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Application of an optimisation model to studying some aspects of Russia's economic development

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Abstract: The global climate change is one of the most important and disputable problems in the modern world. The Kyoto Protocol is an effort of the international community to control environmental impacts. To study pros and cons of Russia's participation in this initiative, different integrated assessment models for evaluating greenhouse gases (GHG) reduction policies can be engaged. In the present paper, an approach to modelling is briefly described and some simulation results are discussed. The emphasis is on obtaining the 'optimal' temporal dynamics of economic-energetic indices for different scenarios of Russia's development. The main result shows that, in the first commitment period of the Protocol, GHG emissions in Russia can reach the critical level in some extreme cases.

Keywords: evaluation of GHG reduction policies; Kyoto Protocol; model for evaluating regional and global effects; MERGE; scenarios of Russia's economic development; inter-temporal optimisation; Russia.

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1 Introduction

The driving forces of the global climate change, one of the most actual problems in the modern world, are not completely studied yet; so, ecological, social and economic consequences of this process are rather disputable and complicated from the analytical viewpoint. The experts of the Intergovernmental Panel on Climate Change and from scientific institutions are in agreement that the dramatic climate change observed in the recent time is explained to some extent by the increase of the atmospheric concentration of greenhouse gases (GHG), first of all, CO_2, due to man's impact that is characterised by the essential increase of fossil fuel consumption in industry and power engineering. At the same time, there is no universally recognised opinion on measures aimed at preventing temperature rise.

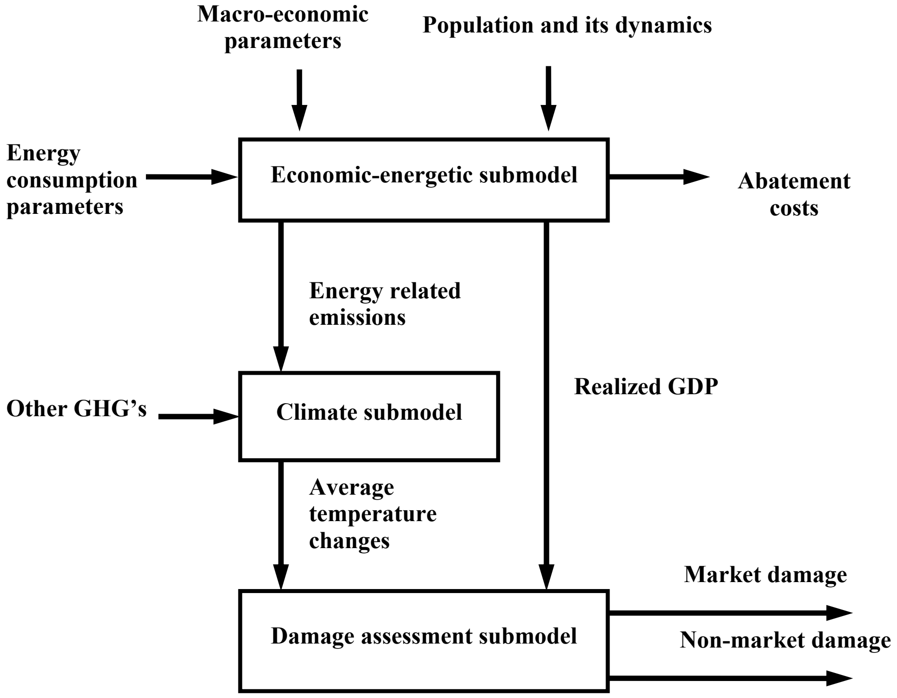
One of the efforts of the international community to control environmental impacts is the Kyoto Protocol to the United Nations Framework Convention on Climate Change (it was passed in December 1997). As is known, after the waivers of ratification of the Kyoto Protocol by the main countries producing GHG emissions, USA and China, the future of the Protocol directly depended on the position of Russia. Even after the ratification of the Kyoto Protocol in November 2004, the debate in Russia about future costs and benefits of being a party to the Protocol has continued with hardly mitigated intensity since many statements of the Protocol and mechanisms of its application have an ambiguous value in the context of developing economy of Russia. In the discussion (see, for example, Izrael et al., 2002; Kokorin et al., 2004), arguments of proponents and opponents of Russia's participation in the Kyoto Protocol are rather seldom based on results of application of appropriate integrated assessment models (in particular, in order to evaluate regional and global effects of GHG reduction policies). In the present paper, one of the first attempts to bridge this gap is undertaken. An approach to modelling is briefly described and some simulation results (with the emphasis on the temporal dynamics of economic-energetic indices for Russia) are discussed.

