in shorter episodes like glacials or interglacials.

distinctions are made between carbon budget in shelves, in surface oceans, and in deep ocean, respectively. It is a much-debated question, whether the CO_2 mass infiltrated annually into biomass from the atmosphere and CO_2 mass released yearly from biosphere due to decomposition are comparable to each other. The most recent calculations suggest that the latter is less with an order of magnitude than the former (*Houghton*, 1996; *Lassey*, 1996). Therefore the arrow is directed from atmosphere to the biosphere in *Fig. 2* and not vice versa. The biomass contains $8x10^{14}$ kg C, in the soil the estimated mass of organic carbon (like peat, humus, marsh gases etc.) is $2x10^{15}$ kg. Mass of carbonates in minerals, rocks and fossils is as much as $5x10^{20}$ kg, that is nearly ten thousandth of the total mass of Earth ($6x10^{24}$). Another transport takes place through the oceans, both in form of carbon exchange between the atmosphere and oceans, and between the oceans and biosphere, respectively. In oceans $1.3x10^{17}$ kg CO_2 is dissolved, which is the source of organic carbons for living creatures in water.

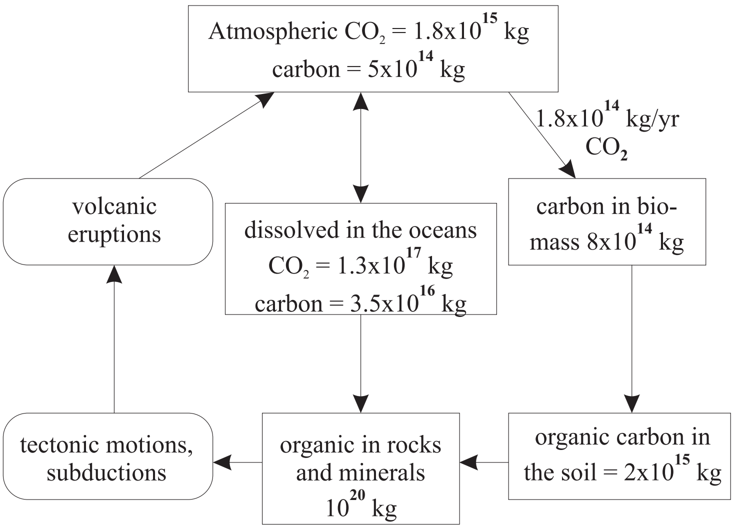

Fig. 2 Carbon cycle in Earth-atmosphere system

Due to subductions some carbonates sink deep into the mantle of the Earth, warming up by several 100 K. The carbonates however can not catch CO_2 above cca 350°C, so the latter will be released, and more or less portion of it may be transported into the atmosphere mostly by volcanic eruptions.

It is rather questionable how much fossil fuel may be used from the litosphere, but no doubt will remain about the increase of its price. In 1973 e.g. the price of a barrel of oil increased from 4 USD to 11.7 USD, and this fact caused dramatic consequences in countries, whose developed industry has been maintained by imported energy sources, like Japan. Recent price of a barrel of oil varies about 20 USD. Similar could be stated about hard coal and natural gases.

It is quite sure that mankind will not reduce energy consumption in the near future. Therefore we have to find some solutions for our energy problems. In this paper we shall present two possible solutions, one active and one passive possibilities. The first is the harnessing of chemical energy accumulated annually from solar energy in biosphere. The second is the reduction of waste in energy consumption.

HARNESSING OF CHEMICAL ENERGY ACCUMULATED ANNUALLY FROM SOLAR ENERGY IN BIOSPHERE

The annual radiation absorbed in the Earth-atmosphere system is as much as $3.86x10^{24}$ J/year (with 0.3 albedo). The estimated amount of chemical energy accumulated yearly in biosphere from solar energy ranges from about $6x10^{21}$ to $4x10^{22}$ J/year, i.e. cca 0.15-1% of solar energy.

The annual energy consumptions of mankind were in recent years as follows:
1980: $3x10^{20}$ J; 1985: $3.3x10^{20}$ J; 1995: $5x10^{20}$ J.

Hence the world 1995 energy consumption is 1-8% of chemical energy gained yearly from solar radiation in biosphere. Supposing 20% efficiency, there would be needed to use roughly 6-20% chemical energy accumulated yearly in biosphere in order to satisfy the energy consumption of mankind, or at least a great part of it.

In the light of these theoretical calculations we ought to consider some practical realizations concerning the energy transformation. Carbohydrates can be transformed into alcohol, which is a high quality fuel. During the World War 2 and a couple of years after it, artificial gasoline was used in a few European countries. There are biogas producting plants offering energy from biomass, too.

In some of developed countries there is significant surplus in production of cereals and provisions. The governments of these countries urge the farmers to leave unutilized parts of their fields. These uncultivated fields might be used for growing industrial plants like sugar-beet, sugar broomcorn, potato etc. Each provides some kind of carbohydrates, basic chemical material of alcohol manufacturing (*Hunkár*, 1996).

ECONOMY IN CONSUMPTION OF ENERGY

In the late 19th and early 20th centuries, when introduction and general use of engines took place, like steam-engine, steamer, locomotives, heat-engines, motorvehicles, aircrafts, wide-spread use of electricity, in the beginning the energy was cheap and the quantity of energy use increased rapidly. The use of electricity in households has become more and more common, transport replaced animal and human powers gradually with mechanical vehicles. In 1860 the world energy use was supplied by animal power in 73%, by human force in 15% and the residual 12% was gained from other sources (wind, hydraulic power, steam-engine etc.) (*Sabady*, 1980). Nowadays in a developed industrial country the per capita use of energy is approximately equal to 200-500 slave power or 20-50 draught animal force (*Koppány*, 1989).

