Application of integrated assessment model MERGE to studying ecological-economic indices

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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 different aspects of the problem of climate change. Primarily, it was destined for the quantitative estimation of emission trajectories and results of applying abatement measures. In the paper, we modify the model in order to extend its functionality. The emphasis is on the adaptation of MERGE to the modern crisis state of the world and regional economy and on the incorporation into the model of a simplified scheme for accounting a green GDP, which informs on the effectiveness of the nature management. The main goals of numerical experiments are the testing of possibilities of Russia's participation in some Kyoto-type initiatives on greenhouse gases (GHG) emission reduction and the analysis of ecological indices of Russia's GDP. Calculations with MERGE demonstrate the attainability of the national emission targets consisting in stabilizing the carbon dioxide emissions at 70–75 % of the 1990 level by 2020–2030. At the same time, the problem of increasing the ecological effectiveness of Russia's GDP is very actual and requires an urgent solution.

Keywords Integrated assessment model · Ecological-economic indices · GHG emissions · Green GDP

Introduction

The problem of forecasting climate changes and planning mitigation measures is one of the most actual challenges facing the modern world. The driving forces of the climate dynamics are not completely studied yet; so, ecological, social, and economic consequences of this process are rather vague and complicated from the analytical viewpoint. Many experts are in agreement that the dramatic climate change observed in the recent time is substantially explained by the increase of atmospheric concentration of GHGs due to man's impact. The contemporary official viewpoint in Russia reflected in the Climate Doctrine of the Russian Federation (CDRF 2009) consists in the admission of the necessity to form a comprehensive science-based approach for analyzing climate issues. In connection with possible GDP losses due to the negative influence of climate changes, Russia's participation in global initiatives on GHG emission reduction and the orientation to the rational nature management gain in importance.

One of the first efforts of the international community to control environmental impacts was the Kyoto Protocol to the United Nations framework convention on climate change (the UNFCCC) passed in December 1997 (Brendenich and Magraw 1998; Kokorin et al. 2004). This pilot project, which assumed voluntary obligations of participants to reduce GHG emissions, expired in 2012; its effectiveness is disputable up to now (Ghezloun et al. 2013; Nordhaus 2006). At the recent time, the debate in Russia about the influence on economy of some Kyoto-type agreements on GHG emission reduction/control has

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resumed. The matter is in the Paris Agreement (UNFCCC 2015) that is an agreement within the framework of the UNFCCC dealing with GHG emissions mitigation, adaptation, and finance starting in 2020. This deal was discussed and adopted by consensus at the 21st Conference of the Parties of the UNFCCC in Paris on 12 December 2015; then, it was signed by 175 countries (including China, Russia, and USA) on 22 April 2016 in New York. The agreement sets a target of limiting global warming by 2100 to “well below” 2 °C, as compared to the pre-industrial level. To accomplish that, each nation chooses its own target for the emission reduction and updates that mark each year. Russia undertakes the voluntary obligation of the gradual reduction of emissions by 25–30 % relative to the 1990 level in 2020–2030. According to some experts’ estimates, the toughening of ecological requirements connecting with such an obligation can essentially modify parameters of the economic development and can result (combining with the crisis) in a decrease of GDP growth rate additionally by 1–2 % point per year comparing with the scenario without any obligations. In this connection, it is important to verify (by modeling) whether the attainability of different emission levels in the nearest future is possible for all realistic scenarios; this becomes one of the main goals of numerical experiments described in this paper. Controversial questions concerning different aspects of carbon tax levy and carbon absorption by forests are out of the scope of this paper.

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. Let us emphasize another one important feature of the state-of-the-art IAMs: such a modeling is in an extreme need of implemented tools for accounting GDP ecological characteristics. Studying special indices of sustainable development formalizing the influence (as a rule, negative) of economic processes on the environment provides opportunities to overrun the traditional concept of GDP and to analyze pros and cons of the transition to green economics. The incorporation into an appropriate IAM of some scheme for accounting GDP ecological characteristics is another goal of our investigations. The authors believe that the specific optimization model for evaluating regional and global effects of GHG reduction policies named MERGE can be used to achieve purposes mentioned above. This model was well recommended during the debate in Russia about costs and

