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A new Version of Integrated Assessment Model MERGE

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ABSTRACT: The optimization Model for Evaluating Regional and Global Effects of greenhouse gases reduction policies named MERGE is an actively usable tool for studying some aspects of the problem of climate change. It is first of all destined for the quantitative estimation of emission trajectories and results of applying abatement measures. In the paper, the emphasis is on the adaptation of the integrated assessment model MERGE to the modern state of the world and regional economy and on the analysis of possibilities of Russia's participation in some Kyoto-type initiatives on greenhouse gases emission reduction under different assumptions on the dynamics of regional economic-energetic indices. Calculations with the MERGE model demonstrated the attainability of the national emission targets: stabilizing the carbon dioxide emissions at 75 per cent of the 1990 level by 2020 with further reducing to 70 per cent by 2030. Some trends in the structure of energy sector and fossil fuel exports are also analyzed.

Key words: Integrated assessment model, Optimization, Economic development,GHG emissions

INTRODUCTION

The problem of forecasting climate changes and planning mitigation measures is one of the most actual challenges facing the modern world. Despite the fact that the driving forces of the global climate change and its control possibilities are not completely studied and formalized yet; many experts are in agreement that the dramatic climate change (more "nervous" climate with a large number of temperature jerks, abnormal precipitation, strong winds and so on) observed in the recent time is substantially explained by the increase of atmospheric concentration of greenhouse gases (GHGs) due to man's impact that is characterized, first of all, by the essential increase of fossil fuel consumption in industry and power engineering. To study different aspects of the problem of climate change, so-called integrated assessment models (IAMs), which exploit, as a rule, an interdisciplinary approach, are involved. Their important application is in constructing a set of possible scenarios of social economic development at global and local levels with further choosing of an optimal trajectory based on some quality criterion. Therefore, these models can be helpful in decision making for the authorities as a tool for evaluating long-term strategies of the economic development. Ten years ago, during the debate in Russia on future costs and benefits of being a party to the Kyoto Protocol (Kokorin *et al.*, 2004), arguments of proponents and opponents were seldom based on results of applying appropriate IAMs but now attempts to bridge this gap are actively undertaken (ERIRAS, 2013; Bashmakov & Myshak, 2013; Bystray *et al.*, 2013). In the light of the fact that international negotiations on the climate change issues entered a new phase in 2012 (a new climate agreement, which necessity is extremely confirmed by the increase of the global emission growth rate since 2000 up to 3.3%, compared to 1.1% in the 1990's, will be prepared by 2015 and will come into force in 2020), now is the time to discuss different aspects of Russia's participation. One of the models involved in the process is MERGE developed by American scientists (Manne *et al.*, 1995; Manne, 2003) and modified at the International Institute for Applied Systems Analysis (Laxenburg, Austria) and the Institute of Mathematics and Mechanics, UB RAS (Ekaterinburg, Russia) (Kryazhimsky *et al.*, 2005; Digas *et al.*, 2009; Digas & Rozenberg, 2010, 2013). According to the commonly adopted classification (Weyant, 1996), MERGE belongs to policy optimization IAMs, which optimize key policy

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control variables such as carbon emission rates and/or carbon taxes, time frames for implementing new technologies and so on. The models take into account formulated economic policy goals (for example, maximizing the welfare or minimizing the cost of meeting a carbon emission or concentration target). In such models, inter-temporal optimization procedures are often applied.

The novelty of the present work consists in the adaptation of the model MERGE to the modern state of the world economy and in performing a series of new numerical experiments.

MATERIALS & METHODS

In addition to the quantitative estimation of results of applying different GHG emission reduction policies and of implementing new energetic technologies, the model MERGE allows to analyze possible trajectories of the social-economic development of a region under different assumptions on the dynamics of its economic-energetic indices. It consists of three interrelated submodels (the economic-energetic, the climate, and the damage assessment) and includes more than 20 thousand equations and inequalities and more than 30 thousand scalar variables.