2 MERGE: structure and possibilities

As a main tool for estimating economic consequences of Russia's participation in the Kyoto Protocol, we use the specific optimisation model for evaluating regional and global effects of GHG reduction policies named MERGE. It was elaborated by American scientists (Manne et al., 1995; Manne, 2000) and was modified at the International Institute of Applied Systems Analysis (Laxenburg, Austria) and the Institute of Mathematics and Mechanics, Ural Branch of RAS (Ekaterinburg, Russia) (see Maksimov et al., 2006). This model, belonging to the class of so called 3E (energy-environment-economy) integrated assessment models, consists of three interrelated parts describing basic processes connected with the problem in question. The scheme of MERGE with its main components is presented in Figure 1. We give a brief outline of each submodel: the economic-energetic module, the climate module and the damage assessment module (for more detailed information on MERGE, see, for example, Manne et al., 1995).

The economic-energetic submodel is used for forecasting the GHG emission dynamics and for estimating the economy-wide costs of different emission constraints (abatement measures) at the regional and global levels. In all versions of this module, the world is divided into geopolitical regions; each of them is considered as an independent price taking agent (a single producer-consumer) and is subject to inter-temporal financial constraints (to carry out investigations described below, we treat Russia as a separate region). The module is a fully integrated applied general equilibrium model. At each point in time, supplies and demands are equilibrated through the prices of internationally traded commodities, including oil, gas, coal and carbon emission rights. The submodel is not a set of recursive procedures determining a system's state through its previous history, but an optimisation model finding optimal trajectories of regions' development by means of maximisation of the sum of the discounted utilities of regional consumption over the whole time interval. Input parameters of the economic-energetic submodel are the following: population, its dynamics, forecast for GDP per capita dynamics, macroeconomic indices, energetic characteristics (in particular, carbon emission coefficients stipulating emissions for different technologies). Among output parameters of the module are the optimal dynamics of regional development (in particular, realised GDP and its characteristics: carbon intensity, structure (consumption, investments, export/import), energy related GHG emissions (specified by GDP value, energy efficiency and carbon emission rates of energy consumption), hypothetical abatement costs due to some specific constraints (for example, according to the Kyoto Protocol).

Figure 1 Overview of MERGE



The core of the optimisation procedure is a production function of the Cobb–Douglas type describing the dynamics of regional production Y. The main variables of this function are capital stock K, available labour L and energy inputs (electric energy EE and non-electric energy NE). In order to minimise the number of parameters requiring calibration or econometric estimation, the following production function is chosen:

$$Y(t,rg) = \left(a \cdot (K(t,rg)^{KPVS} L(t,rg)^{1-KPVS})^{\rho} + b \cdot (EE(t,rg)^{ELVS} NE(t,rg)^{1-ELVS})^{\rho}\right)^{\frac{1}{\rho}},$$

$$\rho = 1 - \frac{1}{ESUB},$$

where t is time; rg is a region; a and b are scaling parameters; $KPVS$ is a share of capital in capital-labour aggregate; $ELVS$ is a share of electric energy in energy aggregate; $ESUB$ is elasticity of substitution between capital-labour and energy aggregates.

