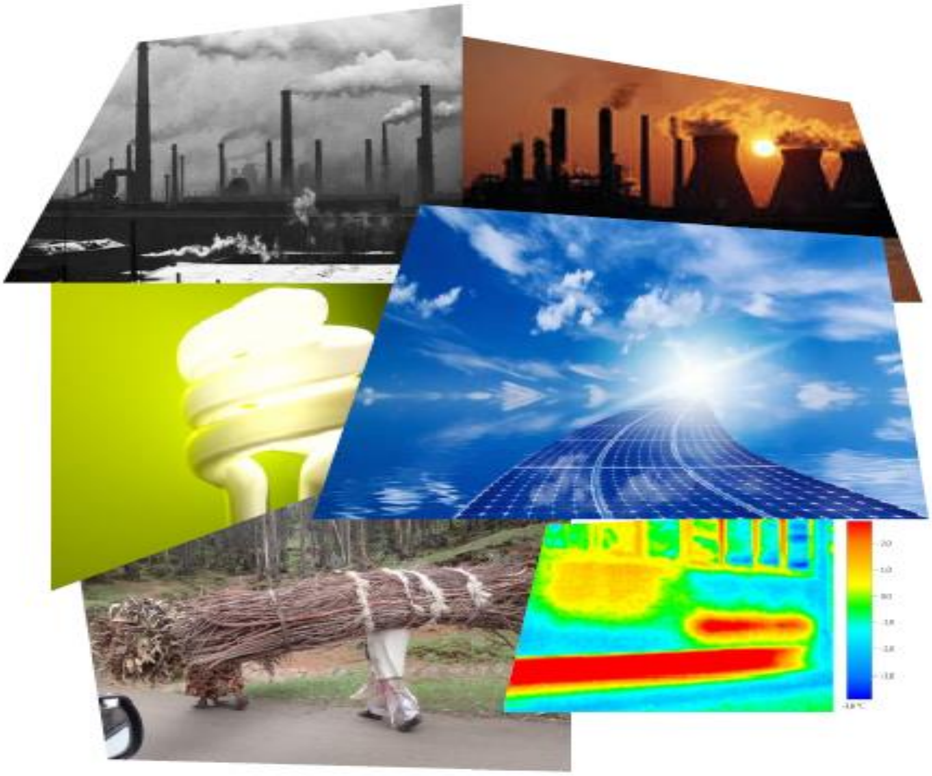
Center for Energy Efficiency (CENEf))

Costs and Benefits of Low-Carbon Economy and Society Transformation in Russia.

2050 Perspective

Igor Bashmakov editor



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Contents

Introduction

This report presents the results of a study titled *Costs and Benefits of Low-Carbon Economy And Society Transformation in Russia. 2050 Perspective.* The study was accomplished by the Center for Energy Efficiency (CENEf) in cooperation with experts from the Institute for Economic Forecasting of the Russian Academy of Science, Energy Research Institute of the Russian Academy of Science, Russian Presidential Academy of National Economy and Public Administration (RANEPA), Gaidar Institute for Economic Policy (IEP), and Massachusetts Technology Institute (MIT). Some results obtained by the International Energy Agency were also used in the study.

This is a unique project for Russia. A number of research groups have developed scenarios of energy-related greenhouse gas (GHG) emissions (i.e. emissions from all activities that involve fuel combustion and fugitive GHG emissions in fuel production, transportation, or end-use processes). This was done building on preliminarily coordinated scenario assumptions underlying long-term GHG emissions trajectories to ensure better comparability of results and wider coverage and appropriate structuring of GHG emission control options. "Action plan to ensure the determined volume of greenhouse gas emission" approved by the Russian government in April 2014 includes the development of greenhouse gas emission projections to 2020 and to 2030. This study is an important step towards this plan implementation.

The project purpose was to identify costs and benefits of Russia's low-carbon development to mid-XXI century and to find out if low-carbon development hampers or drives Russia's economic growth. Involvement of several Russian and foreign research groups allowed it to come up with well-balanced answers to two questions: (1) is there a correlation between the economic growth in Russia and transition to low-carbon development trajectories; and (2) what GHG emission control commitments can Russia make to 2030 and to 2050.

The report consists of three sections. Section I is a summary for policy-makers which presents the results of the research in a clear and concise form. It formulates the basic findings and shows the degree of experts' agreement. This section not only shows emission trajectories, but presents a detailed picture of the potential evolution of Russia' energy system. This energy picture color palette is much richer, than the one normally used in official documents, including in Russia's Energy Strategy. It displays wider and more comprehensive potential alternatives for energy sector development pathways to 2050.

Section II was developed by CENEf and elaborates on the coordinated assumptions underlying long-term projections of greenhouse gas emission trajectories. The participating research groups kept to these assumptions while developing their scenarios to ensure better comparability of projection results and to better comprise and structure the variety of emission control options.

Section III presents only the contribution by Igor Bashmakov (CENEf). Contributions by other research groups, including by Yuri Sinyak (Institute for Economic Forecasting of the Russian Academy of Science), Alexey Makarov (Energy Research Institute of the Russian Academy of Science), Sergey Paltsev and Elena Kalinina (MIT), Oleg Lugovoy, Dmitry Gordeev, and Vladimir Potashnikov (RANEPA and IEP) are available only in Russian at www.cenef.ru.

This research is intended primarily for the expert community and decision-makers. A resume for the general public, i.e. for those interested in climate stabilization issues, was also developed, yet is not part of this report. This resume is structured as answers to twelve frequently asked questions.

This report builds on a series of earlier studies that focused on whether or not it is possible to make a transition to low-carbon economy in Russia. The first study in that series[1] was devoted to the identification of factors behind Russia's energy-related greenhouse gas emission evolution back in 1990-2011. The second study[2] focused on the comparison of Russia's energy-related greenhouse gas emission projections to 2060 that were developed in 2008-2012.

Hopefully, this first ever positive experience of cooperation and projections exchange between the research groups will lay a basis for an ongoing forum to discuss long-term perspectives of Russia's economic, energy, and environmental development, and the results of this cooperation will become a reliable base for decision-making related to Russia's greenhouse gas emission control policies.

The authors would like to offer their special thanks to Tatiana Shishkina for editing this report and translating it into English and to Oksana Ganzyuk for getting it ready for print.

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[1] Bashmakov I.A. and A.D. Myshak. Factors driving Russia's energy-related greenhouse gas emission. Analysis based on data from the National Inventory Report. – Moscow. Meteoagentstvo Roshydrometa, 2012. (In Russian).
[2] Bashmakov I.A. and A.D. Myshak. (2013). Comparison of energy-related greenhouse gas emission projections for Russia for 2010-2060. Problemy prognozirovaniya (Problems of forecasting). In print.

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Section I

Summary for Policy-Makers

1 Global trends in greenhouse gas emission and emission control targets

It has been proved that anthropogenic impact is the dominating factor behind global warming. Greenhouse gas absorption abilities of ecosystems are limited. Therefore, in the same way that an attempt to add more water to a full glass leads to a water spill over the tablecloth, relatively small (in relation to the carbon budget) additional anthropogenic GHG emissions increase greenhouse gas concentrations in the atmosphere and contribute to the global warming.

The anthropogenic impact can be mitigated through emission control policies. This is exactly the focus of the UN Framework Convention on Climate Change (1992) and the Kyoto Protocol (1997). The Framework Convention has formulated the goal of avoiding dangerous anthropogenic impacts on the global climate. Avoiding dangerous impacts is currently understood as maintaining average global surface temperature change below 1.5-2^{o}C of the pre-industrial era. The Kyoto Protocol was supposed to help industrialized countries reduce their emissions by 5% over 2008-2012 in relation to the 1990 level. In 2009 an unsuccessful attempt to extend and expand the Kyoto Protocol was made in Copenhagen. However, many countries and groups of countries committed to control GHG emissions to 2020 and beyond.

In 2000-2010, global GHGs emission was growing faster (at 2.2% per year), than in three previous decades (at 1.3% per year over 1970-2000), despite the economic stagnation and the efforts taken by the increasing number of countries to implement the UN Framework Convention on Climate Change and the Kyoto Protocol (Fig. 1)[3]. Carbon dioxide emission accumulated since 1750 has doubled over the last four decades: from 900 bln. t CO_2 in 1750–1970 to 2000 bln. t CO_2 in 1750–2010. CO_2 remains the major anthropogenic greenhouse gas (its share in 2010 was 76%). Methane is responsible for another 16%, nitrogen monoxide for 6%, and other greenhouse gases for 2%. GHGs emission from fossil fuel combustion in 2013 exceeded 32 bln. t $CO_{2\text{-eq.}}$ and in the absence of tough emission control policies may grow up to 50-70 bln. t $CO_{2\text{-eq.}}$ by 2050 and to 90 bln. t $CO_{2\text{-eq.}}$ by 2100.

Energy sector (energy production, transformation, storage, transmission and distribution processes) is the major and the fastest growing GHGs source. In 2010, 35% of GHGs emission was observed in the energy sector, 24% in the land use and land use change, 21% in industry, 14% in transport, and 6% in buildings. With indirect emissions from electricity- and heat generation included, the shares of industry and buildings grow up to 32% and 18% respectively. Limiting global warming to 2^{o}C will require reduction in specific GHG emissions from electricity generation to a level below 100 g $CO_{2\text{-eq.}}$/kWh in 2050 and nearly to zero in 2100.

Calculations show that without substantial additional emission control policies it will be practically impossible to keep GHG ($CO_{2\text{-eq.}}$) concentrations in the atmosphere at 450-500 parts per million over the next 20 years. It means that unheard-of emission reduction efforts will be required in 2030-2050, or that large-scale use of technologies that allow for GHG removal from the atmosphere or for atmosphere cooling will be needed beyond that period. Albeit mitigation of climate forcing involves significant costs (and estimated levels of these costs are very different), they can be substantially reduced through the removal of barriers to the market penetration of low-carbon technologies and through taking account of a variety of related indirect positive impacts.

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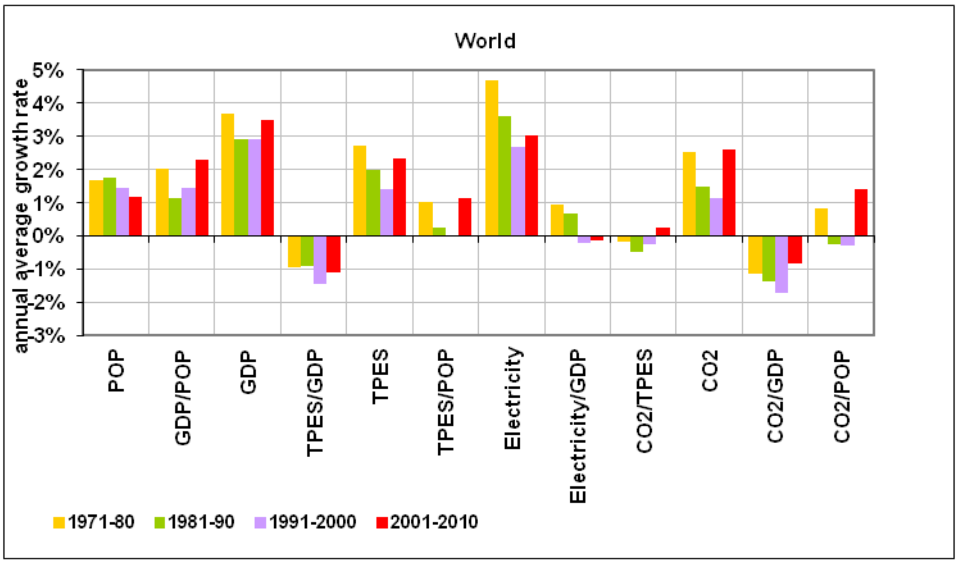
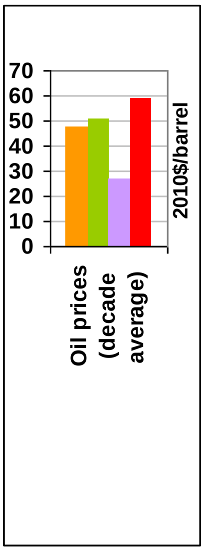
[3] This section relies on WGIII IPCC AR5 findings. See Climate Change 2014. Mitigation of climate change. Summary for policy makers. Working Group III contribution to the Fifth Assessment Report of the IPCC. Accepted by the 39th Sessions of IPCC. Berlin, Germany; and T. Bruckner, I. Bashmakov, Y. Mulugetta and others. Energy Systems. Chapter 7. Climate Change 2014. Mitigation of climate change. Summary for policy makers. Working Group III contribution to the Fifth Assessment Report of the IPCC. http://www.ipcc.ch/

The major drivers behind global GHGs emission growth were economic and population growth that exceeded the mitigating effects of energy efficiency improvements, while the impact of carbon intensity of energy was differently directed (Fig. 1). Acceleration of GDP per capita growth resulted in the acceleration of the global GDP growth even with slowing down population increase. The rates of energy intensity reduction driven by improved technological and sectoral structure of GDP were (1) lower, than in the 90'es; (2) uneven (the reduction trend was interrupted thrice over the last 10 years); and (3) insufficient to block primary energy demand growth. This growth was determined by sources in non-OECD countries. Per capita energy consumption once again showed intense growth after stabilization in the 80'es and 90'es.

Figure 1. Combination of factors that determined global energy demand and energy-related CO_2 emission dynamics in 1971-2010





Sources: Databases (IEA, 2011a); (IEA, 2011b); (BP, 2011).

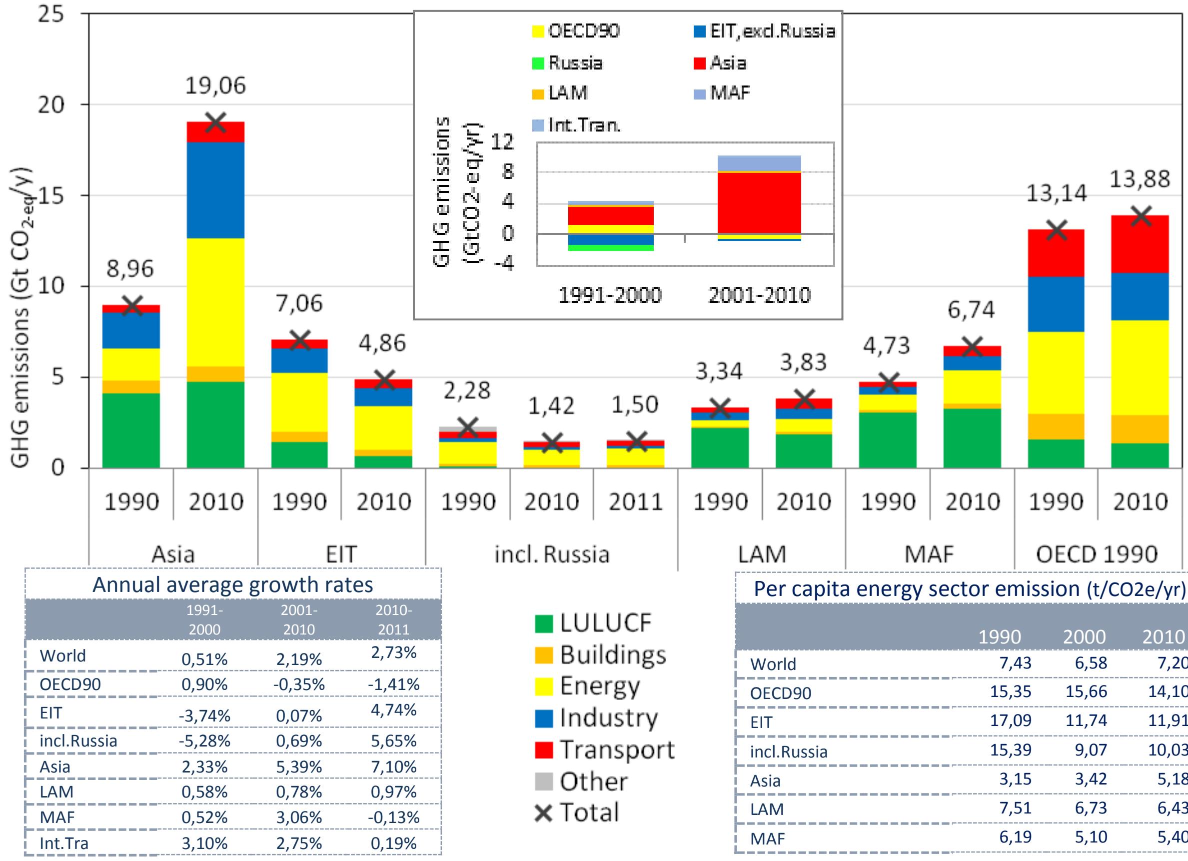
Global energy balance diversification trend was generally sustained, but fossil fuels maintained and strengthened their dominating role. Oil kept losing its market share; however, oil consumption was growing up at 1% per year, primarily in transport and in the developing countries. After peaking in 2005, oil consumption in OECD countries has been declining. Natural gas consumption was growing up at 2.7% per year, yet over the last decade natural gas lost the status of the fastest growing fossil fuel. In early XXI century the long-term downward trend in the role of coal in the global energy balance was temporarily broken. Coal consumption was growing up at 4% per year and was responsible for nearly half of primary energy consumption increase. Coal consumption increase in Asia alone (primarily in China and India) over 2000-2010 equaled the total increase in global consumption of energy from all sources in 1990-2000.