Let us stop in detail on the economic-energetic module, since namely this module required essential modifications and namely this module contains parameters varied in numerical experiments. The module, being the core of MERGE, is used for simulating the regional social-economic dynamics (in particular, gross domestic product (GDP), GHG emissions, import/export of energy resources) on rather long time interval. 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. The module is an applied general equilibrium model. At each time moment, supplies and demands are balanced through the prices of internationally traded commodities, including oil, gas, coal, consumables, and, possibly, GHG emission rights. The module is not a set of recursive procedures determining a system's state through its previous history, but an optimization model finding optimal trajectories of regions' development by means of maximizing the sum of discounted utilities of regional consumption over the whole time interval (the total Negishi welfare (Manne *et al.*, 1995; Stanton, 2011)).

The time interval under consideration is divided into *n* intervals by points (in years) $t_0 < t_1 < \ldots t_n$; the value of discretization step is denoted by $\delta_i = t_i - t_{i-1}$, $i=1,\ldots,n$. The inter-temporal optimization consists in constructing a sequence (corresponding to the discrete times) of regional consumption levels; this sequence maximizes the total Negishi welfare:

$$TotalWealth = \sum_r nw_r W_r =$$

$$\sum_r nw_r \sum_{i=1}^{n} \delta_i \, udf_i \log C_i \quad \to \quad \max .$$

Here, we use the following notation (for brevity, the index *r* related to the region, as a rule, is omitted): $TotalWealth$ is the total welfare of all regions; nw_r is the Negishi weight for the region *r* characterizing the ratio welfare/consumption, $\sum_r nw_r = 1$; W_r is the welfare of the region *r*; udf_i is the utility discount factor, $\log C_i$ is the utility function chosen as the logarithm of consumption C_i (the peculiarity of such function is that its second derivative is negative; so, the marginal utility is always positive, but is a diminishing function of the aggregate level of consumption).

The optimization problem in question is a nonlinear programming problem; for its solving, the sequential joint maximization technique (Rutherford, 1999) is applied. The convergence of this method to an equilibrium solution on the whole time interval was theoretically substantiated (Rutherford, 1999). Below, there is the specification of most important variables enabled in the optimization procedure and varied in numerical experiments.

The utility discount factor is chosen as follows:

$$udf_i = \prod_{j=0}^{i-1} (1 - udr_j)^{\delta_{j+1}}, \quad udr_j =$$

$$kpvs / kgdp - depr_j - grow_j ,$$

where udr_j is the average annual utility discount rate on the interval $[t_j, t_{j+1})$, *Kpvs* is the optimal value share of capital in the pair "capital/labor", *Kgdp* is the initial capital/GDP ratio, $depr_j$ is the average annual depreciation rate, $grow_j$ is the average annual potential growth rate.

The annual regional consumption C_i at the moment t_i is calculated by the formula (Manne *et al.*, 1995):

$$C_i = Y_i - I_i - EC_i - NTX_i ,$$

where Y_i is the total production, excluding energy sectors, for the year t_i; I_i is the current investment (annual flow); EC_i is the energy cost; NTX_i is the difference between regional export and import of traded goods (obviously, $\sum_r NTX_{i,r} = 0$ for any time period).

It is assumed that the energy sector contains two types of production, namely, electric and non-electric energy. The international primary energy market deals with oil, gas, and coal. The economic production function describing the dynamics of regional production Y_i depends on four inputs: capital stock K_i, available labor L_i, electric energy E_i, and non-electric energy N_i. In order to minimize the number of parameters requiring the calibration or econometric estimation, the production function is chosen in the form of two Cobb–Douglas type components (capital-labor and energy aggregates) embedded into a function with constant elasticity of substitution (CES):

$$Y_i = \left(aK_i^{\rho\alpha} L_i^{\rho(1-\alpha)} + bE_i^{\rho\beta} N_i^{\rho(1-\beta)} \right)^{1/\rho} .$$

The relation is based on the following assumptions: 1) the four inputs are scaled; 2) there is a unit elasticity of substitution between capital and labor, with α being the optimal value share of capital in the pair, $\alpha = kpvs$; 3) there is a unit elasticity of substitution between electric and non-electric energy, with β being the optimal value share of electricity in the pair, $\beta = elvs$; 4) there is a constant elasticity of substitution *esub* between these two pairs of inputs, $\rho = 1 - \dfrac{1}{esub}$, and *esub* does not equal 0 or 1; 5) the scaling factors *a* and *b* are such that the energy demands in the base year are consistent with the reference price of non-electric energy; in addition, there are autonomous energy efficiency improvements (*aeei*) that are summarized by the scaling factor *b*.