benefits of being a party to the Kyoto Protocol. It was elaborated by American scientists (Manne 2003; Manne et al. 1995) and was modified at the International Institute of Applied Systems Analysis (Laxenburg, Austria) and the Institute of Mathematics and Mechanics, Ural Branch of RAS (Yekaterinburg, Russia), see Kryazhinsky et al. 2005, Digas and Rozenberg 2010, 2013, Digas et al. 2014. According to the commonly adopted classification (Weyant 1996), MERGE belongs to policy optimization IAMs, which optimize key policy 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 present work continues investigations (Digas and Rozenberg 2010, 2013; Digas et al. 2014); its novelty consists in (i) the adaptation of the model MERGE to the modern complicated political situation and to the crisis state of the world and regional economy, (ii) the incorporation into the model a simplified scheme for calculating a green GDP, and (iii) analyzing a series of numerical experiments with new scenarios reflecting key tendencies of Russia’s economy development in the nearest future.

Materials and method

The model MERGE being a typical 3E (energy-environment-economy) IAM, consists of three interrelated sub-models (the economic-energetic, the climate, and the damage assessment) The detailed description of the principles and procedures of MERGE can be seen, for example, in (Manne et al. 1995). The version of the model destined to account some crisis symptoms in economy is presented in (Digas et al. 2014). Therefore, here we restrict ourselves by a brief outline of each submodel with the emphasis set on new possibilities of the calculation procedures. The scheme of the model with its main components is presented in Fig. 1; the new part is marked out with dashed lines.

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 concerning a specific country, we can treat it as a separate region). The module is a fully integrated applied general equilibrium model. At each

Fig. 1 Overview of MERGE model

point in discrete time (it is assumed that the time interval under consideration is divided into n intervals by points (in years) $t_0 < t_1 < \dots < t_n$), 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 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. 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, the realized 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 some emission reduction agreement).

The climate submodel focuses on the most important anthropogenic GHGs (among them are 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. 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. 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 latter analyzes 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 scheme for calculating a hypothetical GDP loss as an approximation to the market damage used in the damage assessment submodel has a specific character; it is rigidly connected with the possible climate change and temperature increase, reflects future deteriorations, and cannot be treated as an estimate of current green GDP. Let us pass to the description of the latest modifications in MERGE united in the new procedure ("Green GDP calculator"), see Fig. 1.

According to the different accounting systems, the green GDP has been classified as two main types (see, for example, Stiglitz et al. 2009; Xu et al. 2010). Type I green GDP accounts the GDP minus the costs of environmental emissions and resources depletion, but it ignores the valuation of natural ecosystem services. On the contrary, type II green GDP focuses on the latter valuation and pluses it into the GDP accounting. Thus, type I green GDP is less than the GDP, whereas type II green GDP is greater. In this paper, we deal with the type I green GDP accounting method (below, we say green GDP meaning type I).

There are many papers (see, Stiglitz et al. 2009; Xu et al. 2010; Veklich and Shlapak 2012 and their bibliography) devoted to the development of green GDP accounting systems. More or less, all of them use the correction of traditional economic indices based on the system of environmental-economic accounting suggested by the UN Statistical Commission (SEEA, see UNDP 2003). The cornerstone of this system is the concept of environmentally adjusted net domestic product (EDP); we treat it as the green GDP. At the current stage, taking into account the possibilities of MERGE, we incorporate into the model a simplified scheme for calculating the regional EDP. It is obtained by subtracting the costs of the natural resource depletion (oil and gas production, deforestation, etc., denoted by RD) and the environmental degradation (air and

water pollutions, waste placement, soil depletion, etc., denoted by ED) from the GDP. Thus, we use the following formula:

$$\text{EDP} = \text{GDP} - \text{RD} - \text{ED}.$$

Let us present the way of calculating the values of RD and ED.