Renewable energy sources were responsible for 13.5% of 2010 global primary energy production and for 21% of electricity production. Renewable energy sources became the third largest electricity generation source after coal and natural gas and have good chances of becoming the second largest source by 2020. Electricity generation by wind plants has grown up 5-fold, and by solar plants 25-fold over the last decade. In 2012, wind plants were responsible for 2% of total electricity generation, and from 2008 onwards this share has been growing at 0.3% annually. OECD countries and China were responsible for the major part of wind- and solar energy generation increase. The share of hydro power plants in 2012 electricity generation equaled 16.3% (BP, 2013).

Nuclear energy sector, overlaid with problems related to security, waste disposal, non-proliferation, and growing capital intensity, was responsible for only 11% of electricity generation in 2012 versus 17% in 1993. The share of nuclear energy in global primary energy production has been declining since 2002, and absolute electricity generation by nuclear plants since 2006. All these trends formed well before the Fukushima nuclear accident in March 2011. After 2006, nuclear energy generation growth has been observed primarily in China and Russia.

Combination of these factors lead to a paradox: **in the decade of the most active GHG emission control policies global downward trend in carbon intensity of energy (1970-2000) was reversed (Fig. 1).** As a result, energy related emissions growth accelerated (Fig. 2). In 2011, emissions went up by 3% (according to different sources), and in 2012 by another 2% (IEA, 2013; BP, 2013; Enerdata, 2013). Global trends mask big differences in the evolution of regional energy consumption scale and structure and of regional emission evolution (Fig. 2).

Figure 2. GHG emissions from fossil fuel combustion by sectors and regions in 1990 and 2010



Annual average growth rates

	1991-2000	2001-2010	2010-2011
World	0,51%	2,19%	2,73%
OECD90	0,90%	-0,35%	-1,41%
EIT	-3,74%	0,07%	4,74%
incl.Russia	-5,28%	0,69%	5,65%
Asia	2,33%	5,39%	7,10%
LAM	0,58%	0,78%	0,97%
MAF	0,52%	3,06%	-0,13%
Int.Tra	3,10%	2,75%	0,19%

Per capita energy sector emission (t/CO2e/yr)

	1990	2000	2010
World	7,43	6,58	7,20
OECD90	15,35	15,66	14,10
EIT	17,09	11,74	11,91
incl.Russia	15,39	9,07	10,03
Asia	3,15	3,42	5,18
LAM	7,51	6,73	6,43
MAF	6,19	5,10	5,40

Notes: OECD90 – OECD member states as of 1990, EIT – economies in transition, LAM – Latin America; MAF – Middle East and Africa. The upper diagram shows contributions made by regions to the emission level change over 10 years.

Source: built by the authors based on IEA/EDGAR dataset (IEA, 2012a; JRC/PBL, 2012), data for Russia from the 2013 National Inventory; 2011 data for regions from IEA, 2013a.

By 2010, Asia had become the major emitter with 41% share in **the global emission. China moved the U.S. from the first place among the largest emitters,** and India went third taking Russia's place. GHG emission growth in non-OECD countries in 1990 accelerated from 1.7% in 1991-2000 to 5% in 2001-2010. Asian countries spurred global GHG emission growth in 2000-2010 exactly in the energy sector. Asia was responsible for 79% of the emission increase over 1991-2000 and for 83% of the emission increase in 2001-2010. Despite the fact that average specific per capita GHG emissions in the world and in many regions have declined, in Asia they showed 64% growth (Fig. 2). In China, they have exceeded the levels observed in some EU countries (for example, in France).

Economies in transition, including Russia, are the only group of countries whose 2010 emissions were much lower than the 1990 levels. Only this group of countries succeeded in decoupling economic growth and GHG emissions: in 2010, GDP of this region was 10% above the 1990 level, while GHG emissions were 29% lower.

In the absence of additional emission control efforts the warming will equal 3.7-4.8^{o}C in 2100. If the warming is to be limited to 2^{o}C, it is important to reduce global GHG emission in 2050 by 40-70%, and in 2100 to practically zero. These are the findings formulated in the Summary for policy makers prepared by the Working Group III in the framework of 5th Assessment Report of the IPCC[4].

2 Russia's greenhouse gas emission trends5

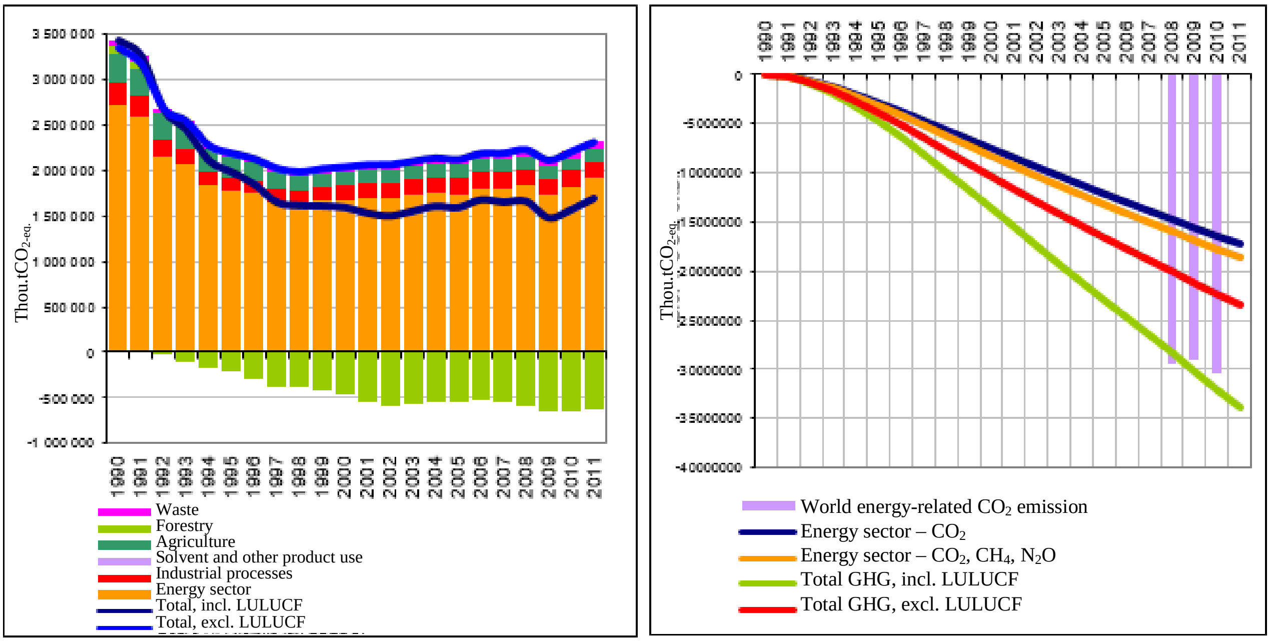
Official information on Russia's GHG emissions can be found in the National Inventory Report on GHG sources and sinks (hereinafter referred to as the National Inventory Report), which is submitted by the Federal Agency on Hydrometeorology and Environmental Monitoring of the Russian Federation (Roshydromet) and prepared by the Institute for global climate and environment of Roshydromet and the Russian Academy of Science (Roshydromet, 2013). This National Inventory Report is prepared on the annual basis and presented to the UNFCCC Secretariat in compliance with Russia's commitments as an Annex I country (Annex I incorporates industrialized countries and transition economies). According to these data, Russia's 2011 emission was 29% below the 1990 level.

Whilst **most countries kept increasing their emissions, Russia alone managed to impede the negative anthropogenic impact for a whole year.** In 1991-2000, Russia made the largest contribution to the reduction in global GHG emissions. The most tangible emission reduction took place in 1990-1998 followed by a subsequent slow growth which was compensated by the growing sinks. In 2011, Russia's emissions and sinks of all GHG from all sources were 51% below the 1990 level. It is one of the most substantial reductions in the world. 2011 energy-related GHG emissions were 30% below the 1990 level. In 2000-2010, Russia's emission demonstrated very small growth. In 1991-2010, cumulative GHG emission reduction in Russia (incl. sinks) equaled 32.3 bln. t $CO_{2\text{-eq.}}$ (Fig. 3). This is more than global annual energy-related CO_2 emission (31.3 bln. t $CO_{2\text{-eq.}}$ in 2011) (IEA, 2013a).

During 1991-2010, Russia was the world leader in cumulative reduction of GHG emission, and to a large extent compensated cumulative emission increase in other regions of the world. While global energy-related CO_2 emission grew up by 45% over 1990-2010, in Russia it declined by 37%. Cumulative reduction of energy-related CO_2 emission in Russia over 1991-2011 equals 5 years' EU emission, exceeds 3 years' emission of the U.S. and 2 years' emission of China. Emissions from the energy sector and industry and leakages from the energy sector dominate in the emission structure. On the whole, the share of energy sector in 2010 total energy-related emission was 71%. The share of industrial process emission and leakages is quite significant (22%) and is not to be ignored in the analysis. The share of industry and construction is 8%, of transport 12%, of commercial, residential and other sectors 7%.

[4] Climate Change 2014. Mitigation of climate change. Summary for policy makers. Working Group III contribution to the Fifth Assessment Report of the IPCC. Accepted by the 39th Sessions of IPCC. Berlin, Germany.
[5] For a detailed analysis of GHG emission trends and factors in 1990-2011 see (Bashmakov and Myshak, 2012).

Figure 3. **Emission evolution and structure by major sectors in the Russian Federation (a), Evolution of cumulative reduction in GHG emissions in the Russian Federation (b)**



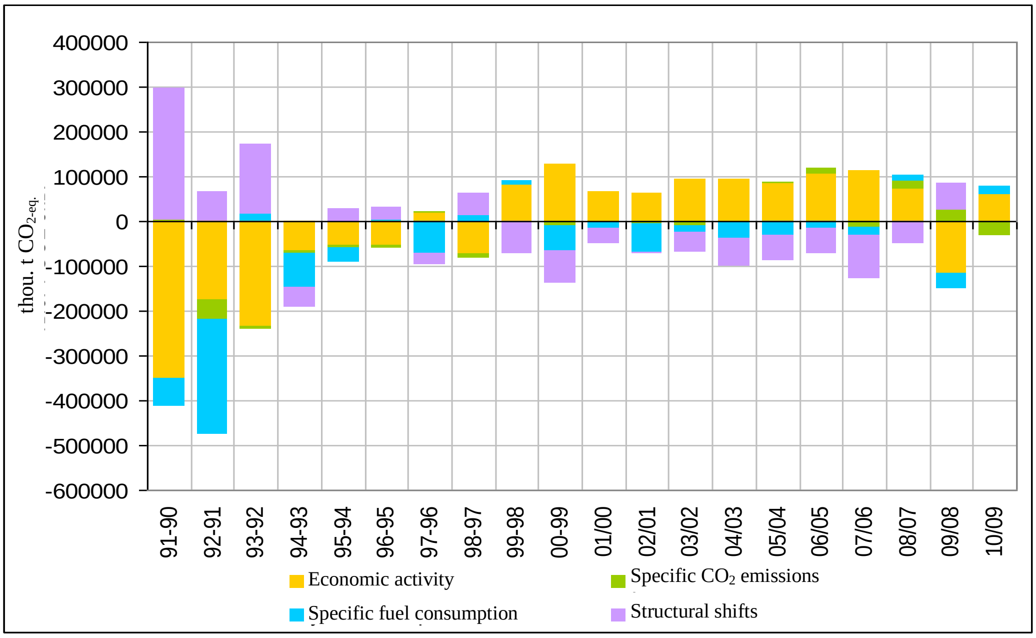
a b

Source: I. Bashmakov and A. Myshak (2012).

Reality dramatically contrasts with the generally held view that the economic stagnation of the early 90'es was the major factor behind Russia's emission reduction. If this had been the only factor and no other policies had had any effect, then Russia's emission would have exceeded the 1990 level as early as in 2011. Until 1995 declining economic activity lead to emission reduction (Fig. 4). This happened again in the years of recession: 1998 and 2009. If economic growth had been even across all activities in 2000-2011 and energy and carbon intensity had not been declining, then in 2011 energy-related GHG emissions would have been 3.6% above the 1990 level. However, in reality 2011 GHG emission was 30% below that level.

Structural reforming policies in the Russian economy substantially contributed to hampering emission growth and to practical decoupling (of economic growth and CO_2 emission). Potential emission growth induced by economic growth was neutralized by a number of factors that were bringing the emission down: structural shifts in the economy were responsible for 84.1% of such neutralization; reduction of specific GHG emission per fuel unit driven by increased natural gas use for another 4.2%; energy efficiency improvement for 8.8%; growing capacity load for 2.3%; and the price factor for 0.5% (Fig. 4). Each percent of GDP increase (reduction) was followed by only 0.35 percent of energy-related GHG emission growth (reduction). Since major emission sources include sectors that are only slightly affected by cyclic economic fluctuations (energy industries, residential sector, and motor transport), with GDP decline the structural factor relatively slows down emission reduction, while with GDP growth it, on the contrary, slows down emission increase. The role of cyclic factors grows up, if capacity load fluctuations are taken into account: when capacity load drops during stagnation, specific energy consumption goes up followed by specific emissions; and when it grows up, a reverse effect is observed.

Figure 4. Contributions made by four factors to annual evolution of fossil fuel CO_2 emission



Source: Bashmakov I.A. and A.D. Myshak (2012).

Technological energy efficiency improvements also contributed to the emission reduction. However, this contribution might have been more substantial, while in reality it did not exceed 1% per year. This rate is about equal to what we see in the industrialized countries. In fact, energy efficiency gap with the industrialized countries was not narrowed in 2000-2010.

The reality has put to shame the thesis made by Andrei Illarionov that hampering CO_2 emission threatens Russia's economic growth. If in 2006-2008 Russia's economy had been growing without "overheating" (at approximately 5% per annum) determined by an attempt to live out another false thesis of GDP doubling within 7 years, there may have been no CO_2 emission increase in 1998-2010 whatsoever. The basic mistake made by Illarionov is that he did not take any account of structural shifts, but just mechanically applied the results obtained for countries with the investment growth model (growth to a large extent determined by the construction of new capacities) to Russia, where in 2000-2011 restorative growth was dominating (output increase through increased load of existing capacities).

3 There is no single road to the future. Evolution of Russia's greenhouse gas emission perspectives[6]

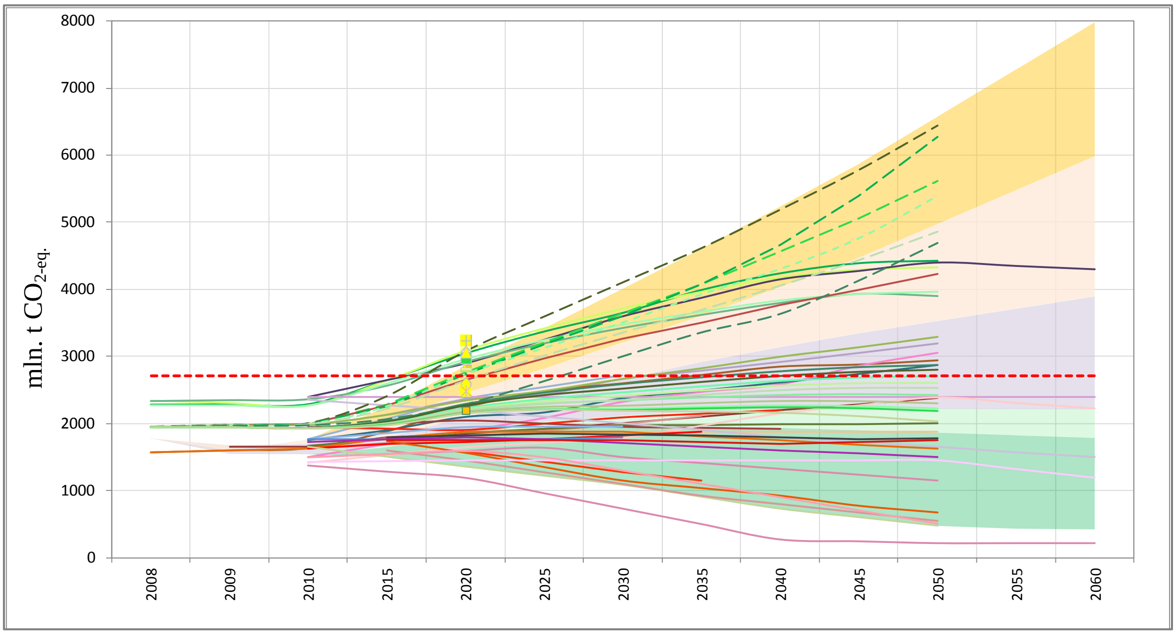
Despite the fact that Russian expert community involved in energy-related GHG emission forecasting is quite small, the scenario database is already well-developed and populated with scenarios that were developed in different years by both Russian and foreign expert groups. In the work done by CENEf (2013) 26 papers and 71 scenarios were analyzed.

