ECOLOGICAL DIMENSION OF GLOBALIZATION

WORLD ENERGY AND CLIMATE IN THE TWENTY-FIRST CENTURY IN THE CONTEXT OF HISTORICAL TRENDS: CLEAR CONSTRAINTS TO THE FUTURE GROWTH

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The paper deals with global energy perspectives and forthcoming changes in the atmosphere and climate under the influence of anthropogenic and natural factors. In the framework of the historical approach to energy development the forecast of the future global energy consumption for the present century is elaborated, and its resource base and the global impact of the power sector on the atmosphere and climate against the background of natural factors influence are studied. It is shown that, following the historical path of global energy evolution, the global energy consumption will remain within 28–29 billion tons of coal equivalent (tce) by the end of the century, with CO_2 emissions peaking in the middle of this century. In this scenario, the CO_2 concentrations will not exceed 500 ppm, and the global temperature should rise by 1.5 °C by 2100, with the growth rate not exceeding the adaptation limits of the biosphere.

Keywords: *energy, climate change, carbon dioxide emission.*

Introduction

Energy is a fundamental base of the evolution of civilization, and the twenty-first century poses for the world energy sector a challenging task of ensuring sustainable development of human society. The progressing growth of population will undeniably lead to the necessity of accelerated development of many regions of the world, and, as a result, to enhanced demand for energy in the nearest decades. Thus, to provide fuel and energy resources to the world economy is one of the principal problems posed to humanity. On the other hand, today energy sector is considered as one of the principal factors entailing global environmental change, which overrides all other anthropogenic factors and compares with powerful natural forces in its impact on the climate of the planet (see Solomon *et al.* 2007). The concern about the scale of observed climate changes (in particular, an increase of the mean global temperature by 0.8 °C over the past 120 years) and anxious projections of further warming (up to 5 °C over the current century) make the ecological policy, along with the state of the resource base, one of the principal regulators of the world energy development.

Journal of Globalization Studies, Vol. 1 No. 2, November 2010 27–40

There have been a great number of publications concerning the above problems over the past decades, and these problems have been in the centre of attention of leading national and international institutions. However, great controversy still exists in the opinions as to the global energy perspectives and the scale of their associated environmental and climate changes.

At the same time, it is quite understandable that without a more or less clear view of the future energy use, one cannot build realistic scenarios of its impact on the environment and climate and develop an efficient adaptation policy. A question thus arises of whether long-term forecasts of energy demand are feasible at all? Many experts, bearing in mind an extensive negative experience in this field (see, for example, a review of scenarios of global energy consumption in Klimenko *et al.* 2001), tend to give a negative answer to this question.

In our opinion, the situation may prove to be not so hopeless if one resorts to a historical extrapolation approach that is widely known in contemporary sociology and economy as the theory of institutional changes (see North 1990), which is based on the concept that the history of complex systems development predetermines their future behavior for many years ahead. In the present work we set ourselves the task to outline the direction of the world energy development, based on the principal trends in its historical evolution, and to assess, from the same standpoint, resource availability and the most probable impact on the global climatic system.

The suggested assessments are based on the so-called genetic forecast of global energy consumption developed at the Moscow Energy Institute (MEI) over 20 years ago (see Klimenko and Klimenko 1990; Snytin *et al.* 1994), and which has shown a remarkable correspondence to the observed data over the past decades. The deviation of projected values from the global energy statistics data was within 2 %, which, in our opinion, makes it possible to build up a super long-term energy forecast with an accuracy sufficient for climatic assessments. A consistent application of the genetic approach to energy use forecasting (identification and extrapolation of historical tendencies to the future) allowed drawing two basic conclusions as to the development of world energy demand in the nearest decades:

1) Stabilization of the national per capita energy consumption at the level primarily determined by climatic and geographic factors (see Klimenko 1994). This process has already been completed in the most developed countries (see Klimenko *et al.* 2001; Energy Statistics Yearbook 2009; BP Statistical Review… 2009; International Energy Annual 2009; Demographic Yearbook 2009).

2) Steady and nearly linear decrease of the carbon intensity of global energy as a result of structural changes in the world fuel mix that lingered for more than 100 years (see Klimenko, V. V., Klimenko, A. V., Andreichenko *et al.* 1997).

The realization of the former tendency should lead to the fact that the global per capita energy consumption will reach 2.9–3.0 tce/year, which, by the way, is quite close to the present level (2.6 tce per capita in 2009); as a result, since the Earth's population is expected to reach 9.5 billion by 2100 (see World Population… 2009), the energy consumption will make 28–29 billion tce/year, which is 1.6 times above the present level. Thus, the historical approach prohibits the energy consumption increase to 60, 100, and, all the more, 200 billion tce/year over the present century, which frequently conceded by the authors of the most radical energy scenarios (see Nakicenovic and Swart 2000).