The natural resource depletion (RD) is assumed to lead to the irretrievable loss of resources, which results in the decrease of their reserves and in the reduction of natural capital. With regard to the index in question, the RD is the sum of two components, namely, the costs of the mineral and raw material natural resource depletion (MRRD) and of the forest resource depletion (FRD):

$$\text{RD} = \text{MRRD} + \text{FRD}.$$

The mineral and raw material resources include oil, gas, coal, metals, and other natural resources, which extraction leads to their complete loss for future generations; therefore, these resources are related to non-renewable ones. Note that MERGE allows us to account the dynamics of fossil fuel only. The MRRD is estimated by the gross value added in the activity category “Natural resource production”, which is one of optimizable parameters in MERGE. The nonrenewable natural resource depletion (here, MRRD) at the time t_i (actually, in the interval $(t_{i-1}, t_i]$, $i = 1, \dots, n$) can be found (Veklich and Shlapak 2012) as the sum over considered resources of the present natural rent values discounted at a rate r and averaged over a period T of the natural resource exhaustion. So, for the j -th mineral and raw material resource, the regional value of the natural rent R_i^j at the time t_i is calculated by the formula:

$$R_i^j = (P_i^j - C_i^j)Q_i^j,$$

where P_i^j is the price of the j -th natural resource at world market, C_i^j is the average cost of the j -th resource production in the region, Q_i^j is the j -th resource production. Then,

$$\text{MRRD} = \sum_j \frac{1}{T^j} \sum_{i=1}^{T^j} \frac{R_i^j}{(1+r)^i},$$

where the discount rate r is assumed to be 2–4 %, the period T^j of the j -th natural resource exhaustion is determined as the ratio of (oil, gas, coal) reserves to the annual production, but not less than 25 years. The alternative way to calculate the MRRD at the time t_i is the usage of the i -th term from the inner sum in the latter formula. The FRD is not simulated in MERGE,

considered as a result of some exogenous process; its dynamics is specified according to the Rosstat data and other sources (Rosstat 2016; WB 2015).

In our scheme, the environmental degradation (ED) is the sum of the damages from carbon dioxide emissions (DCO2) and from emissions of other contaminants (DOC):

$$\text{ED} = \text{DCO2} + \text{DOC}.$$

The damage from carbon dioxide emissions is found as the volume of annual emissions (VCO2, being an output of the economic-energetic submodel) multiplied by the value of estimated marginal losses from carbon dioxide emissions (LCO2, we use the value 20 USD per ton according to the estimate of the World Bank (WB 2015)):

$$\text{DCO2} = \text{VCO2} \cdot \text{LCO2}.$$

The damages from emissions of other GHGs taken into account in MERGE and other contaminants specified exogenously are calculated by similar formulas.

Thus, in the new modification of MERGE, the EDP accounted by the scheme outlined above is treated as the green GDP. Note that, in spite of the importance of taking into account ecologically oriented indices, up to now, there are no annual official statistical datasets on regional green GDPs. However, a practical analysis is performed both by individual experts and by international organizations. For example, by estimates of UN Statistical Department (UNDP 2003), the average EDP values in developed countries are 80–90 % of their GDPs.

Results and discussion

The main goals of numerical experiments are the testing of possibilities of Russia's participation in Kyoto-type initiatives (like the Paris Agreement) on GHG emission reduction and the analysis of ecological indices of Russia's GDP under different assumptions on the dynamics of economic-energetic parameters.

The adaptation of the model to the current state of the world and regional economy included (i) changes in the mathematical procedures for simulating specific features of the economic dynamics (for example, for taking into account the worldwide recession, mutual trade restrictions due to sanctions, and green characteristics); (ii) the usage of new input data (macroeconomic parameters, energy indices, reserves of fossils and so on) from modern sources (Rosstat 2016; WB 2015; EIA 2014; CIA 2013) for constructing scenarios corresponding to the modern multivariate geopolitical situation; (iii) a new, in comparison with the classical version (Manne et al. 1995; Manne

2003; Kryazhimsky et al. 2005; Digas and Rozenberg 2010), division of the heterogeneous world into regions basing on last tendencies of the economic development. The main changes in the algorithmic part were described in the previous section; therefore, we comment the latter two points.

As a main source of input scenarios of possible Russia's economic dynamics, we use the Prognosis of social economic development of the Russian Federation for 2016 and for the planning period 2017–2018 (MEDRF 2015). In the document, the basic, conservative, and optimistic scenarios are considered. All of them follow the hypothesis that the annual growth rate of the world economy is estimated in the range of 3.4–3.6 % for 2016–2020; their specific character results from different development tendencies and foreign-economic activities. 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 (WB 2015; EIA 2014; CIA 2013) is used. Let us present a brief description of each scenario.