Analysis of these scenarios grouped in 5 sets (Fig. 6) showed, that the uncertainty zone of projected energy-related GHGs emission trajectories was very large for papers written in 2008-2012: emission projections for 2050 range between 220 and 6500 million tons $CO_{2\text{-eq.}}$ The 2008-2009 economic stagnation and subsequent re-evaluation of possible economic development

[6] For a detailed analysis of GHG emission evolution projections see (Bashmakov and Myshak, 2013) and CENEf (2013).

rates have given up on the "Sisyphus' Way" set of scenarios (trajectories with GHG emissions exceeding 5,000 mln. t $CO_{2\text{-eq}}$. in 2050). Projections under the "Baseline Zone" set of business-as-usual (BAU) scenarios build on the assumption that such parameters as GDP energy intensity and carbon intensity of energy will show inertial dynamics keeping to the retrospective rates, and no rate acceleration policies, except those already adopted prior to the projection development, will be successfully deployed. For most trajectories in the "Carbon Plateau" set of scenarios the emission will not go beyond the 1990 level until 2060 due to successful modernization of Russian economy. The "Low-Carbon Russia" family of scenarios assume that special emission control policies will be pursued, including GHG emission tax or emission trading; coalbed methane utilization and carbon capture and storage technologies; accelerated transformation of the fuel balance in the electricity and automobile transport sectors through the introduction of emission quotas; etc. However, this family of scenarios is characterized by moderate emission charge and quotas. Finally, the "Low-Carbon Russia – Aggressive Policies" family of scenarios assume that Russia will make tough emission reduction commitments.

Figure 5. Energy-related GHG emission evolution trajectories to 2060 as projected by a number of research groups in 2008-2012



Source: (CENEf, 2013)

Presidential Decree No. 752 "On greenhouse gas emissions reduction" adopted in September 2013 requires emission sustained at no more than 75% of the 1990 level. Projections that were made in 2008-2012 building on very different economic development assumptions are not very much help in understanding if Russia can reliably comply with this Decree. Some other questions are also difficult to answer, for example: what can be the "price" of such reduction? What commitments can Russia make to 2030 and to 2050? Can it cut its emission by 50% or more? Answers are not obvious, but they are important, especially before the new round of negotiations on the new global agreement which is to (may) be signed in Paris in 2015. This project was implemented exactly to find answers to these questions by pulling together efforts of several research groups to update their projections.

4 Coordinated scenarios and storylines

The project purpose was to identify costs and benefits of Russia's low-carbon development to mid-XXI century and beyond, and to find out if low-carbon development hampers or drives Russia's economic growth. Because the project was implemented by several Russian and foreign research groups, it allowed to come up with a well-balanced answer to the question if there is a correlation between the economic growth in Russia and transition to low-carbon development. The study was accomplished by the Center for Energy Efficiency (CENEf), the Institute for Economic Forecasting of the Russian Academy of Science, Energy Research Institute of the Russian Academy of Science, Russian Presidential Academy of National Economy and Public Administration, Gaidar Institute for Economic Policy (IEP), and Massachusetts Technology Institute (The MIT Joint Program on the Science and Policy of Global Change); besides, some projections made by the International Energy Agency were also used in the study.

Long-term projections are essential to reveal serious problems that can be faced by the country in the future, and to make preventive decisions to mitigate, if not address, these problems. The need to change the economic development model; problems determined by a tough demographic situation; the inertia of economic systems that requires both early decision-making and assessing the long-term consequences thereof, are all factors that lead to the increasing number of projections of Russia's economic development as a whole and of its economic subsystems not only to 2030-2040, but to 2050 and beyond.

While all research groups use comprehensive "economy-energy-environment" models for their calculations, these models differ in their level of complexity. They may also differ in the approaches to long-term modeling (optimization or imitation models); in resolution of energy production and consumption processes that involve GHG emissions; and in GHGs coverage; and all these models may reflect the impacts of a wide range of emission control policies with different flexibility.

If balanced decisions are to be made, it is very beneficial to be able to compare projection results and to estimate the degree of agreement or disagreement in the expert community in relation to the most important parameters of sustainable development and GHG emission control policies. Therefore, it is important that at least part of calculations be based on coordinated assumptions and that there be a possibility to estimate the degree of expert agreement or disagreement, which is determined by different concepts, analysis tools, and scenario assumptions. Projections comparability depends on the scenario assumptions, models, problems to be addressed, etc.

GHGs emission evolution scenarios to 2050 and beyond build on social and economic storylines, which are too uncertain to be unequivocal. These storylines are embodied in scenarios that integrate qualitative parameters of development (identification of concepts and drivers of future development and a set of quantitative estimates of input variables, as well as other parameters of models). Different combinations of these zones were selected for scenarios development (Table 1).

In all, research groups developed 30 scenarios that practically comprise the whole variety of "visions" of the future. Not all matrix cells in Fig. 6 are equally populated; however, each family is represented by at least one scenario. CENEf considered 11 scenarios; IEF 8 scenarios; ERI 2 scenarios that were used for the concept development for the RF Energy Strategy to 2050; RANEPA and IEP considered 5 scenarios; MTI 2 scenarios; and 3 scenarios were considered in the IEA publication *2012 Energy Technology Perspectives* (IEA, 2012b). Scenarios with moderate economic growth rates and "current" or "new" emission control policies prevail.

Table 1 Matrix of families of scenarios*

Basic input variables for scenarios	Storylines (concepts of the future)			
	Dynamic growth	**Moderate extensive growth**	**Moderate intensive growth**	**Slow growth**
Population	H	M	M	L
GDP**	H	M	M	L
Factor productivity growth determined by technological progress	High (3-4% per year)	Moderate (1-2% per year)	Better than moderate (2-3% per year)	Low (0.5-1% per year)
Oil production	H	M	M	L
Natural gas production	H	M	M	L
Oil price	H	M	M	L
Emission control policies	current policies	current policies	current policies	current policies
	new policies	new policies	new policies	new policies
	vigorous policies	vigorous policies	vigorous policies	

* H – probable upper zone; M – more probable zone; L – less probable lower zone.

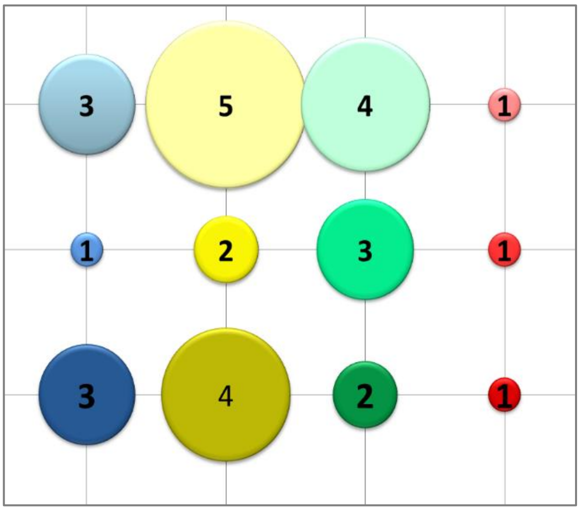
** If GDP is specified in the model, GDP growth parameters are not input variables.

Source: Igor Bashmakov. Section 2.

Figure 6. Distribution of scenarios by families

Economic growth rates

	Dynamic	Moderate intensive	Moderate extensive	Slow
Current policies	CENEf DGr-CP IEF 3-3-1,2-A1	CENEf MIGr-CP IEF 2-2-1,2-A1, ERI Target. IEA 6DS	CENEf MEGr-CP RANEPA BAU MIT Reference	CENEf SGr-CP
New policies	CENEf DGr-NP	CENEf MIGr-NP IEA 4DS	CENEf MEGr-NP RANEPA CAP50 RANEPA TAX	CENEf SGr-NP
Vigorous policies	CENEf DGr-VP IEF 3-3-1,2-A2	CENEf MIGr-VP IEA 2DS IEF 2-2-1,2-A2	CENEf MEGr-VP RANEPA CAP75	MIT Carbon Price



Source: Authors

Box 1. Parameters of possible "visions" of the future

"Dynamic growth". These scenarios assume sustainable GDP growth at a rate faster than 5% per year through the "top-down modernization" by the innovative scenario (that implies dynamic renovation of fixed assets, energy efficiency and labour productivity improvement, yet reduction in capital productivity), and so requiring/assuming a radical increase in the saving rate. These scenarios imply dynamic economic restructuring. The risks involved by these scenarios are related to a bloated public sector and excessive regulation of economy, which are incompatible with the economic efficiency improvement, as proved by the evidence of all countries with centrally planned economies. Besides, the risks include fast debt growth, which is incompatible with sustained dynamic economic growth, as proved by the experience of countries with market economies.

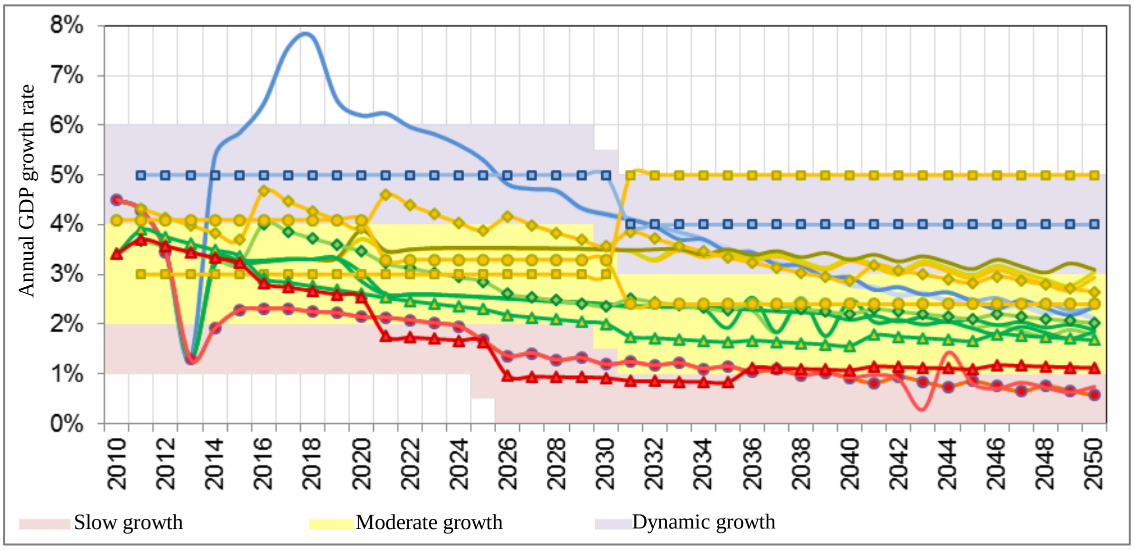
"Moderate extensive growth". Development along this group of trajectories is possible with a successful "top-down modernization" by the innovative scenario, through substantially larger oil&gas revenues, but with an account of restrictions related to the possibility of saving rate growth. With a favourable situation in the hydrocarbon markets and improved factor productivity it is possible to attain 3-4% sustainable annual GDP growth. The risks related to the dominating role of economic regulation against the background of passive business community and so to the dominating role of the state in the economy are preserved. Factor productivity (labour productivity, energy efficiency) growth is lower, than in the next family of scenarios, as determined by lower competition pressure.

"Moderate intensive growth". These scenarios imply modernization to radically improve the quality of governance, to promote dynamic investment activity and to improve factor productivity through reduced monopolization and state interference with the economy. In these scenarios, 3-4% annual growth of GDP is possible even with a less favourable situation in hydrocarbon markets, through the improved performance of the economy, reduced corruption, development of the private initiative and medium- and small business, and therefore flow of investments into less capital-, energy-, and material intensive sectors. It is not so much the growth rates, as the growth quality that makes this family of scenarios different from the previous group.

"Slow growth". Maintaining the current model of political, social, and economic development, given depleted drivers of growth and inability to make a transition to a new development pattern; adaptation of economic and social policies to the reduced oil rent and lack of mechanisms to allow for a capital transfer from the raw materials to other sectors. At the turn of the 40'es, development by this model may lead to the "magic skin" economy, i.e. sustainable reduction in GDP and inability of the improved economic performance to make up for the employment reduction and capital intensity increase.

Most projections agree that GDP growth rates will be moderate and declining. The scenarios substantially differ in the estimates of Russia's economic growth perspectives (Fig. 7), as determined by different "visions" of the future. GDP evolution uncertainty zone is split into three segments: "slow growth" (less probable lower zone) – growth at 2% in 2013-2030, at 1% in 2031-2050 and potential termination of growth beyond 2050; "moderate growth" (more probable zone) – growth at 2-4% in 2013-2030, at 1-3% in 2031-2050; "dynamic growth" (less probable upper zone) – growth at 4% or more in 2013-2030; at 3% or more in 2031-2050. In most models GDP evolution is an input variable; only in some models it is adjusted for the impacts provided by emission control policies. Obviously, levels and structure of primary energy demand affect economic development parameters.

Figure 7. Russia's GDP growth projections to 2060



Source: CENEf based on data provided by project participants

Box 2. List of GHG emission control policies
"**current measures**" include policies adopted by regulations and already in use as of summer 2013, with verification as required to attain the specified targets. These policies partially include the provisions of the "Integrated implementation plan of the Russian Climate Doctrine to 2020" approved by the RF government on 25.04.2011;
"**new measures**" include policies which would allow it to keep emissions at a level at least 25% below the 1990 level[7], including measures specified in the "Integrated Plan", but not launched yet. They may be launched before 2020. These include: development and deployment of economic instruments for GHG emission control; implementation of additional energy efficiency policies, primarily in the industrial sector; implementation of measures aiming to develop renewable and nuclear energy and cogeneration; improvement of fuel efficiency of vehicles; promotion of passive buildings construction.
"**vigorous measures**" measures aiming at a profound reduction in GHG emissions in relation to the baseline and sustaining the emission at a level at least 50% below the 1990 level, including electrification of automobile transport and substantial growth in hybrid car park; transition to a larger-scale construction of passive buildings; deployment of carbon capture and storage in the electricity and industrial sectors; substantial increase in the CO_2 tax rate or more stringent emission restrictions introduced to increase the CO_2 price in emission trading markets.

5 Greenhouse gas emission trajectories

It was not GHGs emission control that hampered economic growth; vice versa, economic growth slowdown, determined by entirely different reasons, and re-evaluated economic development perspectives became a many-fold contributor to the reduction in the upper range estimates of future GHG emission (high agreement). In none of the 30 scenarios maximum 2050 emissions exceed 3,100 mln. t $CO_{2\text{-eq.}}$, while in the pre-crisis calculations they exceeded 6,000 mln. t $CO_{2\text{-eq.}}$. Baseline GHG emission trajectories have shifted far downwards: over 6 years (2008-2014) post-recession re-evaluation of economic development lead to a shift

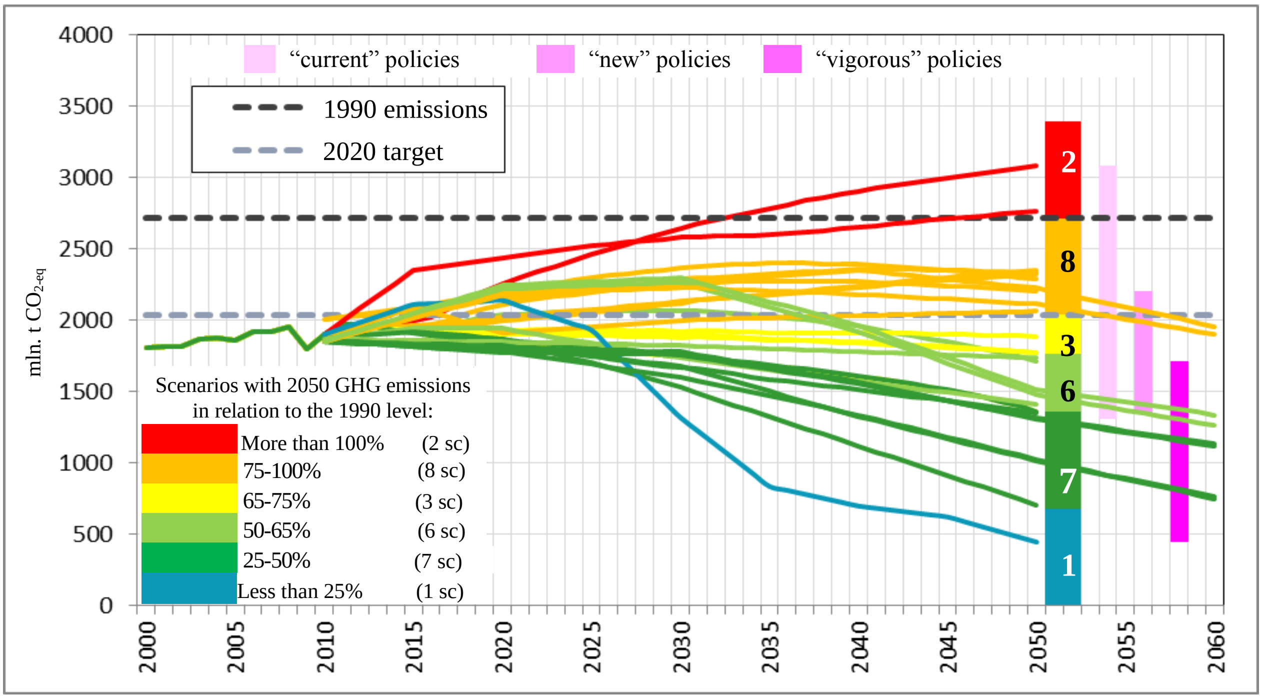
[7] In compliance with the target set in the Presidential Decree No. 752 dated 30.09.2013 "On greenhouse gas emission reduction".

by 1,500-3,200 mln. t $CO_{2\text{-eq.}}$ by 2050 (Fig. 5 and 8), which is comparable to, or much higher than, Russia's 2011 energy-related GHG emission (1,920 mln. t $CO_{2\text{-eq.}}$).