The preservation of the latter tendency means that the growth of the anthropogenic impact on the climatic system steadily slows down and, therefore, one can expect that the anthropogenic emission of CO_2 will fairly soon, within the next quarter of century, reach its maximum. There is no any mysticism in the steady and, apparently, irreversible decrease of the carbon intensity. Moreover, this fact can be philosophically substantiated in terms of the principle of progressive simplification, a phenomenon of widespread occurrence in nature and social life and observed not only in engineering, but also in science, art, philosophy, and theology (see Toynbee 1988). As applied to the energy sector, this principle is manifested in a gradual transfer from more complex, 'conserved' energy sources to more elementary, natural. Such is the trend of global energy development from coal to oil, then to gas, and, finally, to renewable (solar, wind, tidal *etc.*) sources.

Global Resources of Fossil Fuels and Renewable Energy Sources and Prospective Energy Balance in the Twenty-First Century

A necessary test for consistency of any energy scenario includes assessment of its *fuel and energy reserves' availability*. Surprisingly as it may seem, the amount of fossil fuels expected to be consumed in many previous 'high' energy consumption scenarios did exceed not only its proven recoverable reserves, but often also hypothetical additional resources.

In the present work to estimate the consumption of hydrocarbon fuels (oil and natural gas) we made use of the so-called 'depleting resource consumption concept' (Energy and Nuclear Power… 1985) which suggests declining production rates of a resource as its stocks are gradually depleted. In this case, the cumulative consumption trend of the resource is described by a logistic function with an exponential initial portion and an asymptote defined by the ultimate amount of recoverable reserves. For the latter we accept the sum of discovered recoverable reserves and prospective additional resources, which poses the theoretical limit of the availability of this kind of fuel from the geologic and economic viewpoints (in terms of the World Energy Council (WEC) [see WEC Survey… 2001]). In this respect the present research differs from our previous work (see Snytin, Klimenko, and Fedorov 1994) where we took no account of additional oil and gas resources, which resulted in a slightly distorted projection of the structure of global energy balance, envisioning continuous increase of the coal share and, vice versa, decrease of oil and gas share already from the beginning of the current century. In reality, the last decade showed that oil has preserved its leading position in the world fuel mix, while coal consumption, *increasing with the annual rate of 4 %, left natural gas behind*.

Fig. 1 shows a record of changes of discovered recoverable reserves of hydrocarbon fuels over the past 60 years (according to BP Statistical Review… 2009; International Energy Annual… 2009; Energy and Nuclear Power… 1985; WEC Survey 2001). Evidently, the estimates for oil, as well as for gas resources have changed considerably: as compared with 1950, they have increased by an order of magnitude, regardless of current high production rates (about 5 and 4 billion tce/year for oil and gas, respectively). However, it is quite clear that this situation cannot last indefinitely long, and the curve shapes in Fig. 1 show that annual build-up of oil resources today nearly match oil production rate, and the situation with gas will obviously become the same over the nearest decade or two. Thus, the global proven recoverable oil and gas reserves are currently about 240 billion tce each, and the ultimate recovery (including additional recoverable resources (see WEC Survey… 2001), comprises 620 and 490 billion tce, respectively.

Fitting the historical series of the cumulative oil and gas production (see Energy Statistics Yearbook 2009; BP Statistical Review… 2009; International Energy… 2009) by a logistic function with ultimate oil and gas reserves as asymptotes determines the trend in the annual production of hydrocarbon fuels for the nearest decades (Figs 2 and 3). The genetic forecast assumes that these kinds of fuel will cover some 40 % of global energy demand by 2050, but less than 10 % by the end of the century. For comparison in Figs 2 and 3 the principal scenario of the WEC and International Institute of Applied System Analysis (WEC/IIASA) (see Nakicenovic, Grubler, and McDonald 1998) is shown, according to which the total consumption of oil will fully deplete its resources by 2100, and the total consumption of natural gas will even exceed its ultimate resources. The same features are characteristic for the scenario B2 of the Intergovernmental Panel on Climate Changes (IPCC) (see Nakicenovic and Swart 2000). Although this scenario is not specified as a basic one, it assumes moderate demographic and economic growth parameters and is placed in the centre of the spectrum of forty alternative energy development scenarios presented in *(Ibid.)*.

To keep the tendency for specific CO_2 emission decrease with the growing energy production, the suggested genetic forecast requires that the share of coal in the global energy balance be maintained at a level of 15–20 %. Thus, this 'clean energy' scenario assumes that non-fossil energy sources will cover about 30 % of the energy demand by 2050 and up to 65 % by 2100 against present 20 % (Table 1).

However, the energy consumption parameters over the last decade point to prevailing growth rates of global coal consumption, primarily due to China and India. This tendency provides some evidence in favor of the so-called 'coal bridge' theory formulated three decades ago, according to which this kind of fuel should fill the gap between depleting hydrocarbon reserves and slowly developing renewable energy sources. To account for this tendency, an alternative scenario was developed, that put emphasis on coal whose annual consumption was estimated by a procedure analogous to that used with oil and gas (Fig. 4). The shape of fuel mix for this scenario ('coal energy'), which expects that by 2100 the share of coal will increase to 30 % and non-CO_2 emission energy sources will make about a half, is also presented in Table 1, along with the WEC/IIASA and IPCC data (see Nakicenovic, Grubler, and McDonald 1998; Nakicenovic and Swart 2000).