Note that, in the previous versions of the model (Manne *et al.*, 1995; Manne, 2003; Kryazhimsky *et al.*, 2005; Digas *et al.*, 2009; Digas & Rozenberg, 2010), the production function was written for the new vintage production; this resulted in the impossibility to take economic crisis phenomena (for example, slumps in regional GDPs) into account.

The dynamics of the regional capital stock satisfies the following equation:

$$K_i = K_{i-1}(1 - depr_{i-1})^{\delta_i} + af\left(I_{i-1}(1 - depr_{i-1})^{\delta_i} + I_i \right),$$

where *af* is the accumulation factor depending on the value δ_i, the initial investment I_0 is given, and the terminal constraint $I_n \ge K_n(grow_n + depr_n)$ should be fulfilled. The labor L_i (in the model, the labor force is measured in special efficiency units) is actually an exogenous parameter and is explicitly calculated:

$$L_i = L_{i-1}(1 + grow_{i-1})^{\delta_i} .$$

The energy cost EC_i depends on electric energy E_i, non-electric energy N_i, various price parameters, and coefficients characterizing specific technologies and relations between them. This cost is explicitly calculated (the formula is omitted here due to its inconvenience). There are some restrictions on annual changes of production volumes for electric and non-electric energy.

Thus, the main parameters to be optimized in the problem of maximizing the total Negishi welfare are electric energy E_i, non-electric energy N_i, investment I_i, and the difference between export and import NTX_i $(i = 1, \ldots, n)$.

Completing the description of the economic-energetic module, we list main inputs and outputs. Input parameters are population, its dynamics, forecast for GDP per capita dynamics, macroeconomic indices (*grow*, *depr*, *aeei*, *kpvs*, *elvs*, *esub*, etc.), energetic characteristics and coefficients (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, the realized GDP and its characteristics: carbon intensity, structure (consumption, investments, export/import)), energy related GHG emissions (specified by GDP, its energy intensity, and carbon emission rates of energy consumption), hypothetical abatement costs due to some specific constraints (for example, according to Kyoto-type initiatives).

The climate module of the model MERGE takes into account the most important anthropogenic GHGs and calculates their atmospheric and oceanic concentrations through emissions and pre-industrial levels. 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 module analyzing 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. Actually, the damage of this type is treated as a part of GDP that is lost due to climate changes stipulated by temperature increase. Many experts believe that, in different economic estimates, it is reasonable to use so-called “green GDP” taking into account mentioned losses and total changes in ecological resources (Stiglitz *et al.*, 2009). Non-market effects have no definite prices; so they must be valued using some alternative methods (among them, future generations’ preferences).

The necessity of constructing a model modification adapted to the current state of the world and regional economy is explained by several reasons. The most important of them is the global economic crisis of 2008–2009 and its consequences, including the start of an essential change of the world fuel and energy balance and the possible worldwide transition to low-carbon development. The adaptation of the model included 1) the usage of new input data (macroeconomic parameters, energy indices, reserves of fossils and so on) from modern sources (EIA, 2013; TWB, 2013; BGR, 2011; IAEA, 2013; WNA, 2013; FSSS, 2014); 2) changes in the mathematical model for simulating specific features of the economic dynamics (for example, for taking into account the worldwide recession caused by the economic crisis); 3) a new, in comparison with (Manne *et al.*, 1995; Manne, 2003; Kryazhimsky *et al.*, 2005; Digas *et al.*, 2009; Digas & Rozenberg, 2010), division of the heterogeneous world into regions basing on last tendencies of the economic development (EIA, 2013) and keeping in mind planned numerical experiments. Let us briefly comment each point assuming that the adaptive changes in the algorithm are described above.