The climate submodel focuses on three of the most important anthropogenic GHG (carbon dioxide CO_2, methane CH_4 and nitrous oxide N_2O). The concentrations of these gases in the Earth's atmosphere have been increasing since the industrial revolution, primarily as a result of human activities. In the model, the emissions of each gas are divided into two categories: energy and non-energy. The economic-energetic submodel calculates energy related emissions for each kind of fuel till 2100. Emissions from other sources are exogenous inputs for the model. The main function of the climate submodel is forecasting atmospheric and oceanic GHG concentrations through their emissions and pre-industrial levels. As an example, we present the discrete relations describing the dynamics of atmospheric GHG concentrations:

$$S_t^G = a_G S_{t-1}^G + E_{t-1}^G.$$

Here S_τ^G is the atmospheric concentration of gas G in year τ (for example, $G = CO_2$); E_τ^G is the emission of gas G in year τ; a_G is the retention factor for gas G in the atmosphere. It is assumed that the basic levels of GHG concentrations (levels of 1990 in the model) are known.

The concentrations are used for determining the actual change in temperature (relative to some initial year), which is one of inputs for the damage assessment submodel.

The damage assessment submodel analyses two types of climate change impacts, namely, market and non-market (ecological) damages. Market effects reflect categories that are included in conventionally measured national income and can be valued by means of prices and observed supply and demand functions. Non-market effects have no definite prices; so they must be valued using some alternative methods (among them, by future generations' preferences).

Note that the description above corresponds to both original model and later modifications. Let us outline the main updates that we included in the latest version of MERGE. Among these updates is the division of the world into the following regions:

1 USA

2 Western Europe

3 Japan

4 Canada

5 Australia and New Zealand

6 Eastern Europe

7 Russia

8 Other FSU

9 China

10 India

11 Mexico and OPEC

12 Rest of world.

Furthermore, the two-year intervals were introduced for simulation within the first commitment period of the Protocol. In addition, the model was adapted to the new datasets from Russian and foreign sources.

3 Results of numerical experiments

3.1 Main aim and input scenarios

The main aim of numerical experiments is estimating economic consequences of Russia's participation in the Kyoto Protocol under different assumptions on the dynamics of economic-energetic parameters (in particular, the average annual GDP growth rate and energy efficiency). Namely, some model scenarios of the development of Russian economy are designed; then a comparative analysis of simulation results and the expert forecasting estimates (Makarov and Likhachev, 2006) is performed.

We consider the following scenarios:

REF the reference scenario of MERGE based on the forecasts for Russia of the Energy Information Administration (International Energy Outlook, 2007).

and three scenarios based on some estimates of the average annual GDP growth rate for 2005–2020 from Russian sources (The Fourth National Communication of the Russian Federation, 2006; Russia in Numbers, 2007), namely:

GOV the governmental scenario, the average annual GDP growth rate is fixed at 6.2% for the time period 2005–2020 (this corresponds to the RF Government's forecast).

DBL the doubling Russia's GDP within ten years scenario, this goal being translated into an average annual GDP growth rate is equal to 7.2%.

PES the pessimistic scenario with the average annual GDP growth rate being fixed at 4.5% and a low rate of energy efficiency improvement.

For each scenario listed above, two variants are calculated: R0 and R1, with identical input parameters. Variant R0 does not include any GHG emission constraints, variant R1 assumes that GHG emission reductions in the world regions bound by the Kyoto Protocol are achieved by domestic measures only (without using carbon emission rights trade and flexible mechanisms of rights redistribution regulated by the Protocol). The GDP loss as the difference GDP(R0) – GDP(R1) actually characterises hypothetical costs of GHG emission reductions. As an initial year for a number of numerical experiments, we choose 2000 because there are no data necessary for modelling starting at a later time moment.

