Critical Levels of Greenhouse Gases, Stabilization Scenarios, and Implications for the Global Decisions

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Emission control is not free. Stabilization costs appear substantial, while monetary value of climate-change caused global damage is still unclear due to lack of costing methodologies. Critical thresholds for climatic variables and respective limits for greenhouse gas content in the atmosphere can serve as majorizing estimates of and tentative substitutes for the optimal long-term levels to be achieved. A natural climate change, the causes of which are to be explained by astrophysics and celestial mechanics, is not fully predictable, which complicates the development of stabilization programs. This means that long-term climate system response to anthropogenic emissions of greenhouse gases should be properly analysed prior to taking the global decisions on control measures, although such investigations should be urged. New stabilization scenarios as well as the role of uncertainties in setting stabilization levels are considered in this paper.

Global CO_2 concentration ranged from 180 to 300 ppmv over past 400,000 years [1], see Fig. 1. It varied roughly within 270-290 ppmv interval over past 1000 years in the pre-industrial era (before 1860), thus was practically stable [2, p. 185]. Since the middle of 19th century CO_2 concentration has been increasing rapidly [2, p. 201] and exceeded 370 ppmv at present, see Fig. 2.

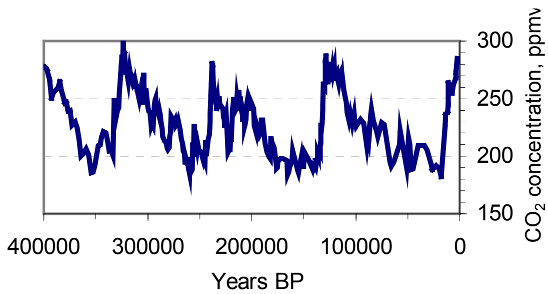

Fig.1. Historical records of CO_2 concentrations, Vostok station, Antarctica.

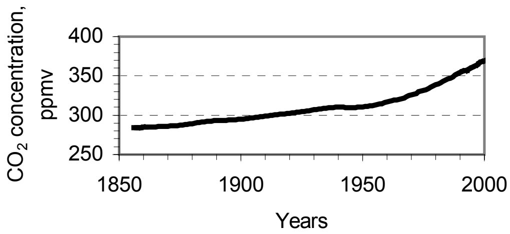

Fig. 2. Increase in CO_2 since 1850s.

Regional natural variations of surface temperature are big on the century scale. For instance, as it is clear from paleodata from Vostok station (Antarctica), in the last millennium 200 and 400 years ago a temperature rise of roughly 0.5 -1.5 ºC emerged, developed and ended within approximately 100 years [14]. These events were caused by solar and orbital factors interacting with non-linear climate system of the Earth.

Unprecedented (for last 400,000 years) rise of CO_2 content in the atmosphere since 1850s and discernable increase in global surface temperature (0.6 ± 0.2 °C) in 20th century, usually associated with anthropogenic enhancement of the greenhouse effect, were the major reasons for the development and adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Its Article 2 states that **"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".** Thus, as long as the ultimate objective of the UNFCCC is not amended, the main aim is **stabilization**, i.e. keeping CO_2 concentration below certain threshold value, certain constant level. However, up to now no decisions on **particular level** were taken, and the nature of the threshold remained unclear.

Stabilization is not free for the world community. Economic analysis of stabilization scenarios using, in particular, 1000, 750, 650, 550 and 450 ppmv of CO_2 as stabilization levels showed that this may cost up to 18 trillions $US of 1992 [4, pp. 544-545]. Of course peoples expect that such non-negligible "investments" will be made in the optimal way.

Usually it is assumed that with no emission control a certain climate-change caused damage to natural systems and socio-economic systems will occur. This damage is seen big, at least comparable with mitigation cost. Otherwise there is no reason for any control measures. In this connection one can consider emission reduction scenarios, the implementation of which prevents a certain part of the damage. However, some residual part remains. If a special set of emission control scenarios is considered, namely, stabilization scenarios (i.e. CO_2 concentration approaches certain constant level), this residual part is monotonically increasing with stabilization level.

A reasonable stabilization level could be determined as the level ensuring equilibrium between overall STABILIZATION COST and climate-change caused RESIDUAL DAMAGE (adaptations are taken into account) associated with given stabilization level. Namely, the following criterion can be used:

{STABILIZATION COST + RESIDUAL DAMAGE}

should be minimal. Of course, discounting coefficients are to be applied as needed in calculating both components of the criterion. Figure 3 illustrates this global approach. In our illustrative example the sum reaches minimum at 650 ppmv CO_2.