It is very likely that Russia's energy-related emissions of three greenhouse gases will approach the absolute upper limit (peak) before 2060 at a level at least 11% below the 1990 emissions (high agreement). Only in two of thirty scenarios with extremely low probability of simultaneous realization of scenario assumptions GHG emissions go beyond the 1990 level. Development by "current" policies scenarios forms the baseline, which does not approach the 1990 level until 2050 (Fig. 8). In many scenarios, after a peak GHG emissions start declining before 2050.

The larger package of emission control policies is used, the lower absolute upper limits (peaks) of three Russia's energy-related greenhouse gas emissions will be (high agreement). Policy packages and structural and technological parameters of economic development are more important, than GDP growth rates, for GHG emission trajectories. Significant reduction in the median emission evolution is only observed when scenarios with highly improbable fast economic growth are replaced with scenarios with moderate intensive growth (by around 500 mln. t $CO_{2\text{-eq.}}$, Fig. 9); and with further transition to moderate extensive growth scenarios or slow growth scenarios, the emission range is much more dependent on the policy packages, than on the economic growth rates. In "vigorous" policies scenarios, emissions keep at 35% below the 1990 level.

Figure 8. Distribution of GHGs emission trajectories by emission reductions

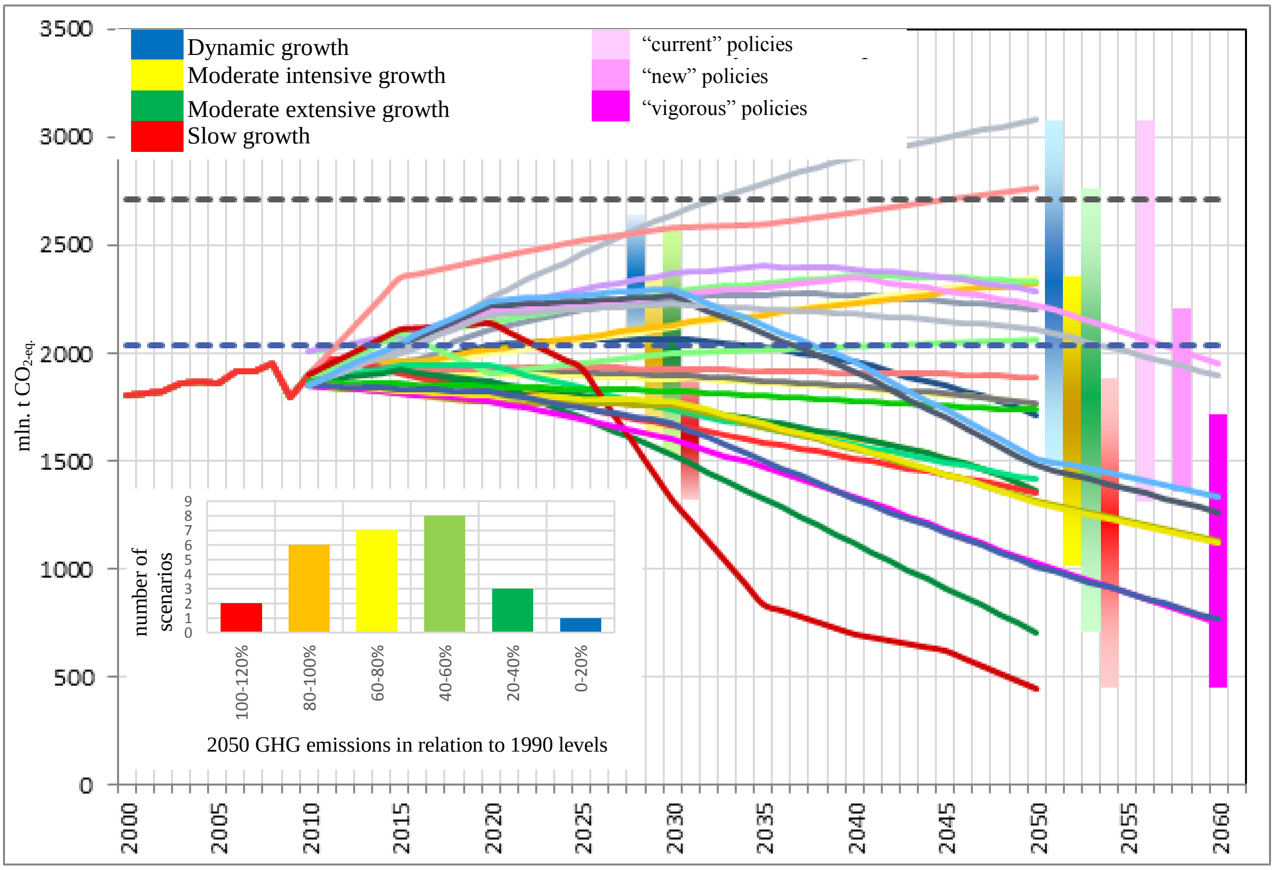


Figures in the multi-colour column show the number of scenarios within a particular range.

Source: CENEf based on data provided by project participants (27 scenarios, excl. IEA)

Russia's GHG emission commitments may be formulated in a way different from that of many other countries: not to *"reduce GHG emission by xx%"*, but *"to sustain GHG emission at xx% below the 1990 level"*. This means that Russia's emission may even somewhat grow up. In other words, while many countries are on the "downstream" move to their goals, Russia can move "upstream", as long as its actual GHG emission does not exceed the target level. And when its actual emission does exceed the target level, or the target is substantially lowered, the goal may be formulated in terms of absolute GHG emission reduction, like for other countries.

Figure 9. GHGs emission trajectories in individual scenarios



Notes. The MIT projection was adjusted for 2010 emission. Emission levels in IEF projections are based on the IEF energy balances and IPCC-approved conversion factors.

Source: CENEf based on data provided by project participants (27 scenarios).

Not all scenarios comply with the target specified in Decree No. 752 as sustaining the 2020 emission at 25% below the 1990 level (high agreement). If this target is to be attained, it is important to both improve the effectiveness of “current” policies and to launch a few “new” ones. It is very likely that in “new” policies scenarios GHG emissions in 2050 will not exceed 65% of the 1990 level. In scenarios with “vigorous” policies GHG emissions in 2050 may drop to 50% of the 1990 level[8].

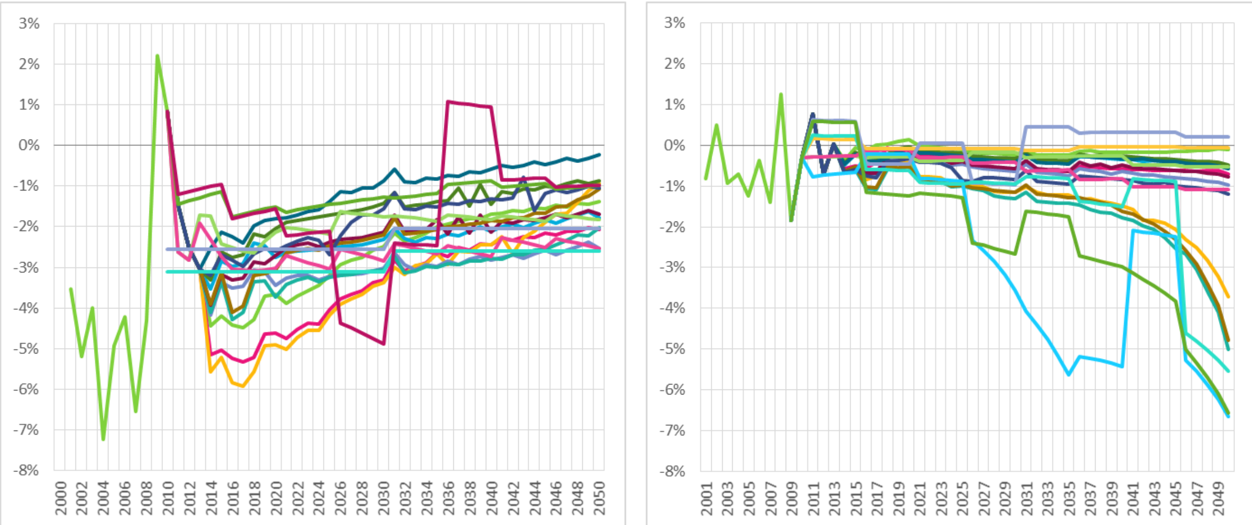
6 Energy- and carbon intensity reduction rates

As the economic growth slows down, energy intensity reduction rates decline (as driven by the reduced contribution from structural shifts and the narrowing gap with best available technologies – BAT), and deployment of low-carbon technologies becomes increasingly important for GHG emission reduction (high agreement). GDP energy intensity reduction rates are determined by the scale of structural shifts in the economy: the faster the growth, the bigger the role played by structural shifts. As the economic growth slows down, the difference between the growth rates in energy intense and other sectors shrinks diminishing the contribution of structural shifts. As technologies are renovated and the energy efficiency gap with BAT narrows, further progress in improving energy efficiency becomes more difficult to achieve. These two factors determine the slowdown in GDP energy intensity reduction from 1.3-3.3% in

[8] According to the available projections, even Chinese energy-related GHG emissions will peak in 2025-2045 (Namazu et al., 2013).

2030 to 1-2.5% in 2050 (Fig. 10a). If GHG emissions are to go down, it is important to spur the reduction in carbon intensity of primary energy, so that the 2030 value falls in the 2000-2012 range with much faster decline thereafter (Fig. 10b). In “current” policies scenarios carbon intensity reduction rates do not exceed 0.6% per year, and in scenarios with “new” policies 1.2% per year, on the entire time horizon. In scenarios that imply profound emission reduction and “vigorous” policies, carbon intensity reduction radically accelerates to 3-5% per year by the end of the period. While until the 30-40’es emission control goals are basically attained through energy efficiency improvements, development of low-carbon energy sources becomes the major driver in the subsequent period.

Figure 10. Evolution of GDP energy intensity and primary energy carbon intensity in individual scenarios (%)



(a) annual evolution of GDP energy intensity (b) annual evolution of primary energy carbon intensity

Source: CENEf based on data obtained from project participants

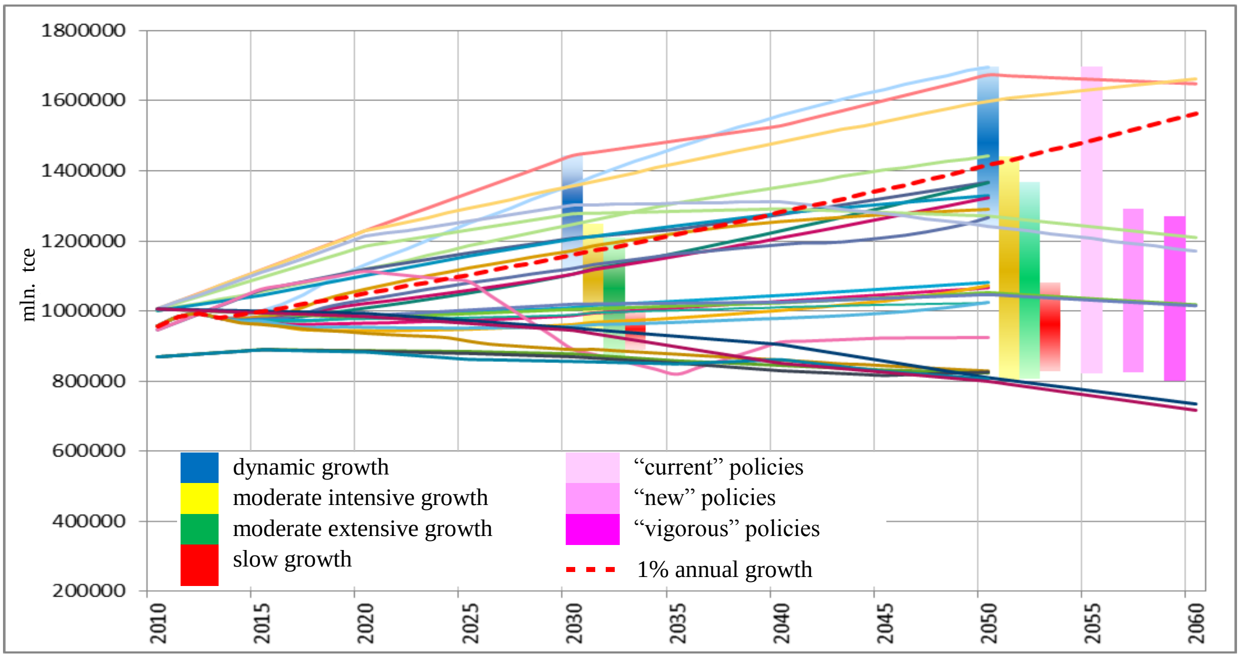
7 Fuel and energy production and consumption

Primary energy consumption growth will be slow: not more than 1-1.5% per year until 2030 and less than 1% per year thereafter (high agreement). In most scenarios with good chances for implementation primary energy consumption grows at not more than 1% per year in 2013-2050 to maximum 1,400 mln. tce in 2050. The growth may be faster to 2030, but then it slows down following the declining economic growth rate (Fig.7) and expanding emission control policy package.

Russia is on the edge of making a transition to a development pathway with practically constant primary energy consumption, which OECD countries have been following for nearly a decade and are expected to follow in the future (medium agreement). In scenarios with “new” and “vigorous” policies stabilization of, or even reduction in, primary energy consumption is possible (Fig. 11).

Faster development of low-carbon energy sources will result in fossil fuel use growing at an even lower rate, than primary energy consumption: it is very unlikely that average annual growth will exceed 0.7% (high agreement). In most scenarios fossil fuel (coal, petroleum products, and natural gas) use peaks in the 30-40’es and then goes down; this peak is the basis of the energy-related GHG emission peak (Fig. 12). The more aggressively “new” and “vigorous” GHG emission control policy packages are used, the lower the fossil fuel use peak. “Vigorous” policies make fossil fuel use absolutely decline.