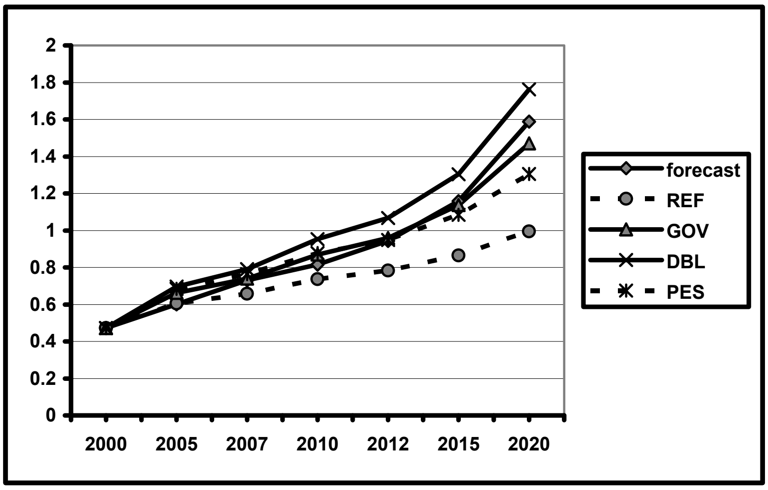
All the simulations are carried out under the assumption of a 'Kyoto forever' scenario (Manne et al., 1995; Manne, 2000; Maksimov et al., 2006) till 2100.

3.2 Comparison of scenarios: key indices

In Figures 2–5, the expert forecast made by the Energy Research Institute of RAS is marked by the word 'forecast', whereas modelling results are denoted by REF, GOV, DBL and PES, respectively. Since results obtained in variants R0 and R1 are qualitatively very similar for all the scenarios, in most cases, we restrict ourselves to considering output data of variants R0.

Figure 2 informs us that, under the model assumptions, Russia's GDP grows with an approximately constant rate. The forecast GDP holds an intermediate position between the model GDP for scenario DBL (doubling every ten years till 2020) and for scenario GOV. Note that the GDP for scenario REF is essentially behind the GDPs for other scenarios (including scenario PES); this testifies to a sceptical attitude to the perspectives of Russian economy on the hand of the Energy Information Administration.

Figure 2 Realized GDP in trln. year-2000 USD; variant R0 for model scenarios



From Figure 3, we conclude that, according to the forecast and for scenarios REF and GOV, CO_2 emissions do not reach the level of 1990 (the Kyoto level for Russia, 0.646 Gt C equivalent) even in 2020, whereas for scenarios DBL and PES the critical level is reached in the first commitment period of the Protocol (before 2012). Thus, the latter two scenarios assume additional expenses for GHG emission reductions in variants R1. This fact is reflected in Figure 4, where the possible GDP losses are presented. For scenarios DBL and PES, these losses exceed 10% of the corresponding GDP values in variants R0 in 2020. Positive (but small) losses for scenarios REF and GOV are explained by the necessity of future costs of GHG emission reductions and optimisation in MERGE over the whole time interval. In addition, this experiment allows us to make some conclusions on Russia's perspectives on the international market for GHG emissions permits, which is one of the Kyoto flexible mechanisms (Bernard et al., 2002; Kadiyev et al., 2008). According to the forecast and for scenarios REF and GOV, Russia actually does not need to reduce emissions for selling permits, since the amount of Russian so called 'hot air' (in addition to the abatement, available for sale) is large enough. The amount of 'hot air', being the difference between the current emissions and the Kyoto level, is varied in 2010 from 0.169 Gt C equivalent (forecast) down to 0.085 (GOV), in 2015 from 0.124 (REF) down to 0.067 (GOV), in 2020 from 0.137 (REF) down to 0.052 (forecast). For scenarios DBL and PES, we deduce that, despite the collapse of the industrial sectors in 1990s, to sell permits, Russia needs additional abatement measures, which can be rather cost-based. The different reasons should be indicated: for scenario DBL, too high average annual GDP growth rate is fixed, for scenario PES, too low rate of energy efficiency improvement is specified.

Figure 3 CO_2 emissions in Gt C equivalent; variant R0 for model scenarios, Kyoto level is Russia's emission level of 1990