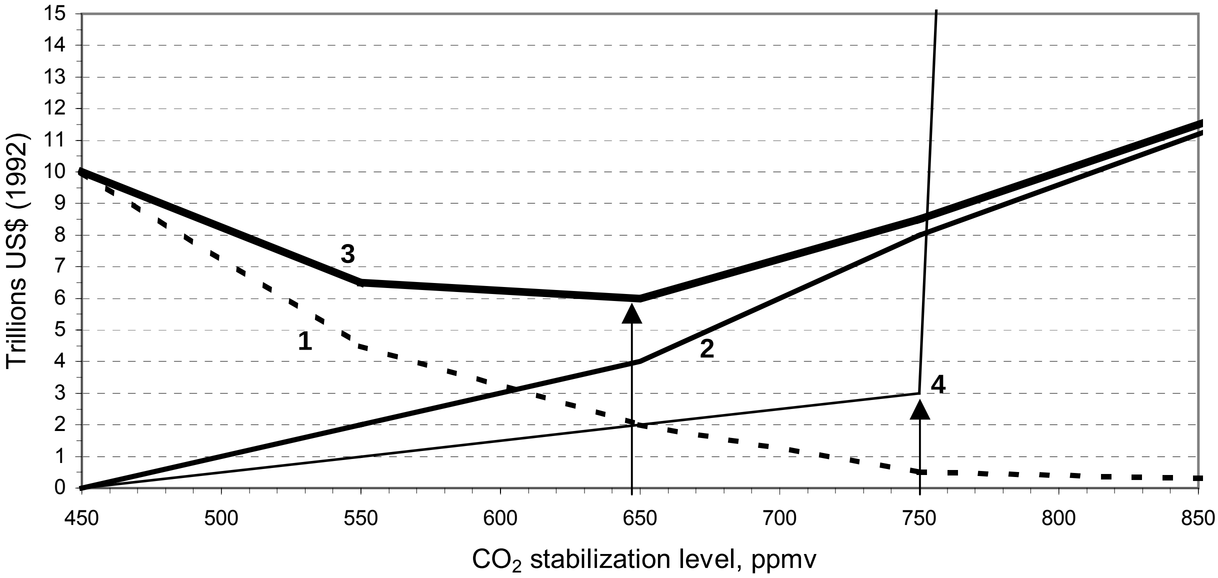

Fig. 3. Stabilization of CO_2 level (illustrative example): 1 - stabilization cost as depended on stabilization level, approximately as given in [4, pp. 544 - 545]; 2 - residual climate-change caused damage increasing with the level; 3 - their sum {STABILIZATION COST + RESIDUAL DAMAGE} as depended on the level; 4 - residual damage associated with certain key vulnerable element.

While costing methodologies for emission control programs are available (although some refinements are evidently needed), the attention paid to the assessment of residual damage was much lesser up to know. The IPCC TAR [3] characterized major actual and potential effects of a change in climate. This was made for certain sectors and regions. Unfortunately, the global estimate has not been obtained even for globally aggregated metrics/numeraires proposed in [15], namely, for market impacts, human lives cost, biodiversity loss, distributional impacts, and quality of life. Thus, the assessment of residual damage in aggregated terms and finally in monetary equivalent is one of priority tasks at present.

However, even with the latter scientific problem solved, the other one of political nature will remain. Reaching the equilibrium between stabilization cost and residual damage at the optimal stabilization level of CO_2 concentration by definition leads to globally positive cost-benefit result. But this "gain" exists only at the global scale, this does not mean in general that every country or region will gain. There will be winners and losers, which is politically not acceptable. Therefore, for the implementation of the above optimisation process a mechanism of compensation is needed, namely, such part of the gain should be taken from the winners in favour of the losers that there will be no losers. Unfortunately, the present realities of international cooperation make this just an ideal theoretical scheme applicable for setting the problem rather than for its practical solution.

The function characterizing RESIDUAL DAMAGE (see fig. 3) is a sum of partial damage functions characterizing climate-change caused damage for different recipients. A partial damage function is just a respective response function, if the response is expressed in monetary equivalent. While assessing different response functions, it is expedient to investigate carefully large-scale key vulnerabilities [13], i.e. the large-scale key elements of the Earth's system that are both highly sensitive to climate change and have limited adaptation capacity (like some physical elements of the climate system, for instance, thermohaline circulation, ocean (with respect to sea level), the cryosphere, south-west Asia monsoon). Their damage functions often demonstrate extremely non-linear behaviour, namely, abrupt rise beyond certain threshold (see line 4 at fig. 3). In this case the optimal stabilization level should not exceed the threshold, otherwise such interference with the climate system may result in practically infinite magnitude of damage. Thus, thresholds of this kind could serve as majorizing estimates of and temporary upper limits for the optimal stabilization level. Recently a set of such thresholds for global surface temperature was analysed in [5]. The concept of critical thresholds for anthropogenic impact on the climate system and biosphere was initially proposed in [7] and recently developed in [8].