Considering the dynamics of the world fuel mix, one can note that the long-term expectations associated with the development of nuclear energy technologies (specifically, the WEC/IIASA scenarios [see Nakicenovic, Grubler, and McDonald 1998]) projecting a growth of the annual nuclear power production over the current century up to 25–40 trillion kWh, which is equivalent to annual combustion of 8–13 billion tce at thermal power plants[1]) have not come true: most experts (see International Energy Outlook 2009; World Energy… 2008) do not see the possibility that the present nuclear electricity production (about 2.8 trillion kWh/year) will increase considerably. Thus, the base scenarios both of the US Department of Energy (see International Energy Outlook… 2009) and International Energy Agency (see World Energy Outlook 2008) suggest that the annual nuclear electricity production will span the range 3.5–3.8 trillion kWh over the period to 2030. Thus, the share of nuclear energy in global energy consumption will comprise no more than several percent. Hydroenergy, regardless of expected increase of its production rate (at present one third of the economic global hydro potential is already harnessed), too, will be able to cover no more than 10 % of the total energy demand. As a result, by 2100, to implement the genetic scenario will require the energy production from non-traditional renewable sources to increase to 16–18 billion tce/year or about 50 trillion kWh/year, which is quite possible, since these production rates are well below the technical potential (and just about three times as high as the economic potential calculated for the conditions at the beginning of this century) of both solar and other kinds of renewable energy (Table 2) whose utilization rates have grown consistently by 8 % a year over the past three decades (see Energy Statistics 2009; International Energy Annual… 2009).

The structure of the world energy balance suggested in the present work for the forecast of global energy consumption up to 2050 is quite similar to that in (Nakicenovic, Grubler, and McDonald 1998; Nakicenovic and Swart 2000) (Table 1). Appreciable differences in the estimates for the shares of hydrocarbon fuels and non-CO_2 emission energy sources arise closer to 2100, resulting from the fact that the status of energy technologies by this time is still difficult to predict. Nevertheless, the share of non-fossil energy sources that we expect by 2100 (55–65 %) is considered in a number of IPCC scenarios (*i.e.* A1T, A1B, and B1 scenarios) (see Nakicenovic and Swart 2000). Thus, even though we made use of quite a different approach to assess global energy perspectives, our suggested structure of global fuel balance does not generally contradict expert assessments for the development of energy technologies and, with regard to fossil fuels, it is fully provided by available natural resources.

Environmental characteristics of the suggested scenarios are determined by the carbon coefficient of global energy consumption (Fig. 5). One can see that, with the recent growing share of coal in the global commercial energy consumption, the long-term tendency for a decrease of carbon intensity reverses, approaching the current 1.9 ton CO_2/tce from the minimum of 1.8 ton CO_2/tce in 2000 but the subsequent decrease to the 'clean' scenario level by the end of the century is anticipated. Surely, such changes should appreciably enhance emissions of CO_2 (and other greenhouse gases). These consequences and their associated global climate changes are considered below.

Atmosphere and Climate Changes in the Twenty-First Century

Dramatic scenarios of future global warming (see Solomon *et al.* 2007) (according to the most extreme of them, the global average temperature will increase by 5 °C over the current century, which has never occurred not only during the history of civilization, but also over the past 40 million years on the whole) are based on models of general atmosphere and ocean circulation simulations. As was repeatedly shown (for example, see Klimenko, V. V., Klimenko, A. V., and Tereshin 2001; Klimenko, V. V., Klimenko, A. V., Andreichenko *et al*. 1997), these models, while getting more and more complicated, are still incapable of adequately representing the observed climate changes and give widely scattered estimates for such an important parameter of a climatic system as the sensitivity to the content of greenhouse gases in the atmosphere, which, according to various estimates (their review is given in Solomon *et al.* 2007), varies in the range 1.5–5.5 deg. with doubling CO_2 concentration. To overcome these difficulties, we have developed a more simple regression analytical climatic model (RACM) (see Klimenko 1997, 2007; Klimenko, V. V., Klimenko, A. V., Andreichenko *et al*. 1997; Klimenko *et al.* 1994; Klimenko, Mikushina, and Tereshin 1999; Klimenko and Mikushina 2005; Khrustalev *et al*. 2008) which combines physical methods for representing thermodynamic processes in the ocean – atmosphere system and statistical methods for correlating their impact (temperature responses) with external perturbing factors. With a correct account for the effect of a few major natural climate forcing (solar, volcanic *etc.*) we estimate the sensitivity of the global climatic system at about 1.9 °C for doubled CO_2 concentration, which falls into the lower range of estimates for this parameter (see Solomon *et al.* 2007).

To estimate the changes in atmospheric CO_2 content, associated with anthropogenic emission, we made use of the box diffusion model of global carbon cycle, developed at the Moscow Energy Institute (see Klimenko, V. V., Klimenko, A. V., Andreichenko *et al*. 1997). The CO_2 concentrations calculated by greenhouse emission scenarios for the 'clean' and 'coal' global energy development models are shown in Fig. 6.