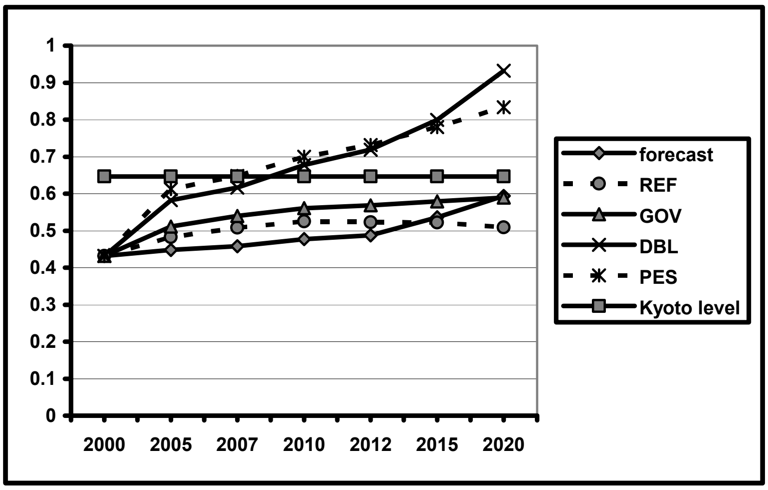
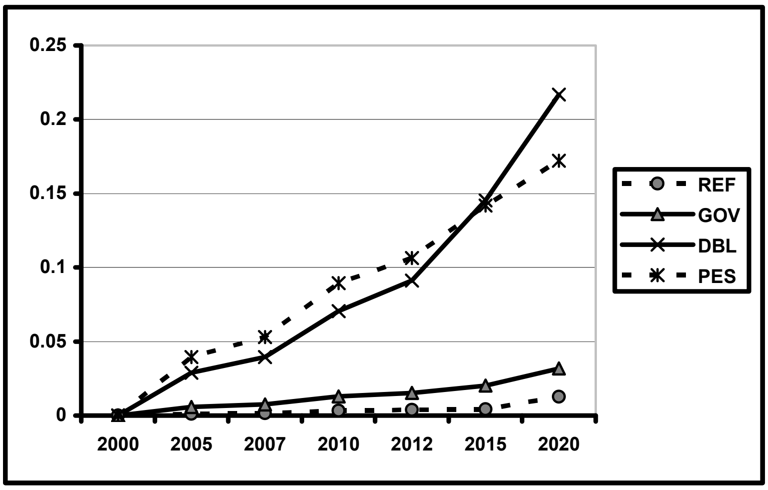
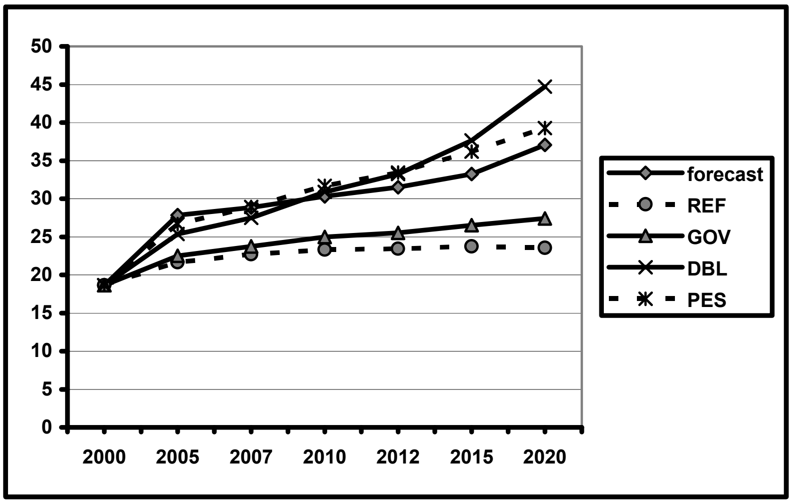


Figure 4 GDP loss = GDP(R0) – GDP(R1) in trln. year-2000 USD; model scenarios



In Figure 5, the temporal dynamics of total primary energy supply is presented. It is evident that the expert forecast (with respect to this parameter) is much closer to the simulation results for scenarios DBL and PES than for scenarios GOV and REF. Note that perspectives of Russian power engineering from the viewpoint of the Energy Information Administration (International Energy Outlook, 2007) and from the viewpoint of Russian experts (Makarov and Likhachev, 2006; The Fourth National Communication of the Russian Federation, 2006) are essentially different (for example, the energy supply in 2020 for scenario DBL is almost twice larger than for scenario REF, 44.7 EJ (exajoules) against 23.5 EJ).