Within the framework of the present paper, it is impossible to specify the whole set of new input data of the model due to their volume; therefore, we restrict ourselves by the references to corresponding sources (EIA, 2013; TWB, 2013; BGR, 2011; IAEA, 2013; WNA, 2013; FSSS, 2014). Let us stop on one piece of data in more detail. Note firstly that the necessity of detailing energetic inputs is explained by the determining role of these parameters from the viewpoint of main simulation goals (estimating the dynamics of regional GHG emissions) and secondly that the nuclear power considered (in the absence of worst-case situations) as decreasing the pressure onto the climate system, is at a crucial point connected with revising opinions on the nuclear energy perspectives due to the March 2011 Fukushima Daiichi nuclear accident. This dramatic event accelerated decision-making process in many countries.

Since the last International Energy Outlook (EIA, 2013) appeared in July 2013 contains only preliminary data for 2011, we mobilized the prognoses by the International Atomic Energy Agency (IAEA, 2013) and the World Nuclear Association (WNA, 2013). Among the most important aspects of the world's development after the Fukushima accident, we mark out a step-by-step partial/total rejection/freezing of the nuclear power by several West European countries and Japan. Now, the nuclear sector has a rather limited growth potential, primarily concentrating in China, India, and Russia. According to the so-called low growth scenario (IAEA, 2013), the world's installed nuclear power capacity grows from 370 GW(e) (gigawatts electrical) today to 456 GW(e) in 2030; in the high projection, it grows to 740 GW(e) in 2030; the probability of the first variant is essentially larger. As a rule, on the base of such "low" (i) and "high" (ii) prognoses, a combined scenario is constructed. Its parameters are calculated as the weighted sums of corresponding values for variants (i), (ii):$X_s=p_lX_l+p_hX_h$ where X_s is the desired value, X_l, X_h are values for variants (i), (ii), P_l, P_h, $P_l+P_h=1$ are estimates of prognosis probabilities. Similar schemes are used in the cases when input parameters from different sources have different values.

The new version of MERGE exploits the division of the world into the regions: 1) USA; 2) OECD Europe (OECD is the Organization for Economic Cooperation and Development); 3) Japan; 4) South Korea; 5) Australia and New Zealand; 6) Canada; 7) Middle East; 8) Africa; 9) China; 10) India; 11) Rest of Asia; 12) Brazil; 13) Rest of Central and South America; 14) Russia; 15) Rest of non-OECD Europe and Eurasia. As an initial year for simulations, we choose 2008. The reasons are the following: the presence of necessary datasets, the start of serious (and not properly formalized) changes in the world economy, and the fact that 2008 is the first year of the commitment period of the Kyoto Protocol, which effectiveness has not been quantitatively estimated yet.

RESULTS & DISCUSSION

The main aims of numerical experiments described in the paper are the analysis of possible trajectories of Russia's economic development and the study of consequences of Russia's participation in Kyoto-type initiatives on GHG emission reduction under different assumptions on economic-energetic parameters (in particular, the average annual GDP growth rate and energy intensity). As a source of model scenarios of possible Russia's economic dynamics, we choose the Prognosis of social economic development of the Russian Federation by 2030 of the Ministry of economic development of the Russian Federation (MOED, 2013). In the document, the following scenarios were considered: conservative, moderate optimistic, and uprated; their specific character results from different models of business behavior and state policies of providing macroeconomic balance. As the fourth scenario, the Reference scenario of MERGE model essentially based on the forecasts for Russia by the Energy Information Administration and the World Bank was used (EIA, 2013; TWB, 2013; BGR, 2011). Let us present a brief description of each scenario.