According to the RACM global climate change projections, assuming the basic forecast of principal climate forcing factors (*Ibid.*) and 'coal energy' scenario, the global average temperature will increase by about 1.3 °C within this century. Although this value even exceeds the maximum Holocene mark, it is, in terms of another important criterion (temperature change rate), probably within the adaptation limits of the biosphere. Simulation of the implementation of the 'clean' scenario similar in goals to those of the Kyoto Protocol (Fig. 7) shows that the measures suggested by this international agreement for climate stabilization, even though they cannot much affect the dynamics of the global average temperature, will still help to reduce the global warming by 0.3 °C. A comparison of the 'clean' and 'coal energy' scenarios (Fig. 7, curves *1* and *2,* respectively) shows that the meeting of the Kyoto Protocol targets can favor a more environmentally safe energy development.

Local climate changes are expected to be quite diverse. Our survey for various parts of Russia (see Klimenko 2007; Khrustalev *et al*. 2008; Klimenko and Mikushina 2005) showed that in the nearest decades the average annual, winter, and spring temperatures will appreciably increase, which, in its turn, will affect a number of applied climate characteristics crucial for different economy sectors. Thus, a shorter and warmer cold period will require less fuel for heating (down 15 % from the present level by 2050) (see Klimenko 2007). Positive changes in transport and agriculture are also expected, which, too, will decrease the required energy consumption. Probably, permafrost areas are the most vulnerable to climate changes and will require huge additional investments in the existing infrastructure (see Khrustalev *et al*. 2008).

A comparison of temperature and precipitation fields for present warming and other historically warm periods which are useful analogs for the expected warming, such as the Atlantic Holocene Optimum (about 7–6 thousand calendar years ago) and the Medieval Warm Epoch (the late ninth – twelfth centuries) (see Klimenko 2001, 2004), shows that considerable temperature changes may occur only in several countries of the Northern hemisphere. Thus, considerably increased average annual temperatures are observed, along with Russia, only in Canada, the Northern part of the USA and Middle and Central Asia, whereas the temperature changes in Europe, South-East of the USA, and most part of China and India are either inconsiderable or even negative. These changes will almost everywhere be accompanied by enhanced precipitation, except for the North East of the USA, the Mediterranean, eastern Provinces of China and South-East States of India, where a certain desiccation takes place.

However, the scenarios of future climate changes, presented in other works, are quite different up to catastrophic ones (Fig. 8). Thus, the most recent IPCC review (see Solomon *et al.* 2007) does not exclude that the global average temperature may increase by 5 °C by the end of this century. Such a large-scale global warming will entail irreversible environmental changes in most regions of the world, including Russia, and, as a result, will have an extremely negative impact on all spheres of human activities. Undoubtedly, the ecological pressure on economy, in particular, in terms of the Kyoto Protocol, is much dependent on whether these projections will be proved or disproved. Provided the catastrophic forecasts are disproved, further tightening of Kyoto constraints will be less likely. At the same time, if things follow an unfavorable scenario, further consolidation of the environmental protection community should be expected. However, we have to repeat that the results of our long-term research provide firm evidence in favor of moderate scenarios of global climate changes.

Thus, our early forecasts (see Klimenko *et al.* 1994; Klimenko 1997) of global climate changes are still valid, which, by the way, evidenced by the fact that they fully represent the actual data for the past two decades (see Klimenko, V. V., Klimenko, A. V., and Tereshin 2001; Klimenko and Tereshin 2010). According to this forecast, we expect that the global average temperature will increase by another 1–1.5 °C over the course of the current century (Figs 7 and 8), which falls below the range of IPCC estimates for possible atmosphere and climate changes (see Solomon *et al.* 2007), even including scenarios assuming the world population decrease (B1), and is five times below the possible temperature rise due to the extreme scenarios group A1FI, which expects the most intensive growth of fossil fuel consumption. Nevertheless, the expected warming is far beyond the range of the natural variability of global climate, recorded in palaeoclimatic data over the past 2.5 thousand years (see Klimenko 2001, 2004); however, the warming rate (about 0.1 °C per decade) appears to be within the adaptation limits of the biosphere (Klimenko and Tereshin 2010). It can be concluded that both the warming expected to occur by the late twenty-first century and the increase in the atmospheric CO_2 concentration will only slightly exceed the scale of global changes that have already occurred over the past century.

Conclusions

The time passed after the publication of the first results of the application of the genetic approach to forecasting future energy use showed that this approach gives encouraging results. Our early forecasts of world energy consumption represent the actual data for the last 20 years remarkably well.

The development of the method of historical extrapolation to assess the future global fuel mix allowed us to develop the perspective energy balance for the current century, in which a key role of fossil fuels will hold up to at least 2060–2065.

This historical scenario of global energy consumption is completely provided by the available resources of fossil fuel and does not contradict the assessments of prospective development of non-fossil energy sources.

An implementation of the historical scenario of energy development is expected to cause moderate atmosphere and climate changes which are quite comparable with the scale of global changes that have already occurred over the past century.

Local manifestations of expected climate changes will be very diverse. Thus, in the nearest decades in moderate and high latitudes we can expect a shorter and warmer cold period, as well as appreciable destructive phenomena in the permafrost zone of the Russian territory.

ACKNOWLEDGEMENT

The study was supported by the Russian Ministry of Education and Science in the framework of the Federal Program 'Scientific and Educational Staff of Innovative Russia'.

NOTE

[1] Recalculation of the so-called primary electricity, *i.e.* non-fossil electric power, is performed by the equation 1 kWh = 0.319 kgce, with the global average efficiency of thermal power plants taken to be equal to 0.385.