Figure 5 Total primary energy supply (both electric and non-electric, in EJ); variant R0 for model scenarios



3.3 *Dynamics of structure of energy sector*

Analysing the dynamics of structure of energy sector of Russia (Table 1), we mark out several tendencies, which are common for the model scenarios and the expert forecast. Since, for the model scenarios, the absolute contribution of the hydro and nuclear energy in the total supply remains almost constant, their summary share falls, whereas this share is unchanged according to the expert forecast. At least till 2020, natural gas plays a definitive role in the energy supply for the model scenarios as well as according to the forecast. For the model scenarios, its share in 2020 is larger than 50%. The share of oil and coal (existing processing technologies) decreases in time for all scenarios. The continuation of calculations (out of the table) demonstrates in perspective a sharp fall of shares of resources mentioned above due to reserve depletion and coming new technologies of coal processing and renewable energy sources (such as solar energy, geothermal energy, biomass energy and so on) to the forefront.

To study some details of energetic dynamics and world-regional primary-energy exports by Russia, we choose scenario GOV, which, on the one hand, reflects the governmental forecast of the Russian economy development and, on the other hand, as follows from aforesaid, is close to the expert estimates. The scheme of finding parameters of the scenario for 2020–2100 coincides with the corresponding scheme of scenario REF (International Energy Outlook, 2007).

Table 1 Total primary energy supply structure (% of total supply); variant R0 for model scenarios

Year	*Scenario*	*Gas*	*Oil*	*Coal*	*Hydro*	*Nuclear*	*Renewables*
2005	forecast	43.0	38.0	12.0	4.0	3.0	0.0
	REF	48.0	32.0	14.6	3.3	2.1	0.0
	GOV	46.2	34.5	14.1	3.2	2.0	0.0
	DBL	42.6	36.8	15.9	2.9	1.8	0.0
	PES	43.6	36.0	16.0	2.7	1.7	0.0
2007	forecast	42.0	39.0	12.0	3.5	3.5	0.0
	REF	46.3	34.4	14.0	3.3	2.0	0.0
	GOV	44.3	37.3	13.4	3.1	1.9	0.0
	DBL	48.2	32.6	14.8	2.7	1.7	0.0
	PES	48.7	32.2	14.9	2.6	1.6	0.0
2010	forecast	42.0	39.0	12.0	3.0	4.0	0.0
	REF	45.5	35.7	13.6	3.3	1.9	0.0
	GOV	49.0	33.4	12.7	3.1	1.8	0.0
	DBL	50.9	32.1	13.0	2.5	1.5	0.0
	PES	50.5	32.2	13.4	2.5	1.4	0.0
2012	forecast	42.0	39.0	12.0	3.0	4.0	0.0
	REF	47.1	34.1	13.5	3.4	1.9	0.0
	GOV	50.0	32.8	12.3	3.1	1.8	0.0
	DBL	52.0	32.3	12.0	2.4	1.3	0.0
	PES	51.6	32.1	12.6	2.4	1.3	0.0
2015	forecast	42.5	38.0	12.0	3.0	4.5	0.0
	REF	49.7	31.7	13.3	3.4	1.9	0.0
	GOV	53.7	29.7	11.9	3.0	1.7	0.0
	DBL	54.0	32.3	10.4	2.1	1.2	0.0
	PES	53.4	31.7	11.5	2.2	1.2	0.0
2020	forecast	43.0	36.3	13.0	3.0	4.5	0.2
	REF	52.6	28.9	13.5	3.5	1.5	0.0
	GOV	55.2	29.0	11.5	3.0	1.3	0.0
	DBL	56.8	31.9	8.6	1.9	0.8	0.0
	PES	55.6	31.1	10.3	2.1	0.9	0.0

There are two energetic categories in MERGE, namely, electric energy and non-electric energy. According to the basic model scenario REF, the global electricity demand grows about six-fold in the 21st century, that is, from 49 EJ in 2000 to almost 300 EJ in 2100. This corresponds to an average annual growth rate of 1.8%. The total demand of non-electric energy in the 21st century grows at a significantly slower pace than that for electricity, i.e., it roughly triples from 250 to 740 EJ, which corresponds to an average annual growth rate of 1.1%. The results obtained for Russia (scenario GOV) taking into account various technologies of the energy production are presented in Figures 6 and 7.