Basic scenario (Bas) is relied on the market expectations concerning energy resources reflected in the consensus-prognosis of world agencies and is worked out under the assumption that the average oil price will be at the level of 50 USD per barrel in 2016, 52 USD in 2017, and 55 USD in 2018. The gas export price will be decreasing during these years due to the essential increase in competitiveness. Against rather negative background, the Russian economy will increase rather slowly: the GDP growth rate is estimated at the level of 0.7 % in 2016, 1.9 % in 2017, 2.4 % in 2018. Note that the authors of (MEDRF 2015) considered the scenario Bas as the most probable one; it was used for specifying the parameters of the national budget for 2016–2018.

Conservative scenario (Con) considers the Russian economy development under conditions of lower prices of fuel-energy and raw materials (comparing with other scenarios) So, it is assumed that the oil price will be not greater than 40 USD per barrel up to the end of simulations. Such trends will result in a sharply negative dynamics of main macroeconomic indices: the GDP will decrease at a rate 1 % per year, and the investments will drop. The transition to a positive GDP dynamics at a rate about 2 % per year will be outlined in 2018 or even later.

Optimistic scenario (Opt) created in accordance with the commission of the President of the Russian Federation is characterized by additional impulses of innovative development (especially, in high-technology sectors) 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 2017–2020; this corresponds to the growth rate of the world economy.

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 GDP will decrease at a rate about 2 % in 2016 with a very slow growth afterwards, the rate of energy efficiency improvement is stable but relatively low, the share of primary-energy export in the GDP is almost constant.

In all the scenarios, the prices at raw materials markets essentially depend on the fact which one from the worldwide scenarios, “shale gas breakthrough” or “shale gas failure”, will be finally put into effect. Additionally, we emphasize that the scenarios Bas, Con, and Ref assume the action of the USA and EU sanctions imposed against Russia and counter-sanctions to be continued for the whole predictive period. As a result, this implies the preservation of the restricted access to the world capital market for Russian companies. In the scenario Opt, we consider the lifting of the mutual sanctions in the nearest future and the development of Russian economy in accordance with prognosis trajectories worked out before 2014. Note that the implementation of possible sanctions into the model MERGE is realized by the application of artificial constraints on some kinds of interregional export/import. The key indices of the scenarios are presented in Table 1.

It should be noted that all the scenarios take into account the available values observed in 2015 (for example, the fact that the Russian economy decreased at 3.7 %), but the data from (WB 2015; EIA 2014; CIA 2013) provide a possibility to choose 2013 (and not later) as an initial year for simulations. The plus of such a choice is that this year was the last one before crisis; this is useful in a comparative analysis.

The current 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.

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 stipulated by some obligations 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. The environmentally corrected GDP (the EDP) is calculated by the formulas described in the previous section. Let us discuss the simulation results for the time period

Table 1 The key indices of the scenarios of social economic development of Russia for 2016–2018

Index	Scenario	2015	2016	2017	2018
GDP change (% to previous year)	Bas	−3.7	0.7	1.9	2.4
	Con		−1.0	1.3	2.3
	Opt		2.3	3.3	4.4
	Ref		−2.0	0.5	1.0
Oil prices, Urals (USD per barrel)	Bas	53	50	52	55
	Con		40	40	40
	Opt		50	52	55
	Ref		45	45	45
Investments change (% to previous year)	Bas	−9.9	−1.6	2.1	2.6
	Con		−6.4	0.6	1.4
	Opt		3.1	6.0	8.3
	Ref		−1.0	0.5	0.5

Fig. 2 CO₂ emissions, the share of Kyoto level; variant R0 for model scenarios

2015–2030. Taking into account the data availability, we choose 2015, 2016, 2017, 2020, 2025, and 2030 as the discrete time moments.

From Fig. 2 we conclude that, for all the scenarios, the Russian energy-sector CO₂ emissions, excluding the net CO₂ absorption by forests, do not even approach the 1990 level (the Kyoto level for Russia, 0.646 Gt C equivalent) on the whole time interval. The model emissions do not exceed 70 % of the Kyoto level past 2020. In 2030, the maximum value (68 %) is reached for the scenario Opt. A considerable reduction of emissions is essentially caused by the planned decrease of energy intensity of the GDP. Thus, according to all the model scenarios, Russia has sufficient reserves for the “painless” participation in environmental initiatives (like the Paris Agreement) with the obligations mentioned above. The results obtained are in agreement with the forecasts of leading Russian experts (see Bashmakov and Myshak 2013; ERIRAS 2014; NIRRF 2013, and their references) 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.