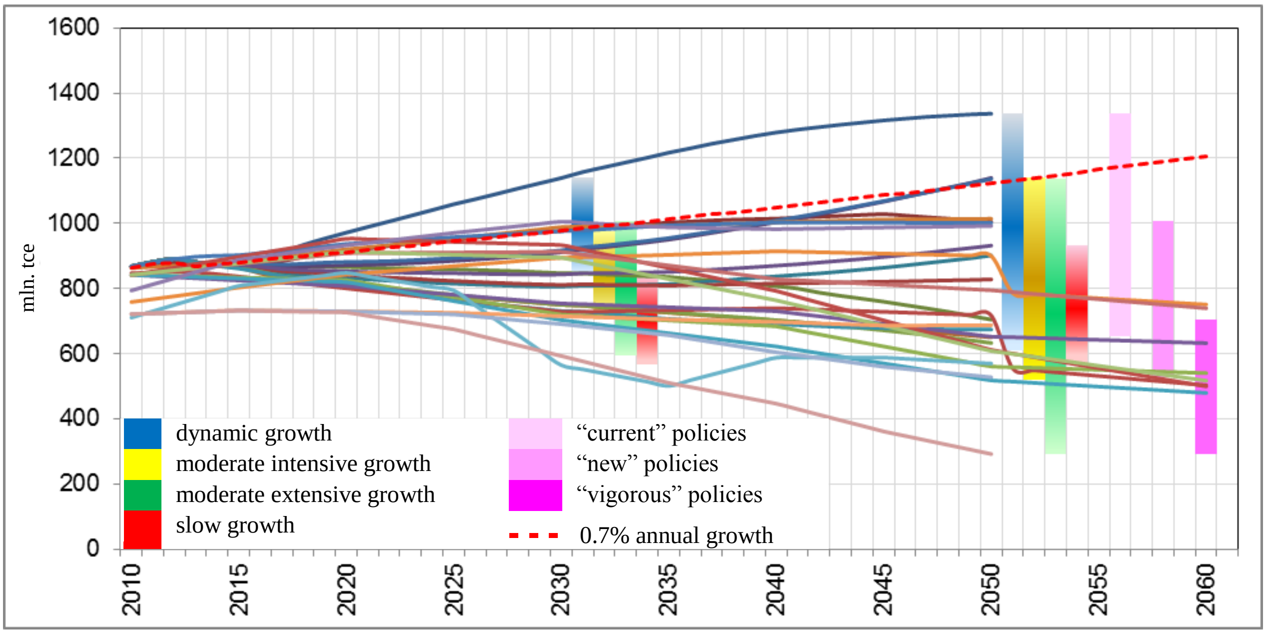
Figure 11. Primary energy consumption in individual scenarios



Note: In primary energy consumption estimations, electricity generation by hydro plants and from renewable sources was determined using the physical energy content method (1 kWh = 0.123/0.33 kgce).

Source: CENEf based on data obtained from project participants

Figure 12. Fossil fuel consumption in individual scenarios

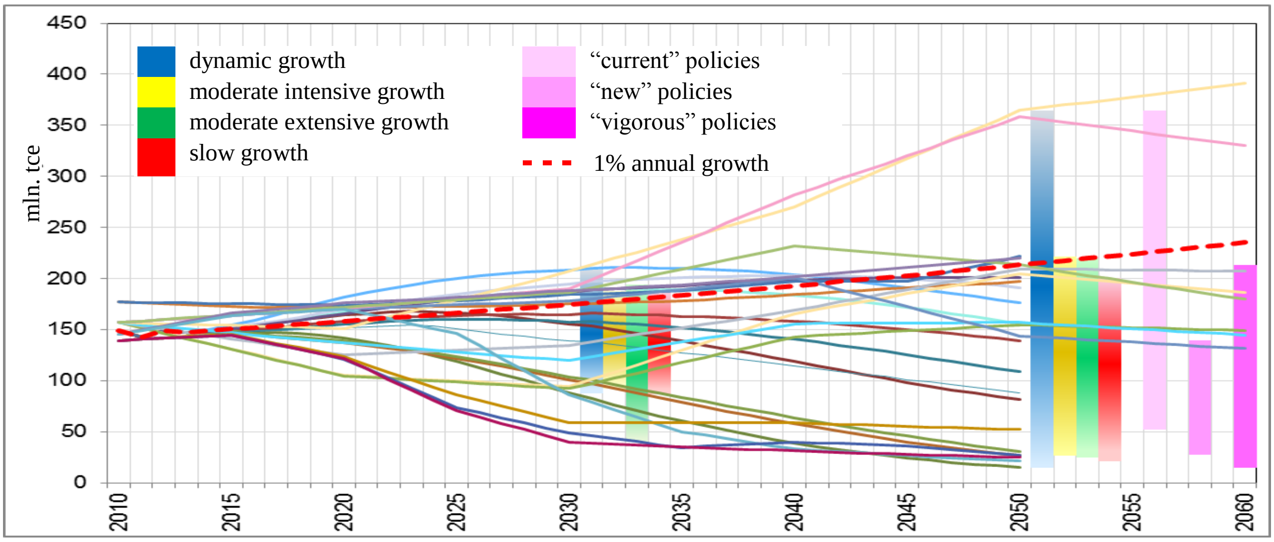


Note: Different initial levels of fossil fuel consumption are determined by imperfect energy statistics and by whether or not any verification was made to account for fuel use reduction in the 2009 recession year.

Source: CENEf based on data obtained from project participants

It is very likely that coal consumption will peak before 2040, and very unlikely that average annual domestic coal consumption growth rate will exceed 1% (high agreement). In scenarios with active deployment of "new" and "vigorous" policies coal consumption may drop 1.5-3-fold in relation to current level (Fig. 13).

Figure 13. Evolution of coal consumption in individual scenarios



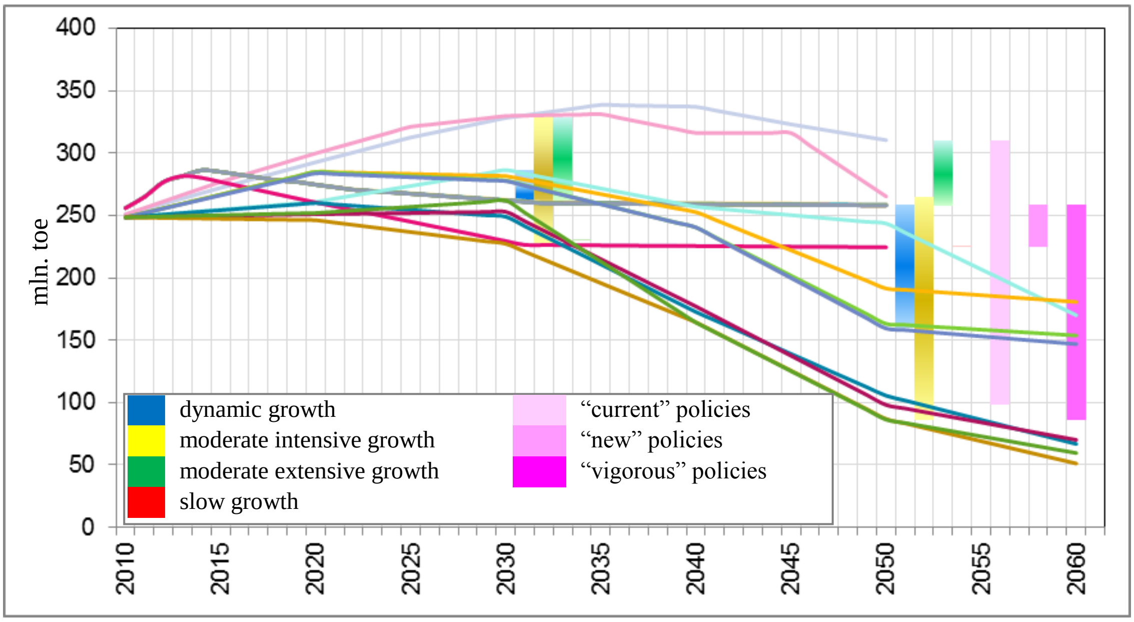
Source: CENEf based on data obtained from project participants

The most significant reduction in coal consumption may take place in 2020-2030, after the carbon price is introduced and makes coal energy uncompetitive. Only substantial carbon price increase to promote carbon capture and storage may sustain the role of coal in the fuel balance of the industrial and electricity sectors after 2030.

Most projections agree that Russia has reached, or is about to reach, oil production peak, and that oil production will start declining thereafter (high agreement). Evolution of domestic crude oil consumption is to a large degree driven by the refinery scale. To 2030, crude oil consumption grows or stabilizes, depending on the scenario, and then stabilizes or drops following the production decline (Fig. 14). Petroleum products consumption growth (primarily in the automobile transport), despite significant increase in natural gas use in the transport sector, leads to the reduction of petroleum products export potential.

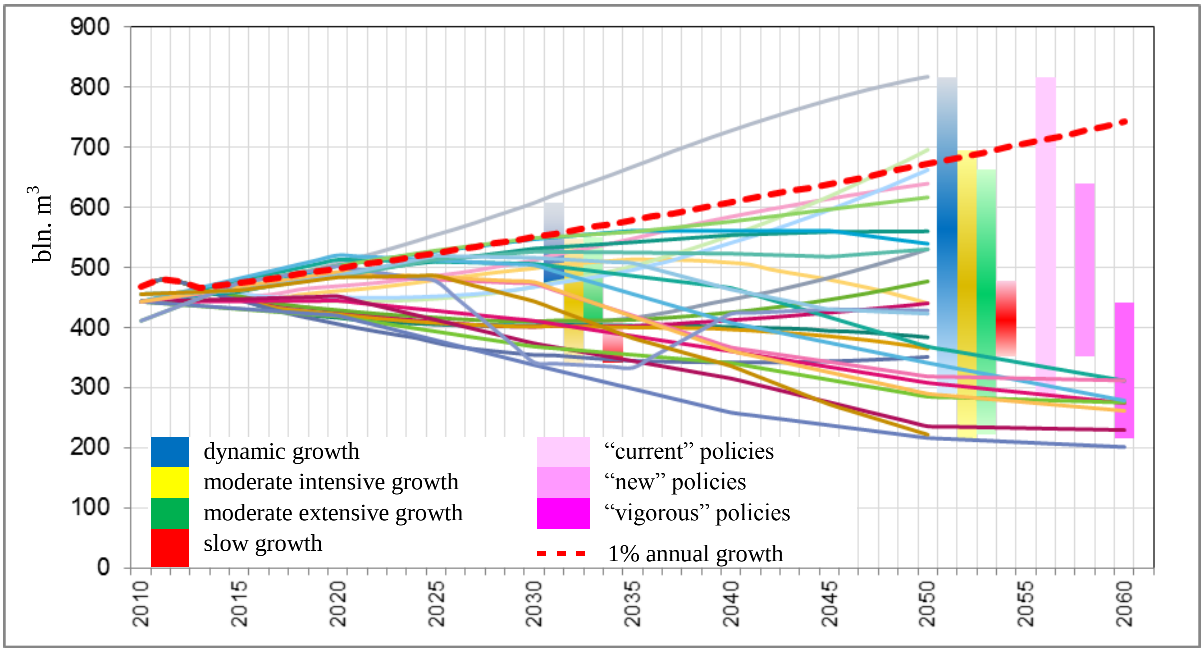
It is very unlikely that average annual growth in domestic natural gas consumption will exceed 1% (high agreement). In most scenarios, especially in those that imply "new" or "vigorous" emission control policies, natural gas consumption stabilizes or even declines (Fig. 15). The widest range of natural gas consumption estimates is observed in the "Dynamic Growth" group of scenarios: between 230 and 810 bln. m^3 in 2050. In "Moderate Growth" scenarios, the range is not so wide. The share of natural gas in the energy balance will remain high. It may go down to 40-50% in 2030 and to 30-45% in 2050 driven by "new" and "vigorous" policies-induced increase in the deployment of low-carbon technologies. Substantial energy efficiency opportunities, especially in electricity generation, are an important factor that determines relatively slow growth of natural gas consumption despite the growing gas-using equipment stock.

Figure 14. Evolution of crude oil consumption in individual scenarios



Source: CENEf based on data obtained from project participants

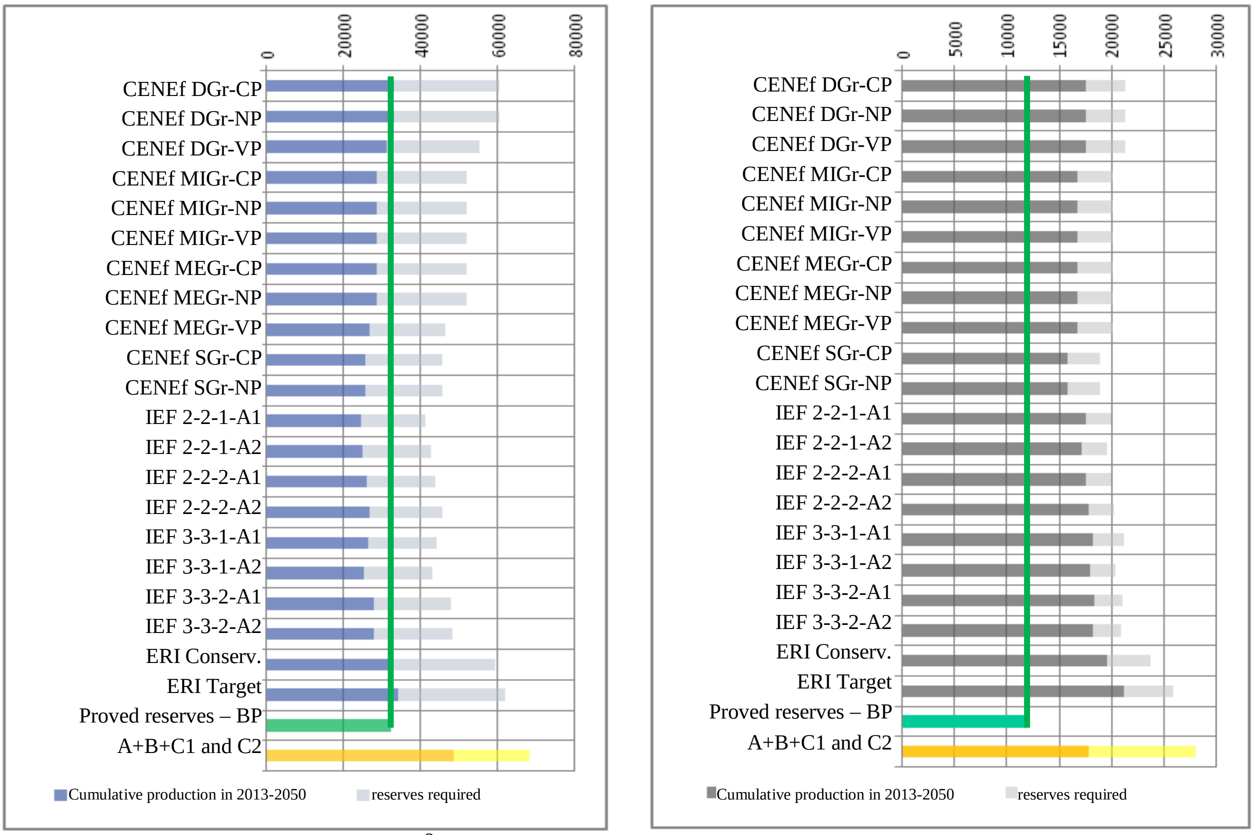
Figure 15. Evolution of natural gas consumption in individual scenarios



Source: CENEf based on data obtained from project participants

Most scenarios agree that natural gas reserves will be adequate to sustain anticipated production levels. However, this is not the case with oil reserves, and so high economic growth scenarios are not really likely (high agreement). Cumulative oil production over 2014-2050 in dynamic growth scenarios with high oil and gas production levels is not sufficiently supported with proved oil reserves (Fig. 16). There is less than 50% probability that oil reserves are sufficient to sustain oil production at the 2050 level for another 10 years. In other words, it is time to launch petroleum products substitution programmes in the transport sector. In many scenarios cumulative gas production is not sufficiently supported with proved gas reserves either. However, the probability of sustaining natural gas production levels to 2050 and beyond is much higher: about 85%.

Figure 16. Natural gas and oil: cumulative production and reserves



a) natural gas, bln. m^3 b) oil, mln. t

Reserves required – reserves sufficient to sustain cumulative production to 2050 and for 30 more years (for natural gas) or for 10 more years (for oil). Green vertical line cuts off required reserves not supported by proved reserves, according to BP.