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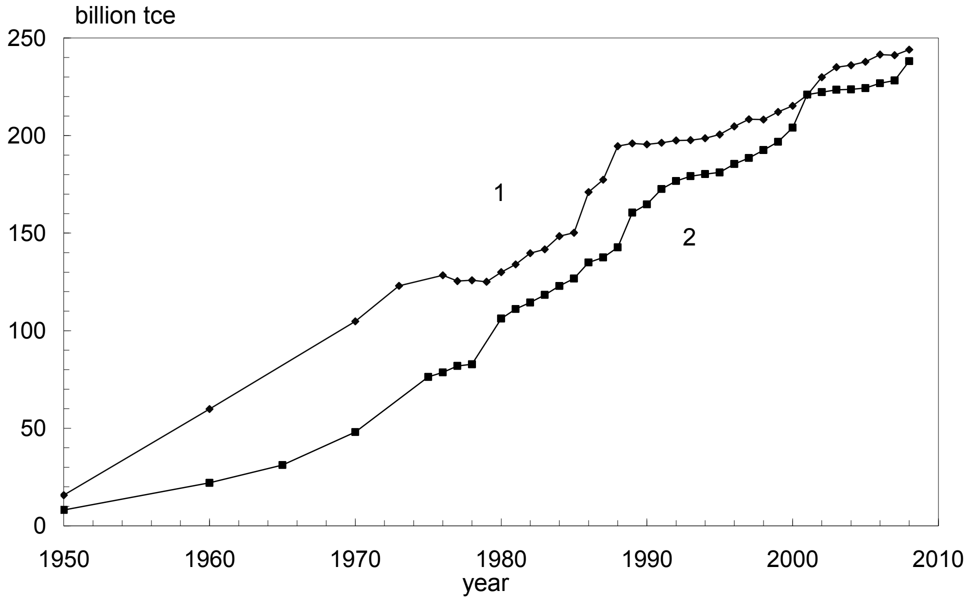

Fig. 1. Record of the estimated proven recoverable reserves of hydrocarbons: (1) oil and (2) natural gas

Source: BP Statistical Review 2009; International Energy Annual 2009; Energy and Nuclear Power 1985; WEC Survey… 2001.

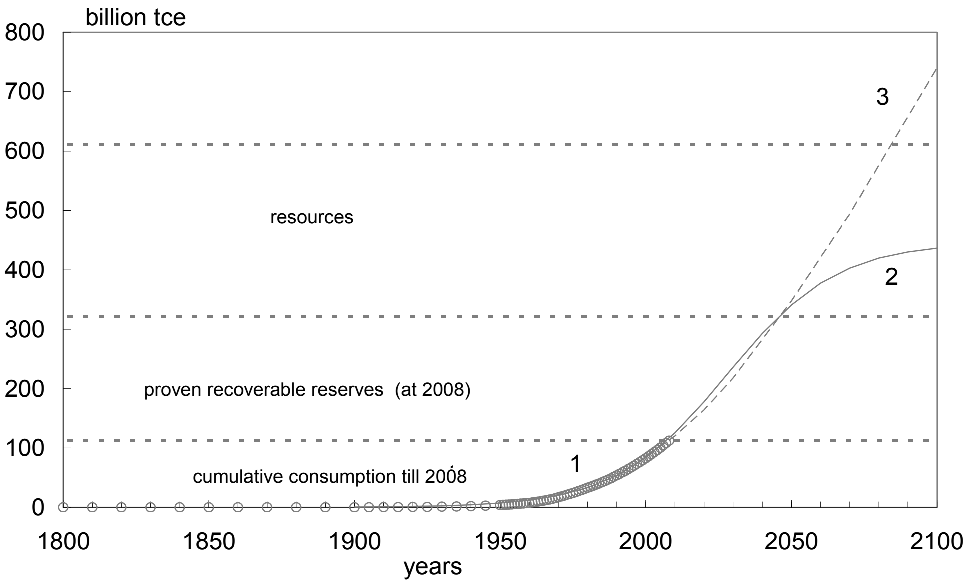

Fig. 2. Cumulative global gas consumption: (1) historical data (Energy Statistics Yearbook 2006; BP Statistical Review… 2009; Energy Statistics Yearbook 2009); (2) forecast of the present work; and (3) WEC/IIASA Reference Case scenario (Nakicenovic, Grubler, and McDonald 1998)