Once adopted a stabilization level, i.e. the upper limit for CO_2 concentration in the atmosphere, one should investigate opportunities to reach it. First attempt to develop pathways from present CO_2 concentration to different constant future levels was undertaken in [6, pp. 75-76]. Polynomial approximation was employed in constructing so called S350 and S750 profiles. Later on, this approach was developed in [16], where well known WRE-profiles were proposed. These concentration profiles were then transformed into respective stabilization scenarios through inverse modelling using Bern-CC [10, 11] and ISAM [12] models. The major limitation of these profiles is their monotonic behaviour, i.e. stabilization level is reached through monotonic increase of CO_2 concentration starting from the present one. Actually this is not the necessary assumption, and the concentration may exceed stabilization level for a while.

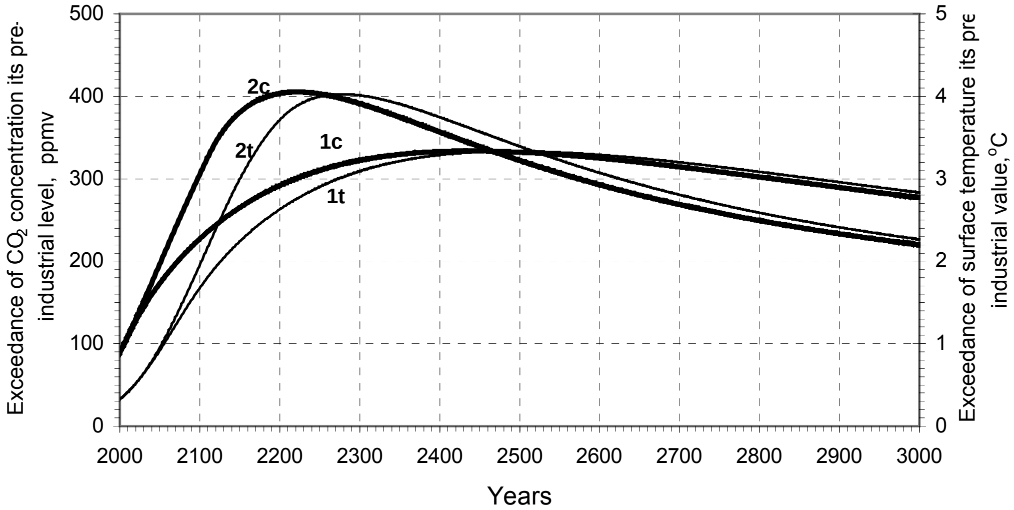

Fig. 4. Changes in CO_2 concentration (heavy lines 1c and 2c) and global mean surface temperature (normal lines 1t and 2t) under two scenarios: 1 - annual, starting from 2012, reduction of global emission associated with fossil fuel burning, cement production and gas flaring by 0.29%, while net-flux associated with changes in land use and land management is annually reduced by 0.1%; 2 - annual, starting from 2112, reduction of global emission associated with fossil fuel burning, cement production and gas flaring by 0.83%, while net-flux associated with changes in land use and land management is annually reduced by 0.1%.

In [9] a particular group of stabilization programmes was defined, namely, BC_T_{st} _T_{imp} и LU_T_{st} _T_{imp} . Each programme is characterized by two parameters: T_{st} (starting year for the implementation of emission reduction programme) and T_{imp} (implementation time). The latter one has the following sense: in each year after T_{st} the global CO_2 emission is reduced by factor $\exp(1/T_{imp})$. Abbreviations BC (burning and cement production) and LU (land-use change and land management) indicate particular type of emissions to be reduced. Implications of simultaneous implementation of two programmes 1) BC_2012_340 and

LU_2012_1000, which leads to annual reduction of emissions by 0.29% and 0.1% , respectively, starting from 2012, and 2) BC_2112_120 and LU_2112_1000, which leads to annual reduction of emissions by 0.83% and 0.1% , respectively, starting from 2112, are shown at Fig. 4. From the first glance they are roughly similar with respect to the effect on the climate system, and no global catastrophic events are foreseen. Which scenario must be preferred is more a question of technological feasibility and economic efficiency.

The following scenario is of absolutely theoretical, hypothetical nature: all known resources of gas, oil and coal (commercially efficient coal fields only) are burned at once at the beginning of 2000, and then anthropogenic emissions of all types are stopped. Implications for the course of CO_2 concentration in the atmosphere and global surface temperature are shown at Fig. 5.