The largest energy consumer is industry. It is evident that the common requirement of mankind is to rise the standard of life, and consequently the energy consumption must be increased. Certainly it will be the case in less developed countries, e.g. in Africa, Latin America and a few countries in Asia. However, sooner or later, the use of fossil energy sources must be restricted, mostly for the permanent rise of their prices.

The change in specific energy consumption of some industrial countries indicates that the economy in this field started in the late 19th or during the first half of the 20th century. The term of specific energy consumption here denotes energy use per 1000 USD GPD. *Fig. 3* presents the variation of specific energy consumption (in ton oil equivalent unit) in a few developed countries since the second half of the 19th century up to the latest available or predictable time. It is noteworthy that by the 1980s the specific energy consumptions are rather close to each other in presented countries. This suggests that a rather similar economical energy use has been introduced in developed countries. With comparison: specific

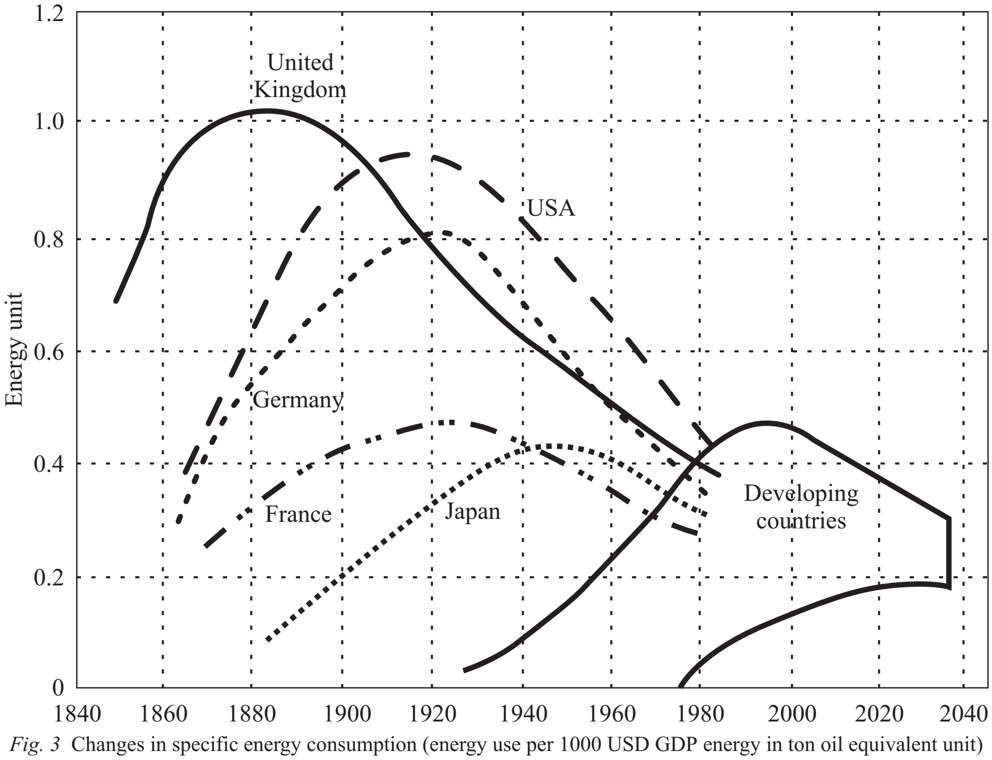

Fig. 3 Changes in specific energy consumption (energy use per 1000 USD GDP energy in ton oil equivalent unit) since middle of the 19th century

consumption in Hungary in late 1980s was about 2-3 times larger than that in West Germany. Thus in Hungary and some other Eastern-European countries one of the main tasks is to reduce the waste of energy use by introducing more economical techniques.

THE RESPONSE OF PLANTS TO INCREASE OF ATMOSPHERIC CO_2 CONCENTRATION

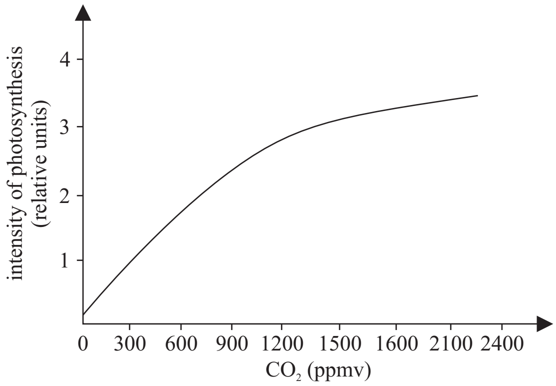

Fig. 4 The change of intensity of photosynthesis of Scotch pine depending on carbon-dioxide concentration

By 1995 it was found that the growth rate of atmospheric CO_2 concentration exhibited a small decrease during the 1985-94 decade (*Climate of Europe*, 1995; *Climate Change*, 1995), the decrease took place mostly in 1991-93. The change was observed among others at Izana. The most likely explanation of slackening in growth rate of CO_2 concentration is the response of plants to increase of CO_2 concentration. A series of biological experiments in laboratories show unanimously the reaction of plants to the change of CO_2 concentration. If sufficient solar radiation is available, the intensity of photosynthesis will grow with growing CO_2 concentration up to 2400-3000 ppmv, e.i. about to amount 8-10 times than PAL (*Fig. 4*).

Although the slackening of growth rate in CO_2 concentration may be a transitional phenomenon and must not be extrapolated to the long-term future, it proves that the change in the composition of atmosphere is influenced by many factors besides the human activity.

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