Figure 3 informs us that, under the model assumptions, Russia’s GDP grows for all the scenarios with

Fig. 3 Realized GDP in trln. USD

approximately constant rates for the interval 2015–2020 (the crisis downfall with subsequent slow growth) and for the interval 2021–2030 (the essential growth with final overcoming of consequences of the crisis). The forecast GDP for most progressive scenario Opt appreciably passes ahead of the GDPs for alternative variants (for example, by 20–25 % in 2025). At last, the GDP for the scenarios Ref and Con are behind the GDPs for other scenarios; this testifies to a sceptical attitude to the perspectives of Russian economy on the viewpoint of the western experts. On the other hand, the differences GDP(Opt)–GDP(Ref) and GDP(Opt)–GDP(Con) can be treated as a measure of the damage to Russian economy caused by the realization of unfavorable scenarios at the fossil fuel market and the continuation of sanctions. In addition, we conclude that, from the MERGE viewpoint, some difference in the initial data (see Table 1) can be transformed into a very essential one in GDP values at the end of simulations.

The EDP dynamics presented in Fig. 4 testifies to a large enough percent of the GDP (about 10 % in 2015) treated as an ecological loss according to the calculation scheme applied. Note that one can observe a positive trend in the form of decreasing the percentage difference between the GDP and EDP downto 5–7 % in 2030. Perhaps, this is explained both by the increase of energy

Fig. 4 The share of EDP in GDP (percent)

Fig. 5 Natural resource depletion (RD) in bln. USD

effectiveness of the GDP due to the new technology implementation and by the specificity of the model dealing with optimal (on the whole simulation interval) trajectories of regional economic development. However, for every time moment and for each scenario, the difference GDP–EDP in percentage of GDP is greater than the annual average GDP growth rate. Thus, by the simulation results, the cost of environmental degradation in Russia exceeds the real economic growth; this conclusion corresponds to the estimate of the World Bank (WB 2015). In addition, we note that, for all the scenarios, the model EDP seems to be overrated (comparing with the real one) since we do not take into account losses of nonrenewable non-fuel mineral resources and some contaminations of the environment. Due to these facts, the model EDP should be considered as an upper estimate of the regional green GDP. Assuming that the actual green GDP is even less than the model EDP, we conclude that the increase of ecological effectiveness of Russia's GDP is a very important problem and requires a speedy solution.

Analyzing the dynamics of the variable RD (Fig. 5), of the CO₂ emissions (Fig. 2) and other contaminants, and of the EDP values (Figs. 3, 4), we deduce that the main negative contribution to the EDP is made by the losses of nonrenewable natural (first of all, mineral and raw material) resources. For example, in 2015, according to the scenario Opt, the model GDP “loses” 80 % (of the difference GDP–EDP) at the cost of RD and 20 % at the cost

of ED. The share of RD does not fall below 75 % till 2030 for all the scenarios. So, the scheme for accounting the EDP used here shows that, at the present time, mainly raw materials character of Russia's economy is more “harmful” than the environmental degradation.

Conclusion

Note that the model dynamics presented in Figs. 2, 3, 4, 5 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.

In the paper, different scenarios of Russia's economic development (based on the official forecasts both from domestic and foreign sources) are considered. The emphasis is on analyzing possibilities of Russia's participation in some Kyoto-type initiatives on GHG emission reduction (like the Paris Agreement) and on studying ecological indices of Russia's GDP. Toward these aims, the optimization model MERGE is engaged and adapted to the current state of the world and regional economy taking into account the specific character of the crisis and post-crisis development. Calculations with MERGE demonstrate the attainability of the national emission targets consisting in stabilizing the CO₂ emissions at 70–75 % of the 1990 level by 2020–2030. Another result is that the problem of increasing the ecological effectiveness of Russia's GDP is very urgent. 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. As to perspectives of the model, the authors believe that analyzing numerical experiments similar to those described above will contribute to a reasonable supplement to MERGE of standard ecological indices (UNDP 2003; WB 2015) estimating the quality of economic development.

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