Conservative scenario (Con) is characterized by a moderate long-term economic growth rate on the base of active modernization of fuel-energy and raw materials sectors of Russian economy under

Table 1. The key indices of the scenarios of social economic development of Russia for 2010–2030 (annual average growth rates, %)

Index	Scena-rio	2010	2011–2015	2016–2020	2021–2025	2026–2030
GDP	Upr	4.3	4.3	7.1	5.4	3.9
	Opt	4.3	3.2	4.3	3.6	3.1
	Con	4.3	2.8	3.1	2.5	1.8
	Ref	4.3	3.8	4.0	3.2	2.4
Population	Upr	0.01	0.28	0.36	0.31	0.27
	Opt	0.01	0.13	0.0	–0.11	–0.18
	Con	0.01	0.13	0.0	–0.11	–0.18
	Ref	0.01	0.28	–0.14	–0.29	–0.44
Energy intensity of GDP	Upr	–0.03	–2.6	–6.2	–4.2	–2.4
	Opt	–0.03	–1.4	–3.4	–2.6	–1.8
	Con	–0.03	–1.5	–2.7	–2.0	–1.1
	Ref	–0.03	–3.1	–2.5	–1.8	–0.5

preservation of relative backwardness in high-technology sectors. The average annual GDP growth rate is fixed at 2.5% for the time period 2013–2030. The Russian economy will increase 1.7 times till 2030, whereas Russia's share in the world GDP will decrease from 4% in 2012 down to 3.4% in 2030.

Moderate optimistic scenario (Opt) is characterized by additional impulses of innovative development and by intensifications of investment orientation of the economic growth. The average annual GDP growth rate is estimated at 3.5% for the time period 2013–2030; this corresponds to the growth rate of the world economy.

Uprated scenario (Upr) is characterized by uprated growth rates, a large-scale industrial export sector, and a considerable international capital inflow. The scenario can be treated as an economic breakthrough; it provides the fulfillment of all the tasks set by the President of the Russian Federation in Decrees Nos. 596–606 of May 7, 2012; these decrees contain economic development benchmarks for the time period till 2020. The average annual GDP growth rate is improved up to 5.3%; this will allow to increase Russia's share in the world GDP up to 5.8% till 2030.

All three scenarios above assume some stabilization of the prices of oil and other raw material resources (so, for the time period 2013–2030, the oil price will be at the level of 90–110 year-2010 USD per barrel; the gas export price, 300–310 year-2010 USD per thousand cubic meters). According to (MOED, 2013), the scenario Con reflects dominating at the present time (after the 2008–2010 crisis) interests in the Russian economy and is characterized by a higher probability of realization than the moderate optimistic and uprated scenarios.

Reference MERGE scenario (Ref) testifies to a skeptical attitude to the short and medium-term perspectives of Russia's innovation development on the hand of western experts. The average annual GDP growth rate is estimated in the range of 2.02.5% for the time period 2013–2030, the rate of energy efficiency improvement is stable but relatively low, the share of primary-energy export in GDP is almost constant. The prices at raw materials markets essentially depend on the fact which one from the world-wide scenarios, "shale gas breakthrough" or "shale gas failure", will be finally put into effect.

Let us note some additional facts. Only the scenario Upr is oriented to the so-called high scenario of demographic forecast for Russia's population elaborated by Rosstat (FSSS, 2014) taking into account the results of the 2010 Russia population census, namely, the increase from 142.9 mln. people in 2010 to 151.4 mln. people in 2030; all other scenarios are based on the medium scenario of demographic forecast with stabilizing the population (142.5 mln. people in 2030) or even decreasing (in the scenario Ref). The key indices of the scenarios are presented in Table 1.

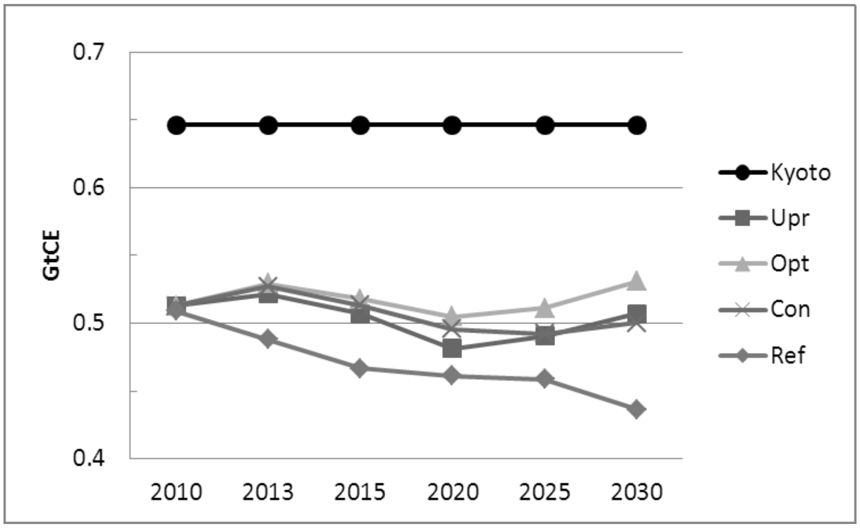

Fig. 1. CO_2 emissions in Gt C equivalent; variant R0 for model scenarios, Kyoto level is Russia's emission level of 1990.