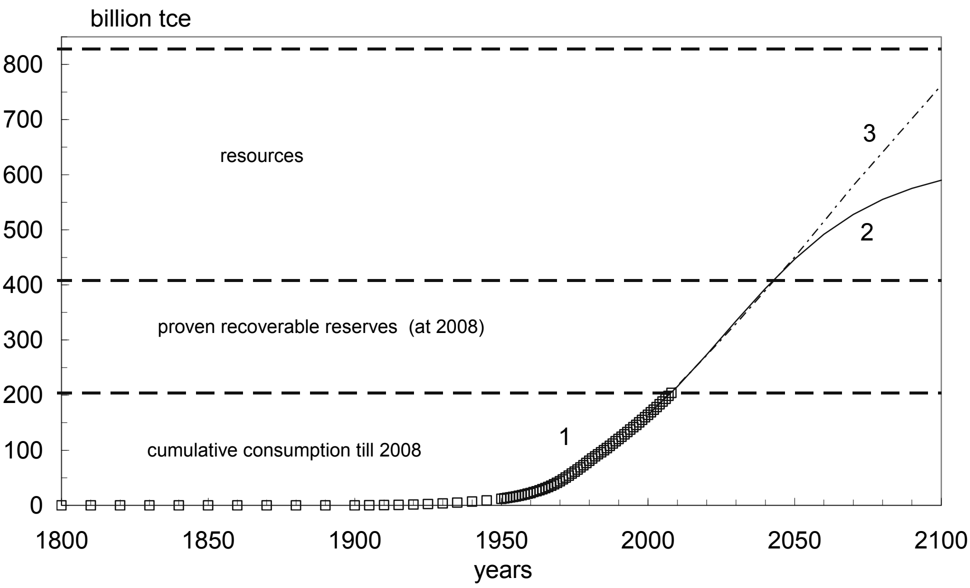

Fig. 3. Cumulative global oil consumption: (1) historical data (see International Energy Annual 2009; BP Statistical Review… 2009; Energy Statistics Yearbook 2009); (2) forecast of the present work; and (3) WEC/IIASA Reference Case scenario (see Nakicenovic, Grubler, and McDonald 1998)

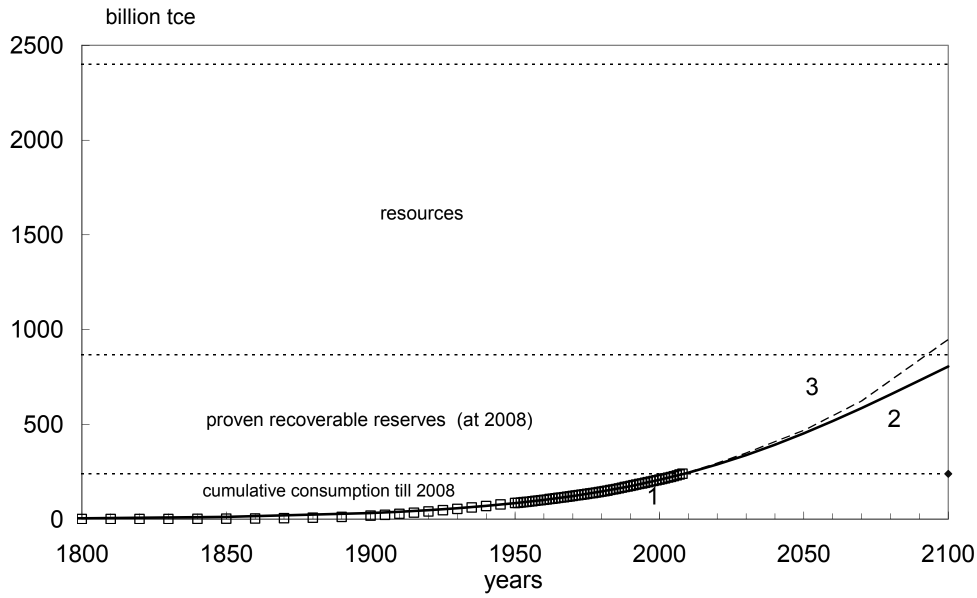

Fig. 4. Cumulative global coal consumption: (1) historical data (see International Energy Annual 2009; BP Statistical Review… 2009; Energy Statistics Yearbook 2009); (2) forecast of the present work; and (3) WEC/IIASA Reference Case scenario (see Nakicenovic, Grubler, and McDonald 1998)

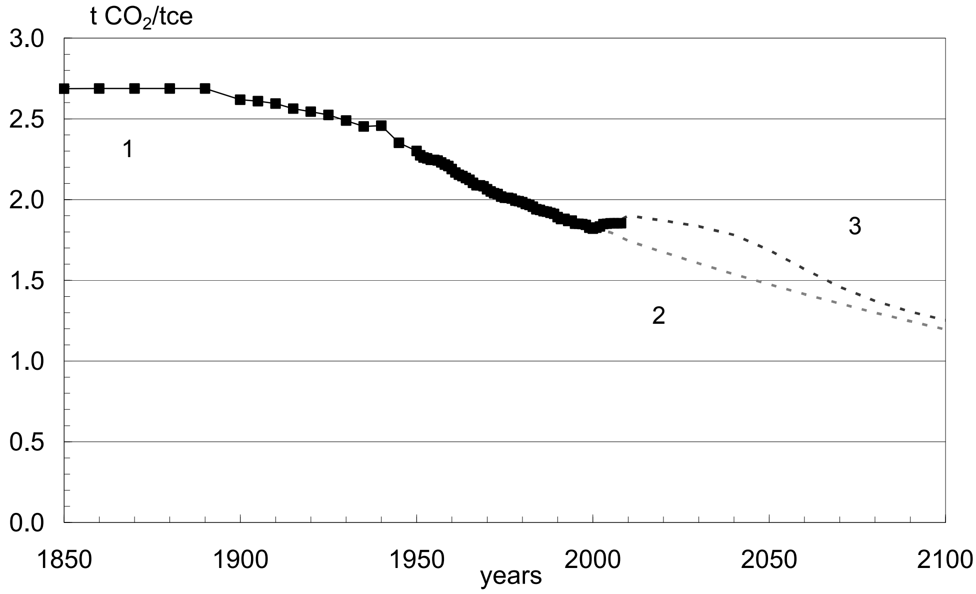

Fig. 5. Dynamics of the carbon coefficient of the global commercial energy consumption: (1) historical data (see International Energy Annual 2009; BP Statistical Review… 2009; Energy Statistics Yearbook 2009); (2) 'clean energy' and (3) 'coal energy' scenarios of the present work