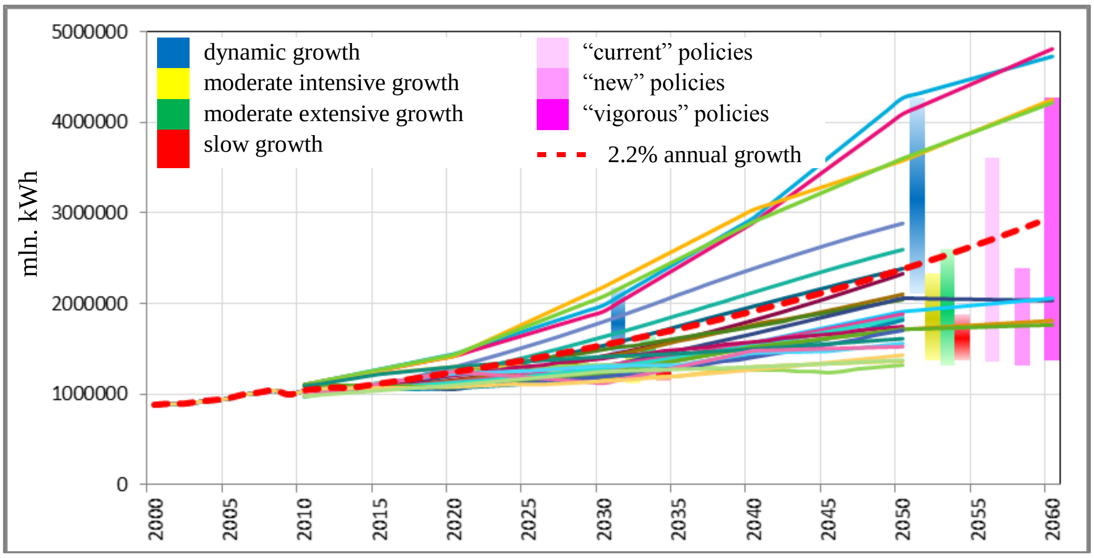
Source: CENEf based on data obtained from project participants

8 Electricity consumption and low-carbon generation technologies

In all scenarios to 2050, electricity generation and consumption will be growing faster, than primary energy consumption. It is very likely that average annual growth in electricity consumption in 2013-2050 will be 0.8-2.2%, and 2050 electricity generation may amount to 1,250-2,400 bln. kWh. The share of primary energy consumption for electricity generation shows sustainable growth in all scenarios, same as the share of electricity sector in the fossil fuel emission structure (high agreement). In 2020, electricity generation may amount to 1,050-1,250 bln. kWh (Fig. 17). Beyond 2020, as the major sectors are electrified, fuel gets more expensive, and "green" and nuclear electricity generation technologies develop, electricity consumption growth may somewhat accelerate. In more probable scenarios, 2050 electricity generation will not exceed 2,400 bln. kWh. The lowest projection estimates for 2050 are around 1,250 bln. kWh.

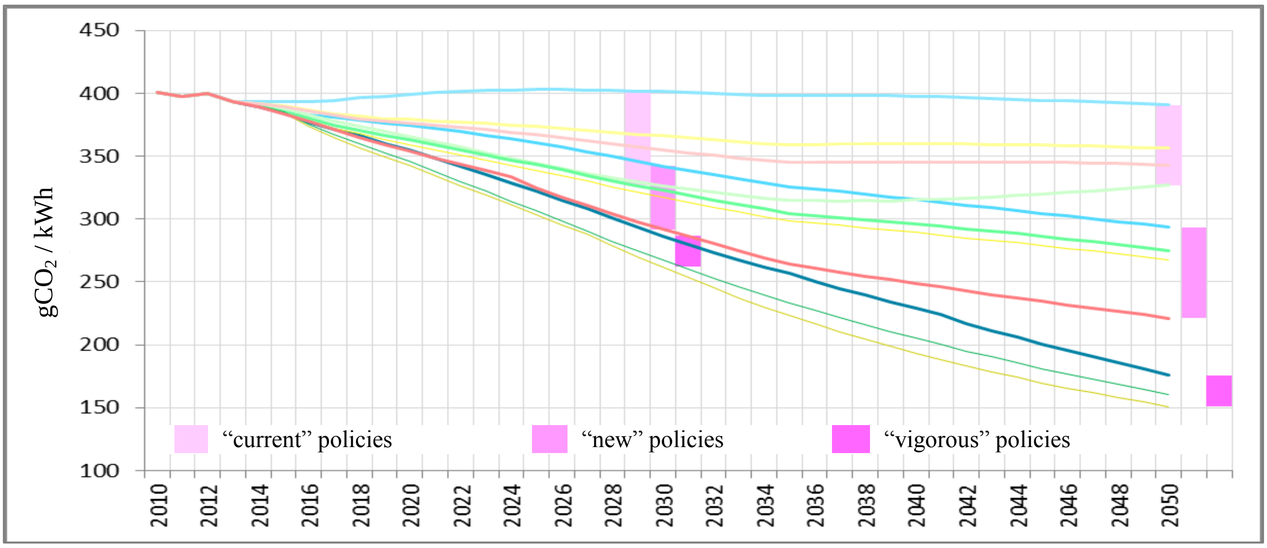
Given growing share of primary energy consumption for electricity generation, reduction of specific GHG emission per unit of electricity produced becomes the key factor in GHG emission control policies (high agreement). One possible method of attaining this goal is by improving the efficiency of electricity generation at coal- and gas-fired power plants (with subsequent development of carbon capture and storage technologies), but a key role is to be played by low-carbon electricity generation. With current policies alone specific emission will go down from 393 g CO_2/kWh in 2013 to 330-390 g CO_2/kWh in 2050 (Fig. 18). In scenarios with “new” policies specific emission goes down to 220-290 g CO_2/kWh in 2050, and in scenarios with “vigorous” policies to 150-175 g CO_2/kWh in 2050. Such reduction is only possible subject to a substantial increase in the share of low-carbon electricity generation.

Figure 17. Evolution of electricity generation in individual scenarios



Source: CENEf based on data obtained from project participants

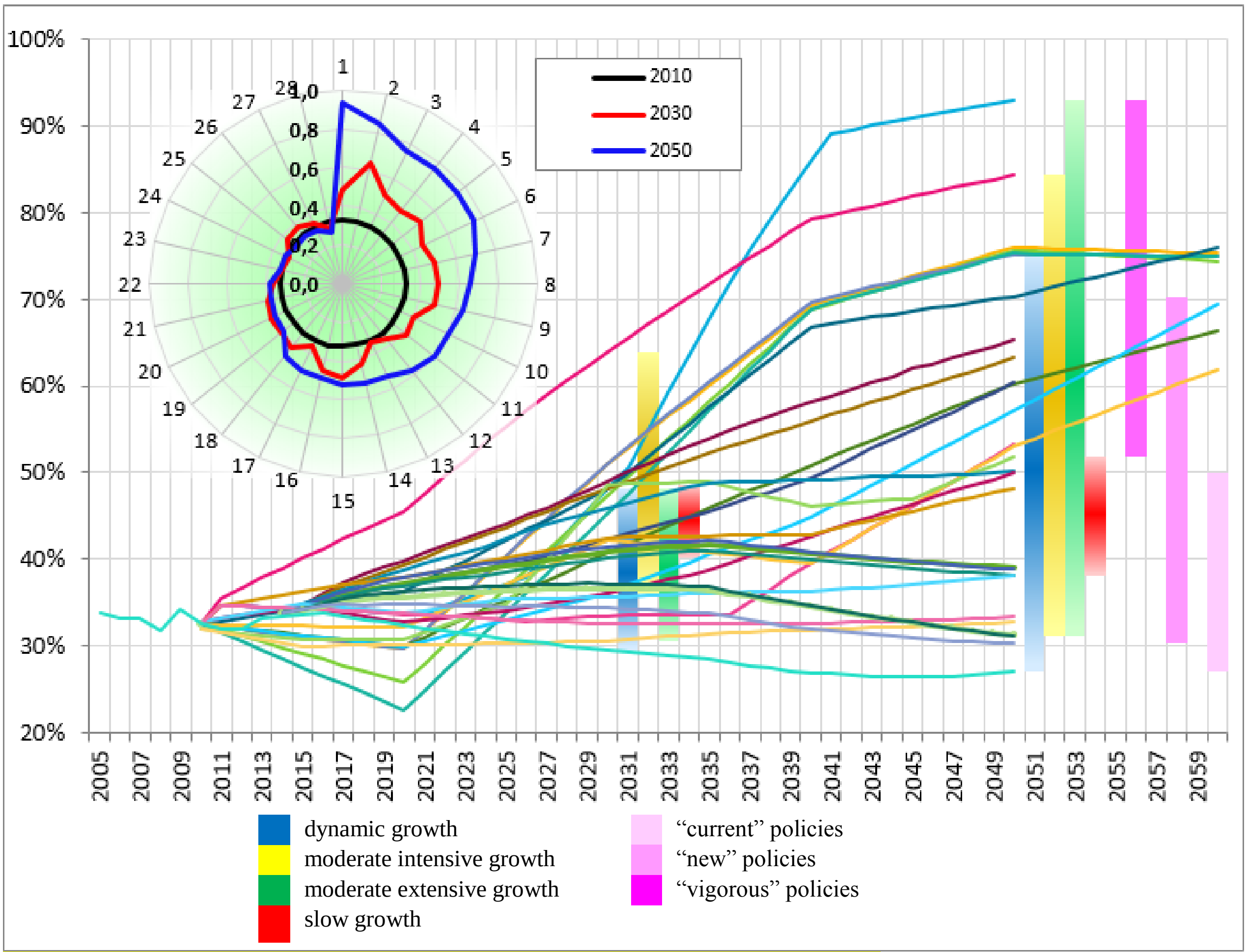
Figure 18. Evolution of CO_2 emission per 1 kWh of electricity production



Source: CENEf based on data obtained from project participants

The share of electricity generation from low-carbon sources (hydro, nuclear, and renewables) is a function of electricity consumption evolution, electricity export, and development of non-fossil fuel generation (high agreement). In 2000-2013, this share stayed at 33-35%. In the 2050 perspective, different evolution of the share of low-carbon electricity generation is observed in different scenarios. It is very likely, that in 2030 this share may fall in the range between 30 and 45%. In 2050, depending on the evolution of electricity demand and progress in nuclear and “green” generation, it may vary between 39 and 50% in “new” policies scenarios and grow up to 60-65% in “vigorous” policies scenarios (Fig. 19).

Figure 19. Evolution of the share of electricity generation from non-fossil fuels

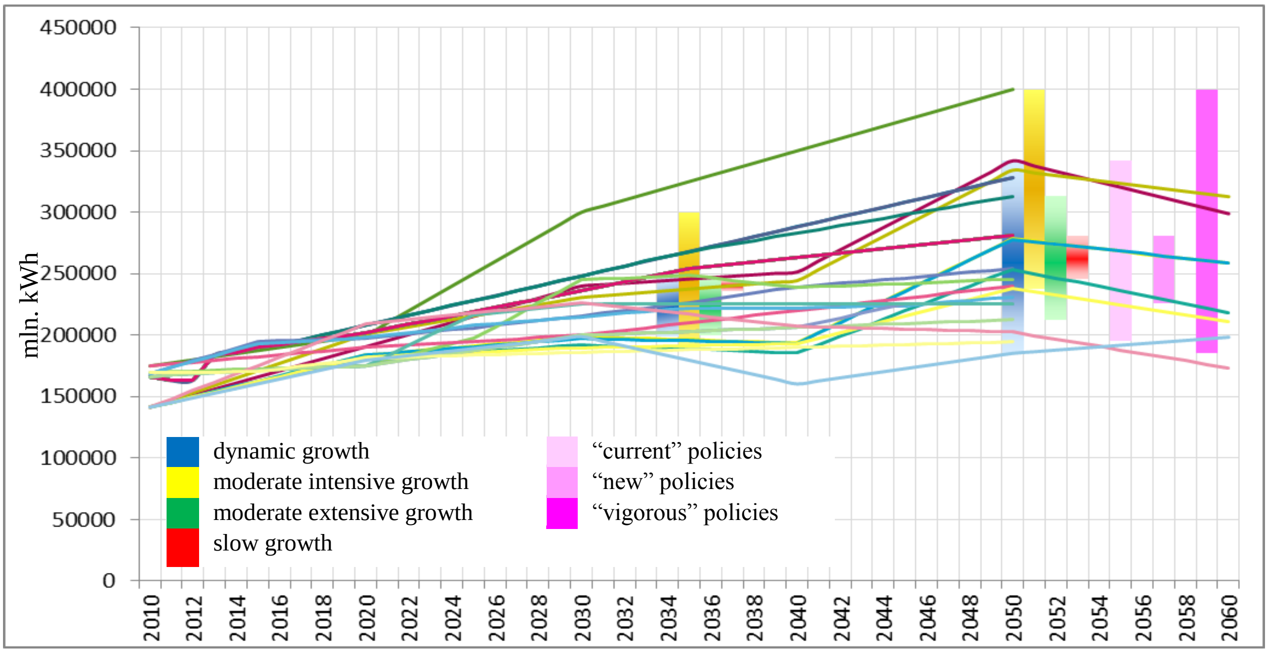


Source: CENEf based on data obtained from project participants

Evolution of electricity generation by hydropower plants is more certain, than by other low-carbon sources. Average annual growth in hydropower generation may amount to 1% in "current" policies scenarios and up to 1.5% in "vigorous" policies scenarios (high agreement). Hydropower generation may grow in different scenarios to 186-235 bln. kWh in 2030 and to 195-400 bln. kWh in 2050, the most likely range being 210-280 bln. kWh (Fig. 20).

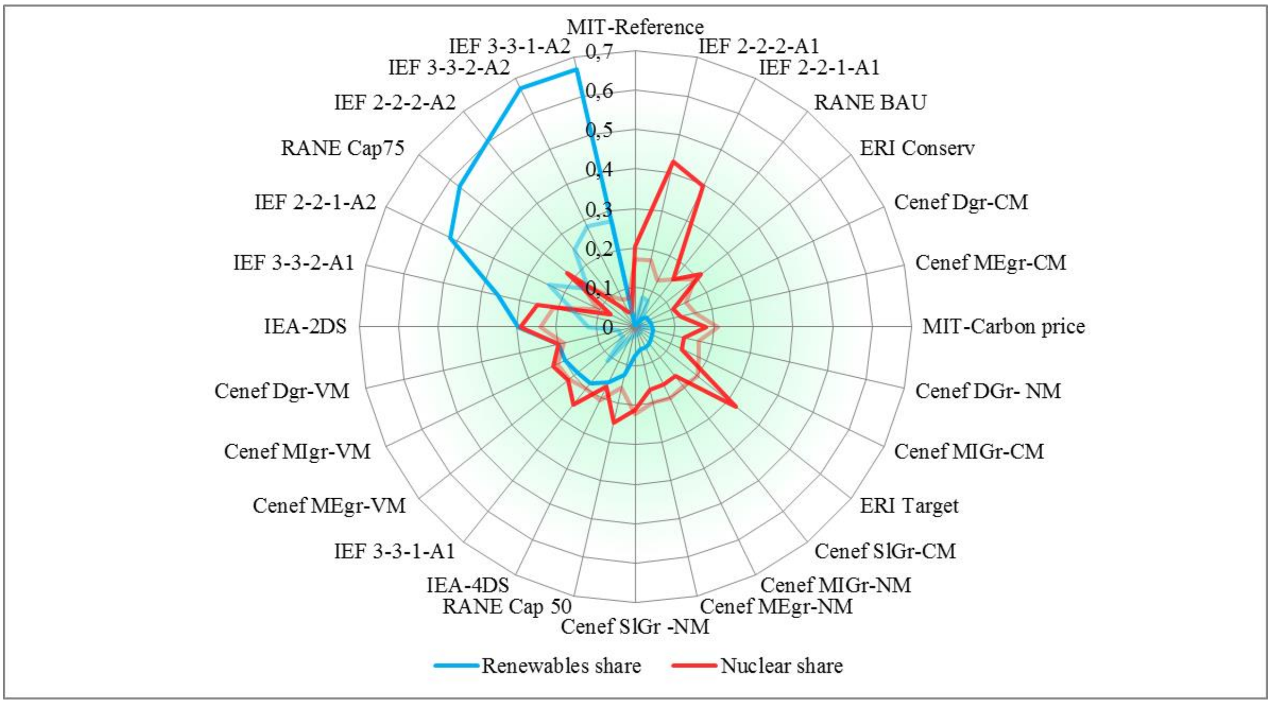
Perspectives for nuclear and renewable sources development are not so clear. Making a focus on one of these two technologies determines the basic bifurcation in low-carbon electricity generation development (high agreement). Substantially different projections of these technologies development (Fig. 21) are determined by different estimates of perspective capital intensity of new capacity commissioning; financial support provided by the government; and deployment of market mechanisms to promote the development of these technologies. Like in other countries, decision-making related to support for various types of low-carbon electricity generation in Russia does not build on economic or environmental, but rather on political (including defense) considerations.