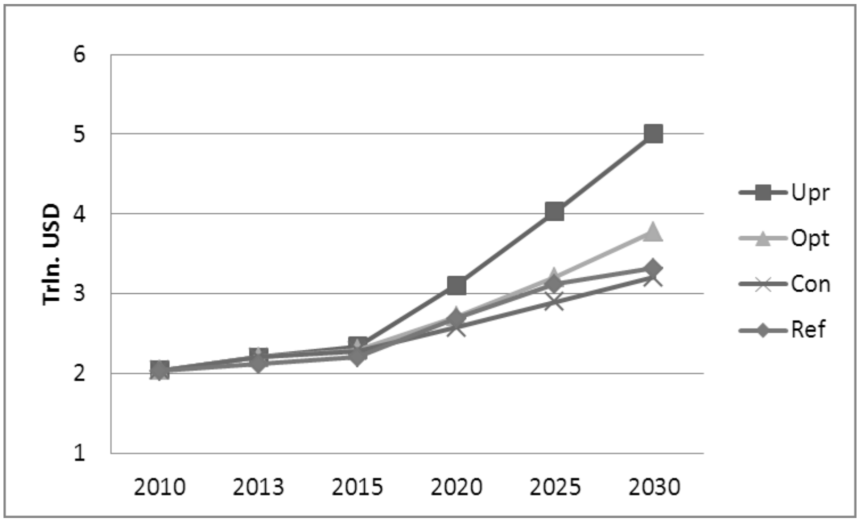

Fig. 2. Realized GDP in trln. year-2005 USD.

For each scenario, 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 some Kyoto-type initiative are achieved by domestic measures only (without using carbon emission rights trade and other mechanisms of rights redistribution). The GDP loss as the difference GDP(R0) – GDP(R1) actually characterizes hypothetical costs of GHG emission reductions.

At the present time, the debate in Russia about signing some agreements on GHG emission reduction/control (for example, in the framework of the Durban platform, with obligations not to exceed the 1990 level of emissions in 2020 and to reduce emissions by 30–50% relative to the 1990 level till 2050) has resumed. According to some experts' estimates, the toughening of ecological requirements can essentially modify parameters of the economic development and can result in a decrease of GDP growth rate by 0.3–0.5 percentage point per year after 2020 comparing with the basic scenario (without any obligations). In this connection, it is important to verify whether the achievement of the 1990 level

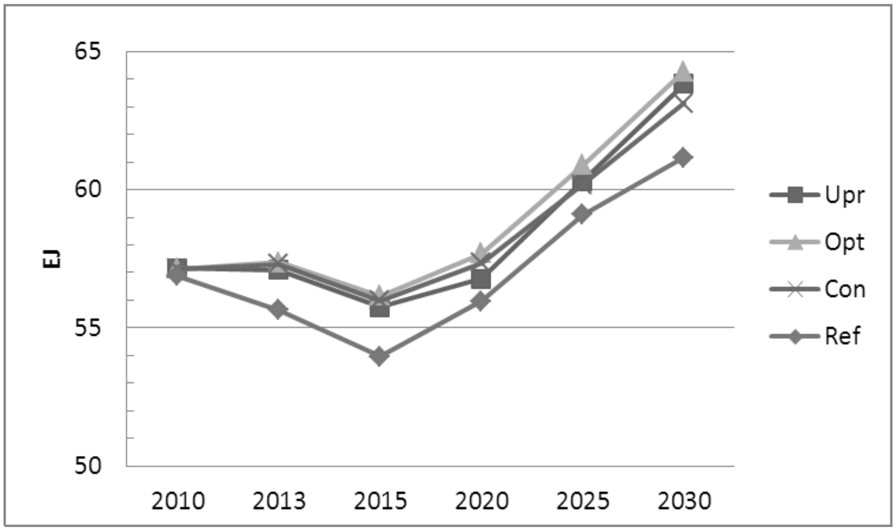

Fig. 3. Total primary energy supply (both electric and non-electric, in EJ)