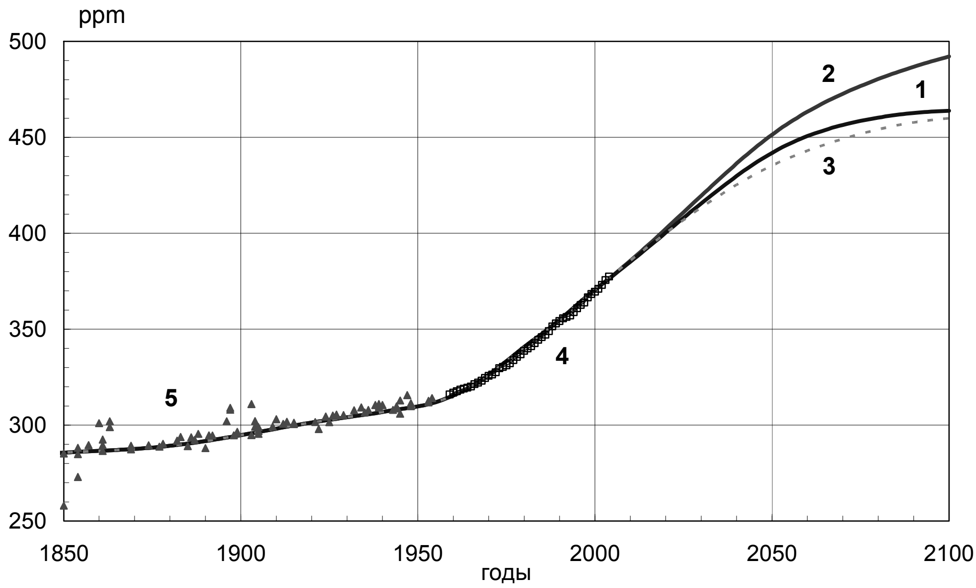

Fig. 6. Carbon dioxide concentration change: model simulations by the emission scenarios of the (1) 'clean' and (2) 'coal' global energy development of the present work, model simulation (3) from (Klimenko, V. V., Klimenko, A. V., and Tereshin 2001) and data of instrumental measurements (4) and ice-cores (5) (Solomon *et al.* 2007)

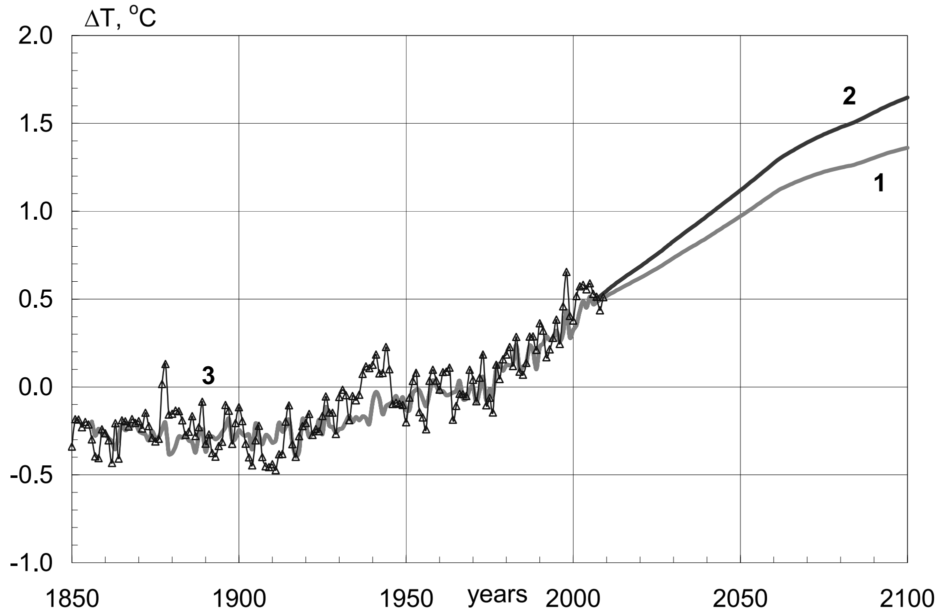

Fig. 7. Global average temperature change (compared with the 1951–1980 mean): model simulation and forecasts for the 'clean' (1) and 'coal' (2) energy scenarios of the present work; and (3) instrumental data (see Solomon *et al.* 2007)