Figure 20. Evolution of electricity generation by hydropower plants



Source: CENEf based on data obtained from project participants

Figure 21. Share of electricity generation by nuclear and renewable sources in individual scenarios in 2030 (light-blue or light-red line) and in 2050 (dark-blue or dark-red line)

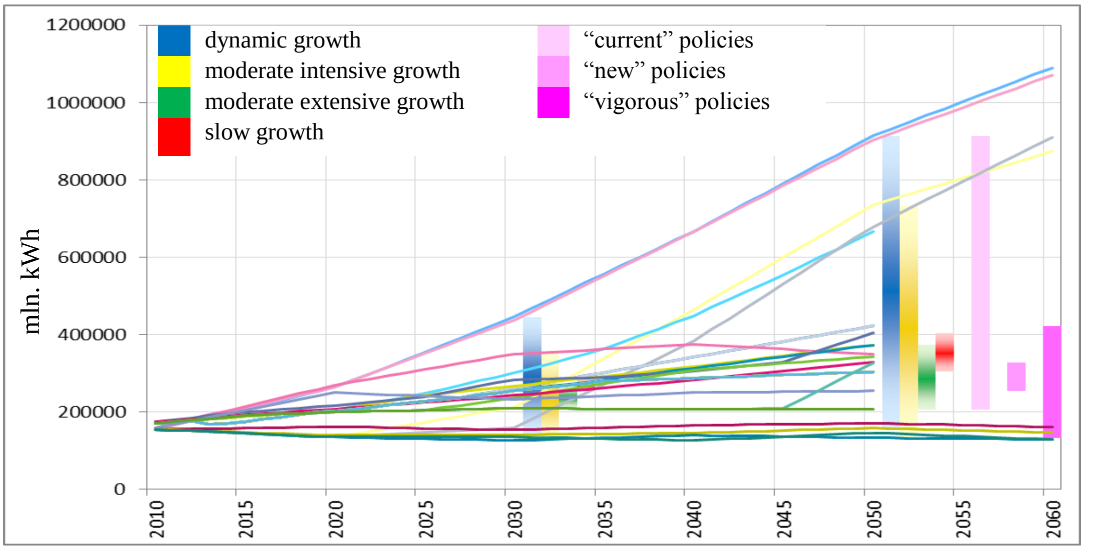


Source: CENEf based on data obtained from project participants

Nuclear energy development perspectives depend on whether or not it is possible to terminate the upward trend in specific construction costs of nuclear plants, to sustain large-scale federal funding for nuclear capacity construction, to address the problems related to fuel cycle and waste disposal, and on whether or not construction of new nuclear plants is acceptable for the society. The ambiguity of these factors determines a wide range of possible contributions of nuclear energy development to GHG emission reduction (high agreement). Most projections agree that electricity generation by nuclear plants may grow at 1-

2.5% on average in 2013-2050 (Fig. 22). This low growth rate correlates with the assumptions about fast growing nuclear capacity specific construction costs, moderate emission control commitments and, therefore, low carbon price. In this case electricity generation by nuclear plants will be around 300-400 bln. kWh in 2050. Otherwise (or assuming high economic growth rates) electricity generation by nuclear plants may increase to 650-930 bln. kWh, i.e. 4.5-5.5 times the 2013 level. One major restriction to further large-scale nuclear energy development is huge public funding demand for nuclear plants construction in view of possibly growing government budget deficit. Russian government spending in support of nuclear energy generation is more than 10 years' energy efficiency government spending.

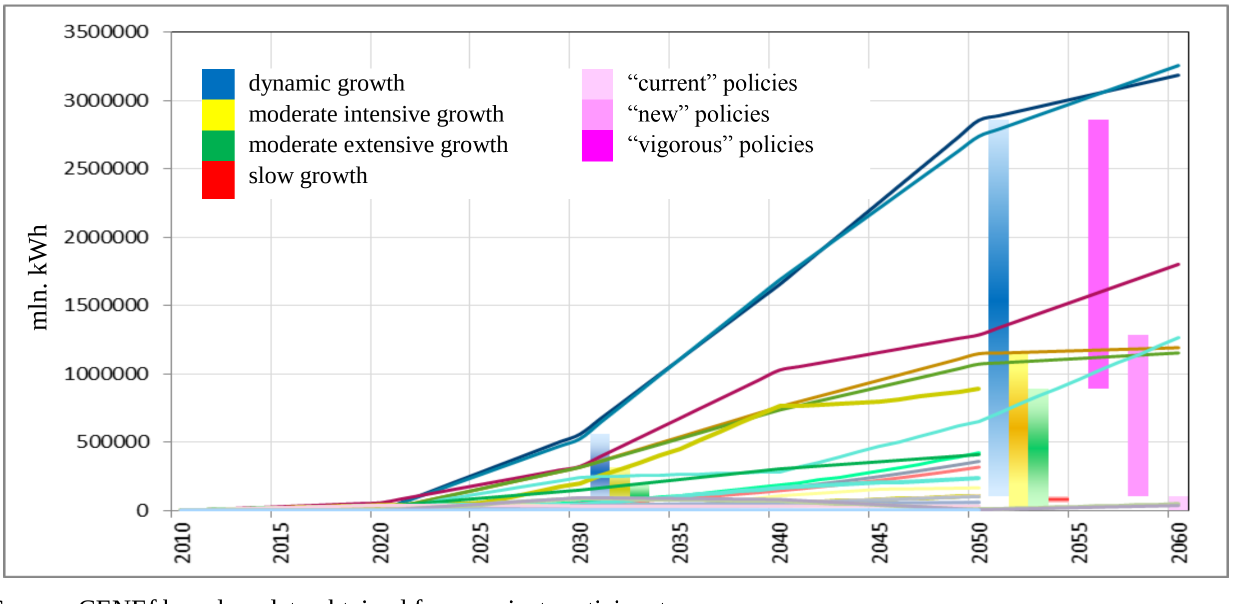
Figure 22. Evolution of electricity generation by nuclear plants



Source: CENEf based on data obtained from project participants

As of today, Russia is lagging behind the globe, as in 2012 more than half of the entire generation capacity commissioned in the world was from renewable sources. However, this may significantly change to 2050 (Fig. 23). **The degree of uncertainty related to the development of renewable energy generation is higher, than of other generation technologies** (high agreement).

Figure 23. Evolution of electricity generation from renewable energy sources

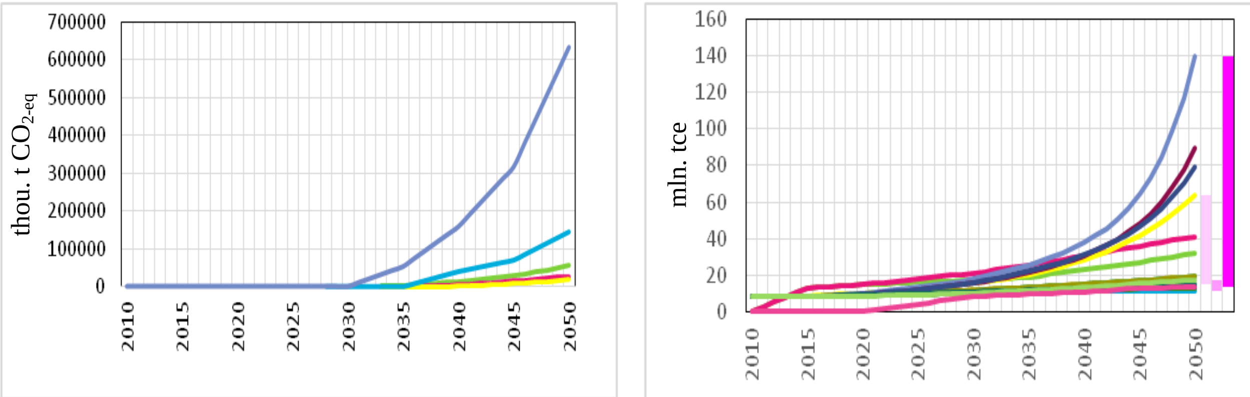


Source: CENEf based on data obtained from project participants

Government spending for the development of renewable energy generation is much smaller, than for nuclear plants. Only in 2013 Russia launched mechanisms to incentivize renewable energy development. Many renewable energy technologies have now come to technical and economic maturity. Previously high specific consumption per unit of installed capacity is fast declining and is currently 2-5 times lower, than in nuclear generation. This makes renewable sources an attractive option even with 2-3 times lower capacity load factor. Russian Government Decree No. 449 dated 28.05.2013 "On the mechanism to promote renewable energy sources to the wholesale electricity and capacity market" aims to increase electricity generation to around 30 bln. kWh by 2020. Growth in electricity generation from renewable sources in scenarios with additional measures amounts to 230-660 bln. kWh in 2050.

The scale of biomass fuel use and carbon capture and storage application grows subject to the implementation of "new" and "vigorous" policies (low agreement). Uncertainty associated with the scale of these technologies use is quite significant (Fig. 24).

Figure 24. CCS application and biomass fuel use



a) carbon capture and storage use

б) biomass fuel use

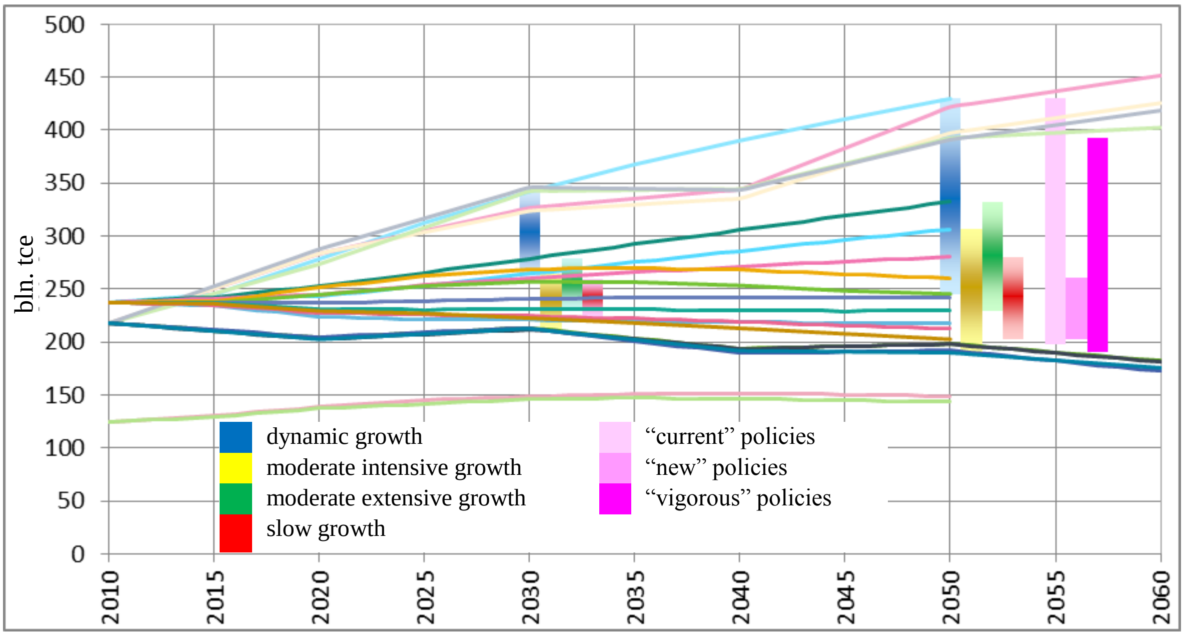
Source: CENEf based on data obtained from project participants

9 Evolution of energy consumption and GHG emissions in major sectors

It is impossible to attain significant reduction in GHG emission solely through measures implemented in the energy sector. It is important to substantially improve energy efficiency and deploy low-carbon technologies in all sectors (high agreement). Technical potential of GHG emission reduction equals 1,100 mln. t $CO_{2\text{-eq.}}$, or 57% of the 2011 emission. In end-use sectors, the potential can be implemented directly (by reducing fuel combustion) and indirectly (by reducing demand for electricity and heat generated by fuel-using sources). There are large direct and indirect emission reduction potentials in residential and public buildings, industrial and transport sectors.

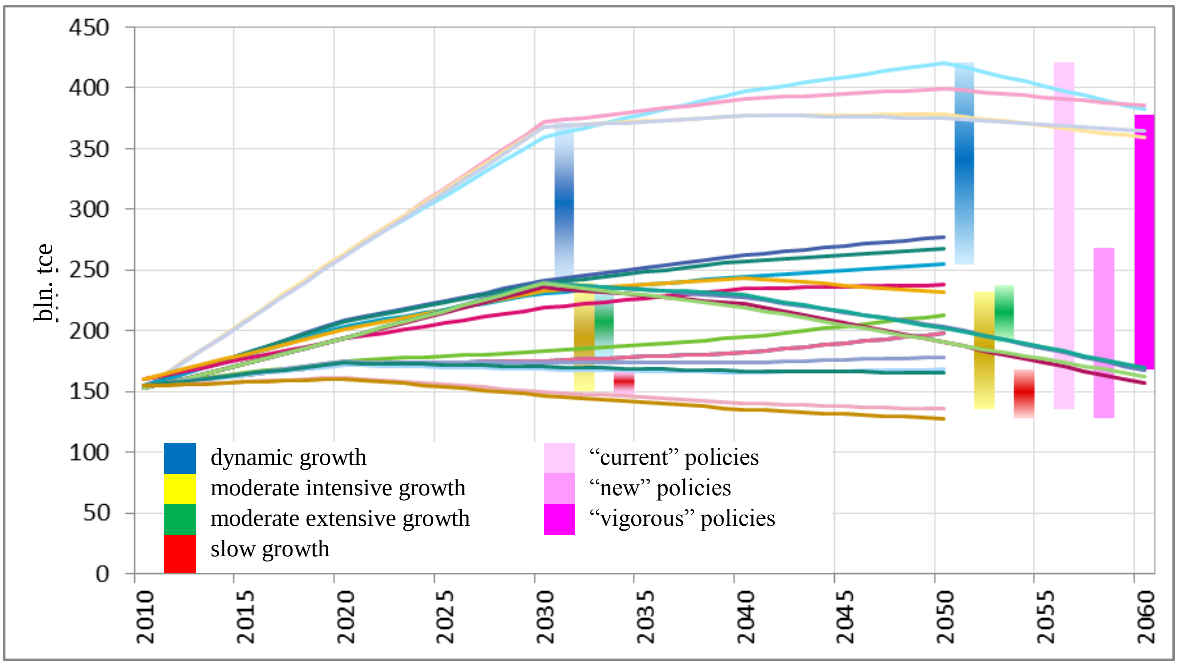
The research groups cannot come to an agreement about the impacts provided by emission control policies on energy consumption by individual sectors depending on how aggressive these policies are (low agreement). Energy consumption in the industrial and transport sectors is obviously driven by the evolution of GDP; however, it is impossible to trace the dependence (if any) on policy packages either in industry (Fig. 25), or in transport (Fig. 26). Further research is required in individual sectors to verify the effectiveness of various emission control policies.

Figure 25. Evolution of industrial energy consumption in individual scenarios



Source: CENEf based on data obtained from project participants

Figure 26. Evolution of energy consumption by transport in individual scenarios

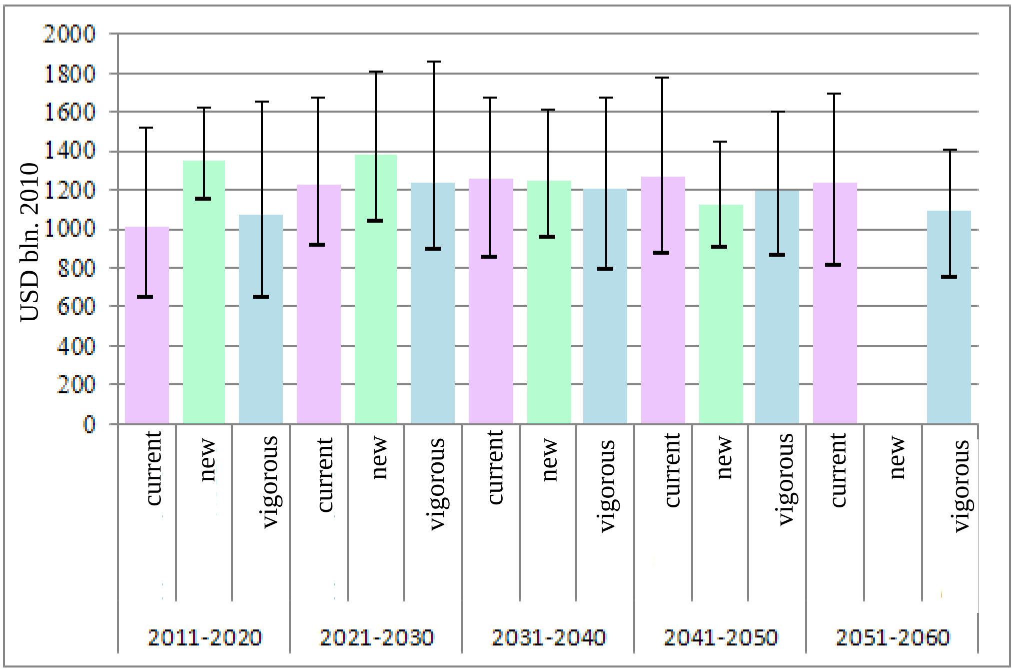


Source: CENEf based on data obtained from project participants

10 Emission reduction costs

Investments in low-carbon technologies and energy efficiency improvements do not provide any significant investment load on the economy (medium agreement). Investment demand is determined by both economic growth rates and the aggressiveness of "new" and "vigorous" policies. Not all the research groups provide data on investments. Projections made by three research groups do not provide sufficient grounds to believe that there is any substantial additional investment demand in "new" or "vigorous" policies scenarios (Fig. 27). The reason for this is that investments in low-carbon technologies and energy efficiency improvements allow for savings on investments in very capital intense oil&gas sector and fossil fuel energy generation. On average, annual investments in energy supply required for economic growth (energy efficiency improvements included) equal USD 100-140 bln. The share of investments in the energy sector both in GDP and in total investments will be gradually declining.