Figure 6 Electric energy mix (in EJ); scenario GOV, variant R0

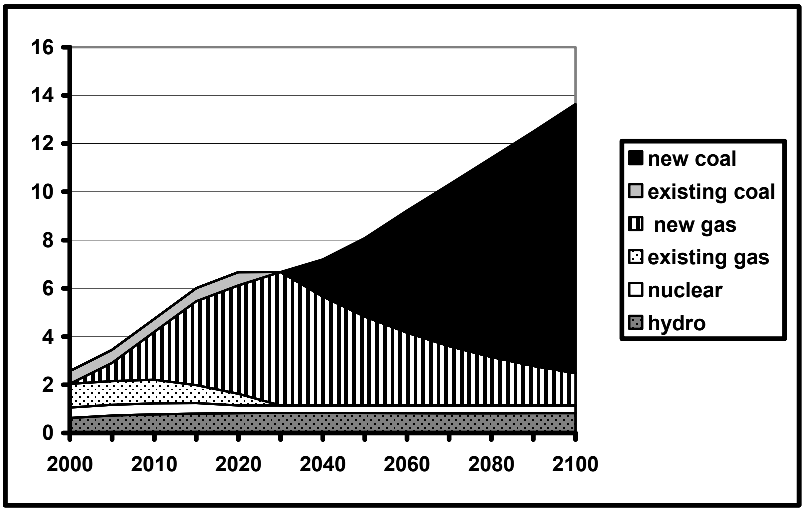
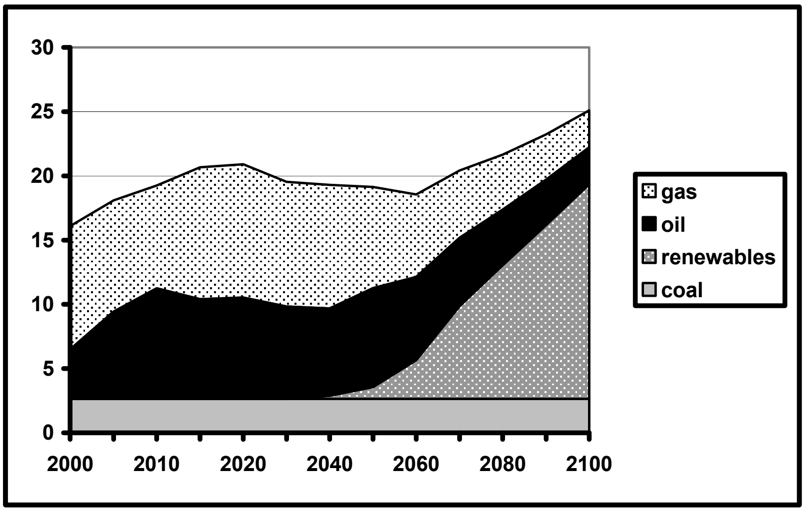


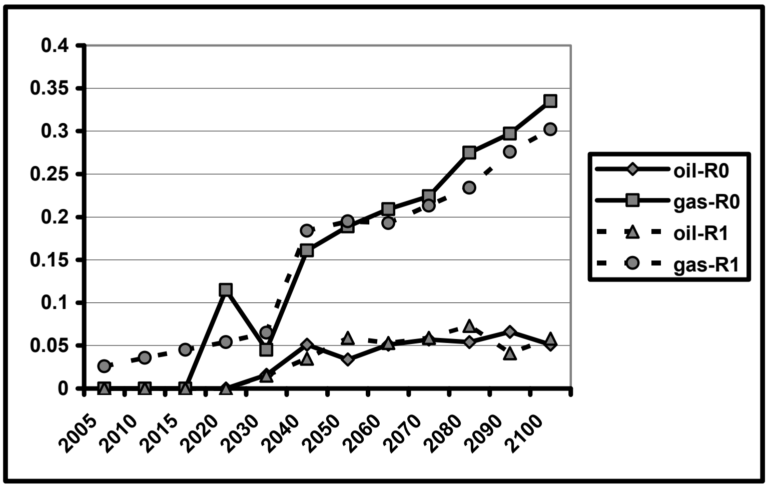
Figure 7 Non-electric energy mix (in EJ); scenario GOV, variant R0