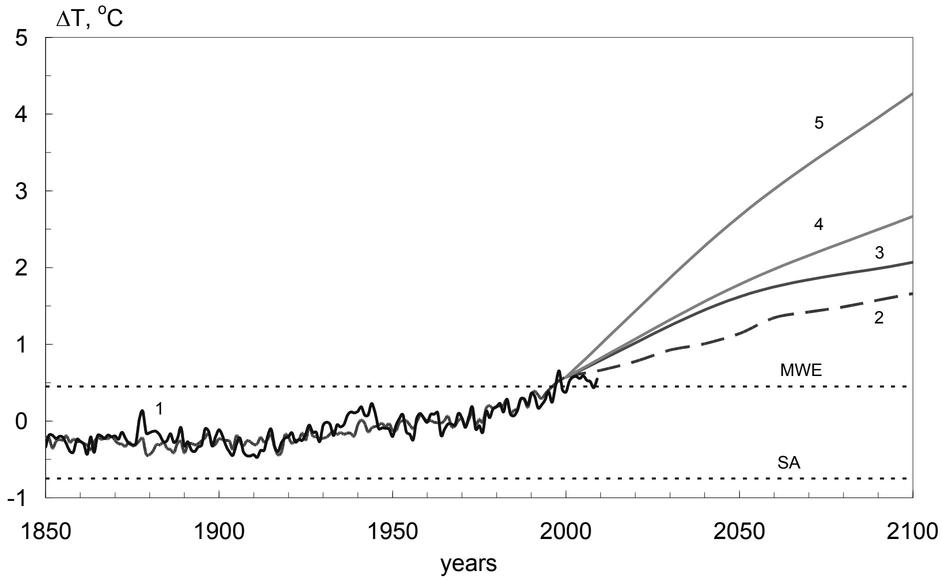

Fig. 8. Global average temperature change (compared with the 1951–1980 mean):
(1) instrumental observations data (see Solomon *et al.* 2007);
(2) model simulation and forecasts by the (2) 'coal' energy scenario of the present work and IPCC scenarios (*Ibid.*): (3) B1, (4) B2, and (5) A1FI.
Temperature levels of the Medieval Warm Epoch (MWE) (see Klimenko 2001) and Cold Subatlantic Epoch (SA) (see Klimenko 2004) are also indicated

Table 1

Global fuel mix for different energy scenarios, billion tce

Scenario	Energy source	2000	2020	2050	2100
'Clean energy' (present work)	Coal	3,2 (23 %)	3,1 (15 %)	3,7 (14 %)	5,5 (19 %)
	Oil & gas	8,0 (56 %)	11,1 (54 %)	10,2 (39 %)	2,0 (7 %)
	Non-CO_2 commercial	1,7 (12 %)	4,2 (20 %)	9,8 (38 %)	18,4 (65 %)
	Non-commercial	1,3 (9 %)	2,1 (10 %)	2,3 (9 %)	2,4 (9 %)
	Total	14,2 (100 %)	20,5 (100 %)	26,1 (100 %)	28,3 (100 %)
'Coal energy' (present work)	Coal	3,2 (23 %)	3,3 (16 %)	6,7 (26 %)	8,1 (29 %)
	Oil & gas	8,0 (56 %)	11,1 (54 %)	10,2 (39 %)	2,0 (7 %)
	Non-CO_2 commercial	1,7 (13 %)	4,0 (20 %))	6,9 (26 %)	15,8 (56 %)
	Non-commercial	1,3 (9 %)	2,1 (10 %)	2,3 (9 %)	2,4 (9 %)
	Total	14,2 (100 %)	20,5 (100 %)	26,1 (100 %)	28,3 (100 %)
Reference case WEC/IIASA (Nakicenovic *et al.* 1998)	Coal	3,2 (22 %)	5,1 (26 %)	6,5 (23 %)	12,6 (26 %)
	Oil & gas	8,0 (56 %)	10,5 (54 %)	13,4 (47 %)	14,4 (29 %)
	Non-CO_2 commercial	1,7 (13 %)	2,6 (13 %)	7,2 (25 %)	21,6 (44 %)
	Non-commercial	1,3 (9 %)	1,2 (6 %)	1,2 (4 %)	0,6 (1 %)
	Total	14,2 (100 %)	19,4 (100 %)	28,3 (100 %)	49,2 (100 %)
B2 scenario IPCC (Nakicenovic and Swart 2000)	Coal	3,2 (22 %)	3,3 (17 %)	3,0 (10 %)	10,2 (22 %)
	Oil & gas	8,0 (56 %)	12,6 (65 %)	17,8 (60 %)	13,4 (29 %)
	Non-CO_2 commercial	1,7 (13 %)	2,2 (11 %)	7,6 (26 %)	21,4 (46 %)
	Non-commercial	1,3 (9 %)	1,3 (7 %)	1,3 (4 %)	1,3 (3 %)
	Total	14,2 (100 %)	19,3 (100 %)	29,7 (100 %)	46,3 (100 %)

Table 2

Potential of renewable energy sources, trillion kWh/year (see Energy and Nuclear Power 1985; WEC Survey 2001; International Energy Outlook 2009; World Energy Outlook 2008)

Renewables	Theoretical Potential	Technical Potential	Economical Potential
solar	8700	720	5,3
hydro	40	15	8,0
wind	500	53	2,4
Wave and tides	22	6	0,6
geothermal	5000000	6	1,0
TOTAL	5009262	800	17,0