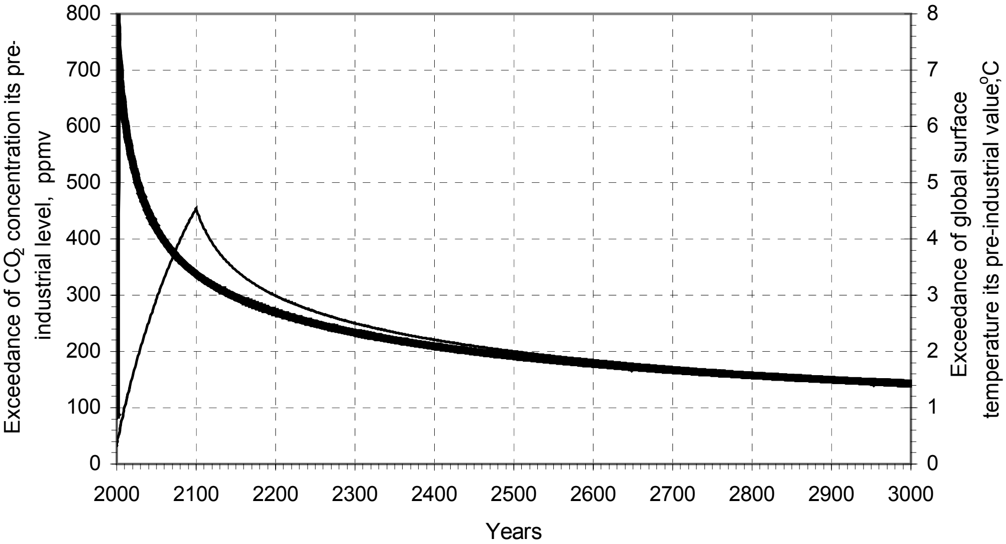

Fig. 5. Changes in CO_2 concentration (heavy line) and global mean surface temperature (normal line) under theoretical, hypothetical scenario: all known resources of gas, oil and coal (commercially efficient coal fields only) are burned at once at the beginning of 2000, and then anthropogenic emissions of all types are stopped.

It should be emphasized that the problem of uncertainty is absolutely crucial for the establishment of critical limits for climate change and further on, for greenhouse gas concentrations (Patwardhan, Schneider, Semenov, 2003). Assume that one estimated a value $\Delta_0 T$ that is an upper limit for an increase of long-term mean surface temperature for a region. Maintenance of actual rise in long-term mean temperature below this limit implies a high confidence in the stability of some key element of the climate system, for instance, the Greenland ice sheet. In this case $\Delta_0 T$ equals approximately to 3ºC according to the IPCC TAR [2, p. 17]. However, any models employed in such assessments cannot be absolutely precise. This inevitably results in uncertainty in a magnitude of $\Delta_0 T$ quantified by probability P of the event: if a long-term increase of mean temperature exceeds ΔT, the chosen key element is assumed losing stability with probability more than $P(\Delta T)$. If one decided to adopt, for instance, a 90% level of confidence, two different critical limits would emerge, say $\Delta_1 T \approx 1$ºC and $\Delta_2 T \approx 5$ºC. If $\Delta T < \Delta_1 T$, the critical threshold would not be exceeded, with probability 90%. If $\Delta T > \Delta_2 T$, the critical threshold would be exceeded with probability 90%. In this example, the range from 1 to 5 ºC is a zone of uncertainty. The size of any zone of uncertainty can be reduced through obtaining new knowledge and data only. This requires more assessments, research, monitoring and modelling activity. However, which value is to be chosen in this example - lower or upper one? Those who prefer a precautionary approach will choose the lower one, while the upper value will be chosen by sceptics. Actually the whole probabilistic distribution should be investigated and taken into account in the establishment of critical limit.

For the achievement of main goals of the UN FCCC and the Kyoto Protocol a wide range of emission scenarios should be explored and those that guarantee keeping the concentration trajectory within the safe corridor should be selected. In particular, the concentration asymptotic value should be less than certain critical limits. Such limits are not yet completely justified and generally accepted. However, the following tentative limits for CO_2 concentration and surface temperature might be proposed for the 21th century:

a) CO_2 concentration should not exceed 550 - 700 ppmv;
b) A rise in surface temperature should be less than 2.5°C for the globe and less than 4°C for the Arctic;
c) Global mitigation costs should not exceed 10 - 20% of the increase in global GDP;
d) Sea level rise should be less than 1 m.

While developing the scenarios leading to the fulfilment of these criteria, yet tentative, one should answer at least the following questions:

- can these goals be achieved (and under which particular scenarios) through the efforts of countries of Annex I only, and what reductions of CO_2 emission will be needed?
- will certain reduction of emissions of developing countries be absolutely necessary for the fulfilment of these criteria, and how can they be quantified at present?
- besides a certain deceleration of the increase of global GDP, will the fulfilment of these criteria require also fundamental restructuring of the existing mode of life in the most countries, as well as certain decrease in living standards?

We hope that the world research community will be able to answer these questions in the near future. This will allow different countries to make national expertise of the climate policy (both home and international) and develop reasonable actions in the sphere of the implementation of UN FCCC and protocols to it.

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