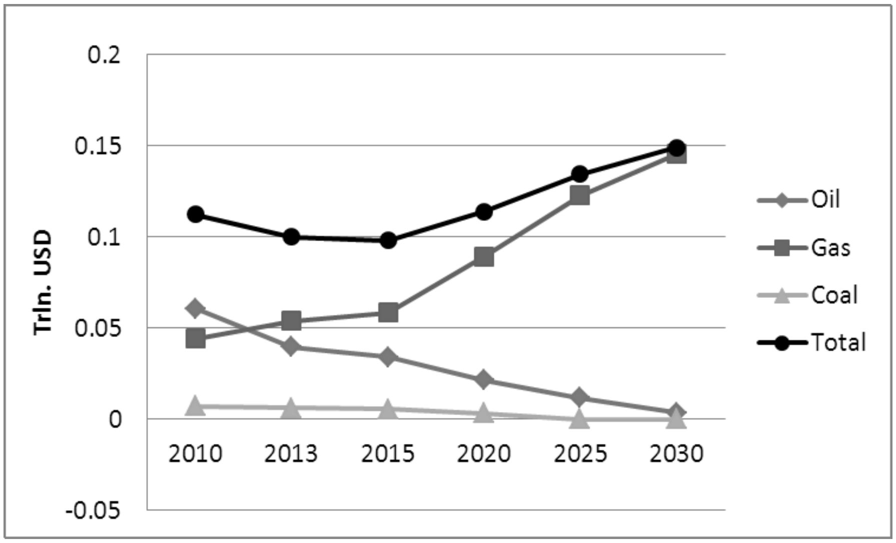

Fig. 4. Fossil fuel exports by Russia in trln. year-2005 USD; scenario Opt.

in the nearest future is possible for all the scenarios tested; this becomes the main aim of our numerical experiments.

Let us discuss the simulation results for the time period 2010–2030. From Fig. 1 we conclude that, for all the scenarios involved, the CO_2 emissions do not even approach the Kyoto level for Russia on the whole time interval. As this level, we consider the 1990 level of Russian energy-sector CO_2 emission, excluding the net CO_2 absorption by forests (0.646 Gt C equivalent). The model maximum (81% of the Kyoto level) is reached in 2010–2013 for scenarios Con, Opt, and Upr. Then, a considerable reduction of emissions is observed; this fact is essentially caused by the planned decrease of energy intensity of GDP. Note that the growth in 2010–2013 obtained in the model is explained by the optimal, from the viewpoint of MERGE, rate of overcoming consequences of the crisis, whereas the real emission was at 69% of the Kyoto level in 2011 (NIRRF, 2013). The document (MOED, 2013) outlines the following emission targets for Russia: in the 2010s, the GHG emissions will be slowly growing to reach 75% of the

1990 level by 2020 with further reducing to 70% by 2030. Such commitments can be treated as the Russian GHG targets within the framework of future international agreements on GHG emission reduction policies.

Thus, despite the model leap caused by the intertemporal optimality, according to all the model scenarios, Russia has sufficient reserves for “painless” participation in environmental Kyoto-type initiatives being under discussion at the present time, especially if an initiative assumes for GHG emissions not to exceed the 1990 level in 2030. Russia even does not need to reduce emissions for selling permits, since the amount of Russian so-called “hot air”, being the difference between the current emissions and the Kyoto level, is large enough. At the same time, it should be noted that the reduction of emissions by 30–50% relative to the Kyoto level till 2050 seems rather problematic. The results obtained are in agreement with the forecasts of leading Russian experts (see, for example, (ERIRAS, 2013; Bashmakov & Myshak, 2013)). It is evident that, for such a dynamics, the simulation of variants R1 with some abatement measures is not reasonable; therefore, we restrict ourselves to considering output data of variants R0.