For Russia, the electricity demand grows from 2.57 EJ in 2000 to 13.64 EJ in 2100 (corresponding to an average annual growth rate of 1.7%); the demand for non-electric energy grows from 16.1 to 25.1 EJ (corresponding to an average annual growth rate of 0.45%). These rates are comparable with those for the global demands. In addition, we can observe other tendencies similar to the global behaviour. As to electricity mix, its generation is characterised by hydro and nuclear keeping their absolute contributions at almost constant levels. In the early years, their combined share is significant, but falls below 10% in 2100 (down from 42% in 2000). Natural gas plays a kind of bridging role in Russia. Its contribution to electricity generation peaks around the middle of the century and then declines as a consequence of resource constraints. In the long run, new coal is the fuel of choice for electricity production. Russia's non-electric energy mix rests on a constant base (2.6 EJ) supplied by coal and its thermal uses. Oil and natural gas increase their dominance until the middle of the century, when resource constraints on these two fossil fuels begin to push renewable energy into the market.

The time dynamics of world-regional primary-energy (namely, oil and gas) exports by Russia is analysed (see Figure 8). Note that there is a stable reduction from some moment of gas export in variant R1 with respect to R0. It is explained by the fact that the need for less carbon intensive fuel increases if necessary to take the Kyoto constraints into account. At that, the dynamics of oil export is practically unchanged.

Figure 8 Oil and gas exports by Russia in trln. year-2000 USD; scenario GOV, variants R0 and R1



Note that the model dynamics presented in Figures 2–8 is optimal (according to MERGE) on the whole time interval; this fact may be quite a reason of the essential deviation of the modelling results from the expert forecast at specific moments. Nevertheless, taking into account all the indices presented above, we can conclude that the expert forecast holds an intermediate position between simulation results for scenarios DBL and GOV.

4 Concluding remarks

In the paper, various scenarios of economic and technological development of Russia (based on official forecasts from Russian and foreign sources) and their influences on the environment in short-term, intermediate-term and long-term perspective are under investigation. Toward this aim, the specific optimisation model MERGE is engaged. The novelty of the work consists, first of all, in the adaptation of the known 3E-model to the specific character of Russia and in designing in such a way a tool for analysing important aspects of economic and technological dynamics. This tool is oriented to be helpful in decision making for the authorities responsible for designing optimal (in some sense) long-term strategies of Russia's development.

With the use of the modified program package, a number of numerical experiments aimed at estimating the effectiveness of GHG reduction policies regulated by the Kyoto Protocol are carried out. The simulation results show that, in the first commitment period of the Protocol, GHG emissions in Russia can reach the critical level of 1990 for a very high average annual GDP growth rate (doubling GDP within ten years) as well as for an extremely low rate of technological development. In these cases, Russia does not have perspectives on the international market for GHG emissions permits as a seller, unless considerable costs for abatements measures are defrayed.

The simulation reveals a number of tendencies in development of energy sector of Russia. So, at the nearest decades, it is expected that the role of natural gas in the energy supply as the least carbon intensive among fossil fuel resources will be dominant. In the second half of the 21st century, it is foreseen that the volume of energy produced from fossil fuels will sharply fall due to reserve depletion. In the long-term perspective, new, more progressive, technologies of coal processing and renewable energy sources (such as solar energy, geothermal energy, biomass energy and so on) come to the forefront.

In addition, the model calculations testify to the effect that Russia will need soon a stable reduction of natural gas export to take the Kyoto constraints into account. At that, the dynamics of oil export will be practically unchanged.

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