Fig. 2 informs us that, under the model assumptions, Russia’s GDP grows for all the scenarios with approximately constant rates for the interval 2010–2015 (the crisis downfall with subsequent slow growth) and for the interval 2016–2030 (the essential growth with final overcoming of consequences of the crisis). The forecast GDP for most progressive scenario Upr appreciably passes ahead of GDPs for alternative variants (by 20–40% in 2030). The GDP for scenario Ref is essentially behind the GDPs for other scenarios (excluding scenario Con).

In Fig. 3, the temporal dynamics of total primary energy supply is presented. Note that perspectives of Russian power engineering from the viewpoint of the Energy Information Administration/World Bank and from the viewpoint of Ministry of Economic Development of the RF are relatively similar (for example, the energy supply in 2030 for scenarios Upr, Opt, and Con is about 63 EJ (exajoules), whereas for scenario Ref, about 61 EJ). The production slowdown till 2015 is evidently stipulated not by a fall in demand but by a planned energy efficiency improvement for all the scenarios (see Table 1) on the background of local reduction of oil export.

Analyzing the structure of energy sector of Russia, we mark out several tendencies, which are common for all the model scenarios. Thus, the shares of the hydro and especially nuclear energy in the total supply increase in time at the cost of decreasing the share of energy production from oil. The contribution of gas and coal (in percent) remains almost constant; at that natural gas plays a definitive role in the energy supply (its share is stably larger than 50%). Note that the continuation of calculations after 2030 demonstrates a sharp fall of the shares of traditional resources (oil and gas) 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 (EIA, 2013; BGR, 2011). Though, the contribution of the latter sources in Russian energy supply is negligibly small at the considered time interval.

The time dynamics of world-regional primary energy exports by Russia is presented in Fig. 4 for scenario Opt (other trajectories are very similar). There is a stable increase from some moment of the gas export, the oil export permanently decreases and, as well as the coal export, tails by 2030. This is caused by the model forecast of a stable growth of the gas demand on the hand of major fossil fuel importers. The oil demand at the world market increases not so rapidly and is satisfied at the cost of some increase in delivery by such exporters as Middle East. The total coal demand, from the MERGE viewpoint, does not increase at all and is covered to a considerable degree by Australia. Note that the basic data on the fossil fuel export/import and temporal trends are taken from (BGR, 2011). One can suppose that, under the necessity of GHG emission limitation/reduction according to hypothetical Kyoto-type initiatives, there would not be an increase of the gas export due to growing Russia’s needs for natural gas as a less carbon intensive fuel.

Let us recall once more that the model dynamics presented in Figs. 1–4 is optimal (according to MERGE) on the whole time interval; this fact may be quite a reason of the essential deviation of the simulation results from the expert forecasts for some parameters at specific moments. Nevertheless, we hope that the results obtained can be useful in the case when the task to examine the viewpoint that climatic risks are dominating and requiring GHG emission reduction to a specific “safe” level becomes actual.

CONCLUSIONS

In the paper, different scenarios of Russia’s economic development (based on official forecasts both from domestic and foreign sources) with the emphasis on analyzing possibilities of Russia’s participation in some Kyoto-type initiatives on GHG emission reduction are under investigation. Toward this aim, the specific optimization model MERGE is engaged. The novelty of the work consists, first of all, in the adaptation of this known 3E (Economic-Energy-Environment) model to the current state of the world and regional economy taking into account the specific character of the post-crisis development. The work can be treated as one additional step in designing a complex tool oriented to be helpful in decision making for the authorities responsible for planning optimal (in some sense) long-term strategies of Russia’s economic-energetic development. With the use of the modified program package, a number of numerical experiments are carried out. The simulation results show that Russia has sufficient reserves for “painless” participation in environmental Kyoto-type initiatives, especially if it is assumed for GHG emissions not to exceed the 1990 level by 2030. In this case, Russia does not need to reduce emissions even for selling permits. At the same time, the reduction of emissions by 30–50% relative to the 1990 level till 2050 seems rather problematic.

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