Figure 27. Investments in individual scenarios grouped by policy packages



Columns show average investment demand in families of scenarios. Lines show intervals between the minimal and the maximal values. Lavender – current policies; green – new policies; blue – vigorous policies. Data on capital investments are provided in papers by IEF, ERI, and CENEf.

Source: CENEf based on data obtained from project participants

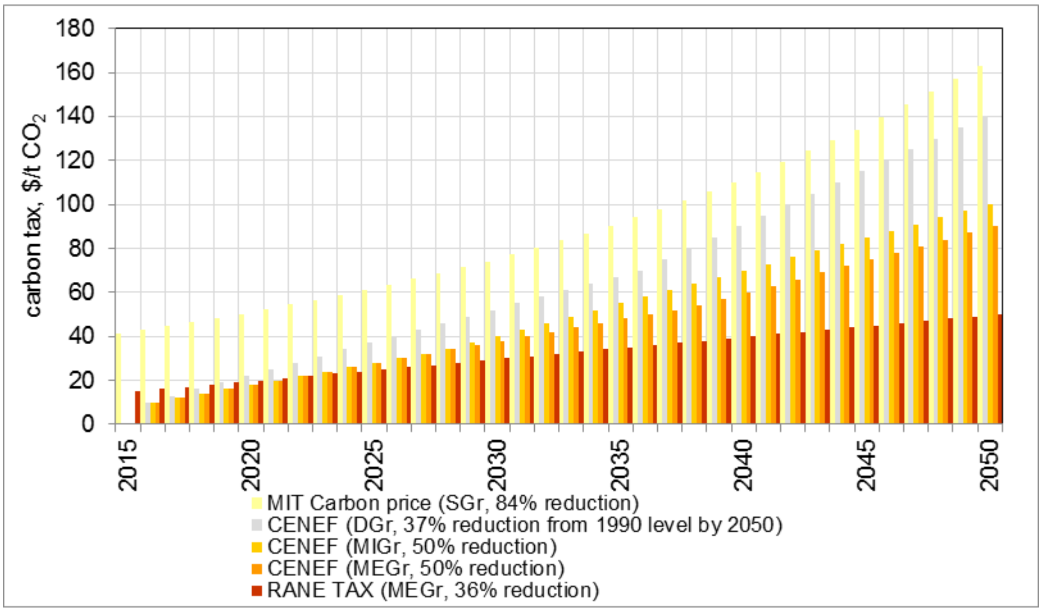
The available estimates do not provide any grounds to claim that investments in low-carbon and energy efficiency technologies will be distracting resources from, and hamper, economic growth (medium agreement). Additional total discounted investments in low-carbon technologies and energy efficiency improvements do not exceed 0.8% of discounted GDP in 2014-2050. This figure is similar to the estimated share of capital investments required to control emission in 2030-2050 in industrialized countries (not more than 1% of GDP)[9]. Given limited potential of Russian hydrocarbons export, discounted savings on capital investments in the oil&gas sector may exceed 0.2-0.3% of discounted GDP. Return on invested capital in the oil and gas production will sustainably decline, at least 1.5-fold. In the 30-40'es, despite huge capital investments in the oil&gas sector, oil production volumes will not be sustained. Specific

[9] Clarke, Jiang et al. (2014).

capital investments per unit of energy savings are 2-3 times lower, than per unit of low-carbon energy generation, and manifold lower, than specific capital investments in the development of new hydrocarbons deposits. Additional capital investments in low-carbon technologies are not to be regarded as loss of economic growth, because these investments offer much higher return on invested capital, than investments in the oil&gas sector development.

If GHG emission is to be sustained at a low level and low-carbon technologies are to be made more economically attractive, it is important to introduce carbon pricing in the form of carbon tax levied on fuel or as carbon price in the GHG emission trading system (high agreement). Five scenarios imply introduction of a carbon price effective 2015-2016 with gradual subsequent growth to 2050. The higher economic growth rates and/or the more radical GHG emission control commitments Russia makes, the higher the carbon price (Fig. 28).

Figure 28. Evolution of carbon price in individual scenarios



Source: CENEf based on data obtained from project participants

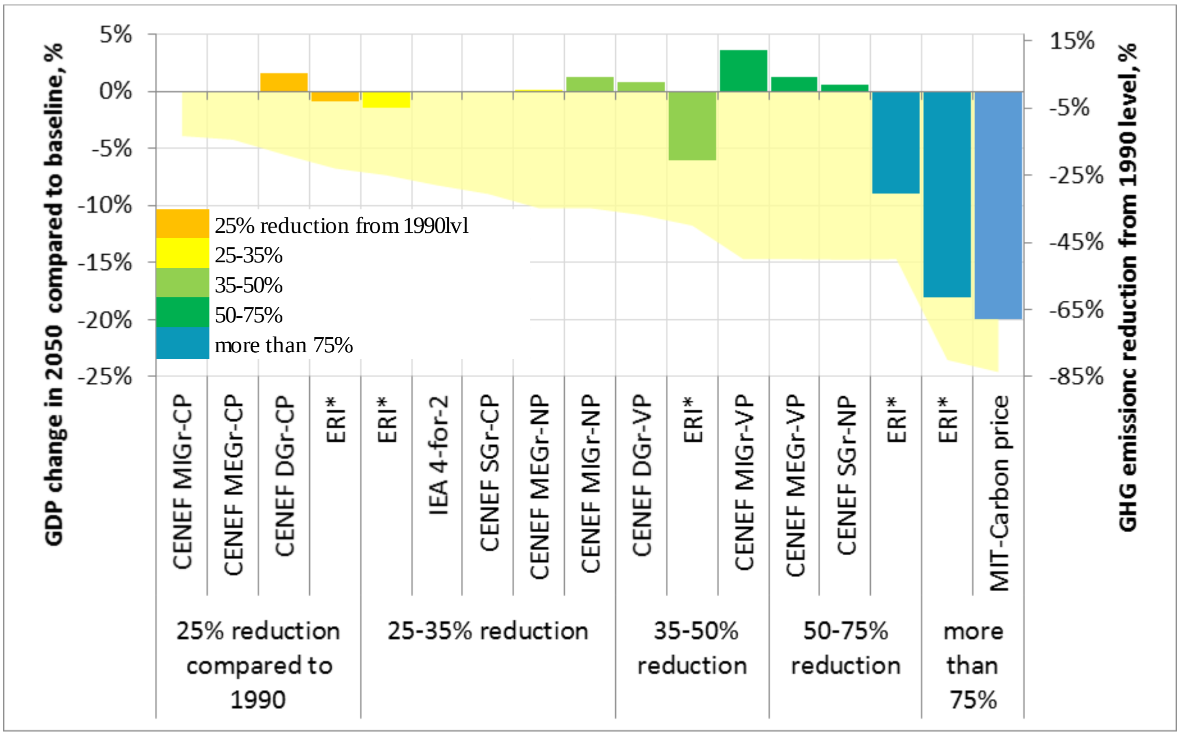
With moderate economic growth, it is possible to sustain GHG emission at maximum 50% of the 1990 level through carbon price increase to or above 100 USD/t $CO_{2\text{-eq.}}$ by 2050. For more profound emission reductions the 2050 carbon price is to exceed 150 USD/t $CO_{2\text{-eq.}}$ (medium agreement). Since decision-making related to low-carbon technologies development is frequently determined by non-economic considerations, it is difficult to accurately assess the impacts provided by carbon price growth. According to CENEf and RANEPA, carbon price increase by every 10 USD/t $CO_{2\text{-eq.}}$ in 2050 leads to emission reduction by 16-25 mln. t $CO_{2\text{-eq.}}$ Carbon price estimates for Russia are comparable with global estimates, which are 20-100 USD/t $CO_{2\text{-eq.}}$ in 2030 and 40-200 USD/t $CO_{2\text{-eq.}}$.in 2050[10]. This price is lower in industrialized countries and higher in developing economies. For example, if Chinese emission is to be reduced by 68% of the 2005 level, the carbon price needs to be 375 USD/t $CO_{2\text{-eq}}$. In India, 2050 emission growth may be limited to 50% of the 2005 level through 144-180 USD/t $CO_{2\text{-eq.}}$ carbon price[11]. Gradual implementation of carbon price leads to end-use energy price growth, which is mitigated by substantial energy efficiency improvement achieved by the time when this price growth becomes noticeable. As a result, energy affordability is practically not affected. In scenarios that do not imply any “new” or “vigorous” policies, fast growth of domestic natural gas demand results in reduced export potential. This problem may be addressed through

[10] Clarke, Jiang et al., 2014.
[11] Namazu et al., 2013.

domestic gas price increase, which, in turn, leads to a substantially higher growth in electricity tariffs, than100-150 USD/t $CO_{2\text{-eq.}}$ carbon price. Depending on the collection scheme, carbon tax could bring 50-100 trillion rubles (in current prices) over 2016-2050, which is comparable with the investments in low-carbon technologies development and energy efficiency improvements. The question is, who will benefit from additional revenues: natural gas producers (from domestic gas price growth) or the government (from the introduction of carbon tax).

Measures aiming to sustain GHG emissions at 25-30% below the 1990 level do not lead to any GDP loss (Fig. 29). Assessments of macroeconomic effects of profound emissions reduction (to 50% of the 1990 level) vary in a wide range: from +4% to –9% of GDP. GDP loss resulting from emission reduction by 80% of the 1990 level may exceed 10% (medium agreement, Fig. 29 and 30). Estimates made by Working Group III in the 5th Assessment Report of the IPCC are also close. For GHG emissions reduction by 40-70% in 2050 and to zero in 2100 they vary between +1 and -4% in 2030 (-1.7% average); between -2 and -6% in 2050 (-3.4% average), and between -3 and -11% in 2100 (-4.8% average)[12]. This is equivalent to 0.06% loss in the average annual growth, which is around 2%.

Figure 29. GDP change as a function of GHGs emission reduction level (compared to baseline)



Light-yellow zone shows reduction in emission by scenarios (right-hand scale).

* Research accomplished by ERI does not include any scenarios involving emission control policies. However, this research group has come up with an assumption about GDP loss per each percent of CO2 emission reduction beyond a certain limit (Veselov et al., 2010; Malakhov, 2010). This ratio was used to estimate GDP loss resulting from the emission reduction by 25%, 30%, 50%, and 80% of the 1990 level.

Source: CENEf based on data obtained from project participants.

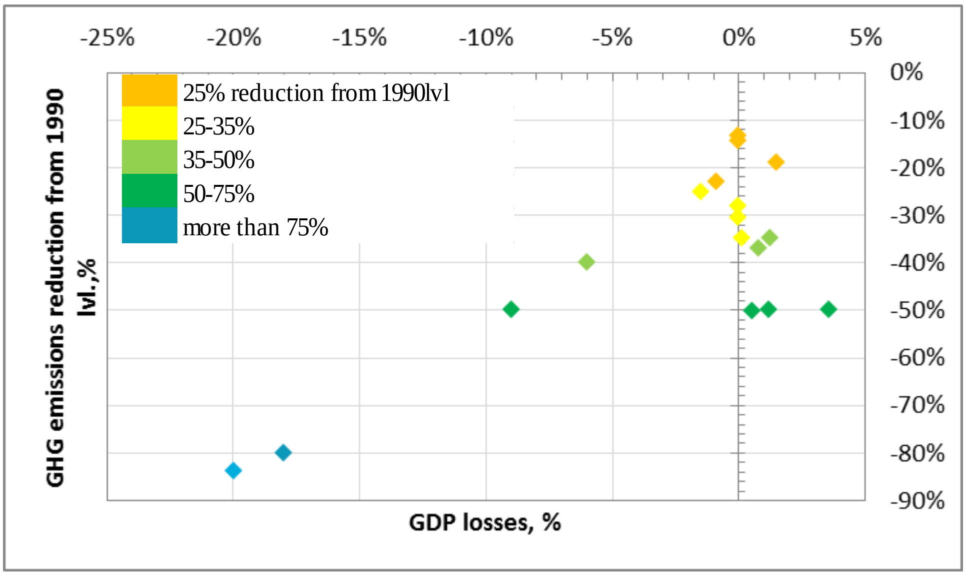
This cost of combating a well-known risk is much smaller, than military spending for opposing a far more uncertain risk; and military spending equals nearly 2.5% of the global GDP. The uncertainty of global GDP growth to 2100 varies between 300% and 900%. In other words,

[12] Climate Change 2014. Mitigation of climate change. Summary for policy makers. Working Group III contribution to the Fifth Assessment Report of the IPCC. Accepted by the 39th Sessions of IPCC. Berlin, Germany.

impacts on the economic growth provided by other factors are one or two orders of magnitude more significant, than possible effects of emission control policies. And if account is taken of benefits associated with climate change slowdown and of the side-effects (improved environment, reduced dependence on energy imports, less frequent accidents, etc.), then obviously, global transition to low-carbon economy is not real costly. Recent estimates of the EU emission reduction by 40% in 2030 equal 0.1-0.3% of GDP, and by 50% - 0.6% of GDP. These measures allow it to reduce energy imports by 0.4% of GDP[13]. The overall effect is not that large. These estimates well correlate with the results obtained for Russia.

Not in all models GDP is adjusted for impacts provided by emission control policies. Macroeconomic effects of emission control policies need to be estimated more accurately. Estimates of potential GDP loss related to the implementation of measures aiming to sustain GHG emission at 40% below the 1990 level are not any higher, than estimated potential damage to Russia's economy incurred by climate change. The loss may amount to 2% of GDP on average, and in some vast enough territories to 5% of GDP[14].

Figure 30. Relationship between GDP change (compared to baseline) and the level of GHGs emission reduction



Source: CENEf based on data obtained from project participants

Inability to improve the efficiency of economy and to reduce production costs is a much more important barrier to Russia's economic growth. In this context potential positive or negative impacts of GHG emission control policies offer way smaller effects.

[13] Enerdata. EU energy and climate policy 2030 targets: how and how much? 25.03.2014.
[14] Katsov and Porfiriev, 2011.

11 What GHG emission control commitments can Russia make to 2030 and to 2050?

Most likely are moderate growth scenarios that imply "new" and "vigorous" policy packages or slow growth scenarios with "new" policies; these development pathways correlate with 2050 GHG emission equal to 1,330-2,330 mln. t $CO_{2\text{-eq.}}$, i.e. 50-85% of the 1990 level (high agreement). Scenario likelihood is assessed using the following criteria: sufficiency of resource base to sustain oil and gas production levels; energy affordability for consumers; possible change in Russia's position in global energy markets. "Dynamic growth" scenarios turned out virtually unlikely. Emission evolution assessments in these scenarios are purely illustrative and have no practical importance. Current estimates (that need substantial verification) show, that scenarios which imply profound – 75-80% or more – emission reduction by 2050 are fraught with large GDP loss. Such substantial emission reduction is possible through large-scale deployment of CCS technology, while the parameters of this technology are not clear enough.[15]

In the 2050 perspective, Russia can make either "soft" or "tough" emission control commitments. "Soft" commitments include those that correlate with the upper range value of the most probable emission evolution with mostly energy efficiency measures, without introducing carbon tax or emission trading and without any significant support provided for the development of low-carbon technologies. "Tough" commitments include those that correlate with the lower boundary of the probable range. "Tough" commitments are determined by the dedication and ability to launch "new" and "vigorous" policy packages. Each commitment can be formulated as the level of emission in the last year of the commitment period, or as average annual emission over the commitment period (similarly to the commitments under the Kyoto Protocol).

"Soft" long-term commitments can be formulated as follows:

- **cap the 2050 emission at maximum 75% of the 1990 level; or**
- **cap average annual emission in 2021-2050 at maximum 75% of the 1990 level.**

These requirements are with guarantee met through successful implementation of both "current" and "new" policy packages. The risk of incompliance is solely related to the rejection of "new" policies or to unbelievably fast economic growth. Depending on the emission profile, in some scenarios the first commitment, in others the second commitment is more difficult to comply with. However, generally, the two formulations are pretty equivalent. Economic development cycles may somewhat "knock up" emission in this or that year, including in 2050, so the second formulation offers more flexibility in commitment compliance.

"Tough" long-term commitments can be formulated as follows:

- **cap the 2050 emission at maximum 50% of the 1990 level; or**
- **cap average annual emission in 2021-2050 at no more than 67% of the 1990 level.**

These requirements can only be met through successfully implemented "new" and "vigorous" emission control policy packages, including carbon tax, which is to grow up to 40-100 USD/t $CO_{2\text{-eq}}$. by 2050. In "Slow Growth" scenarios, even with limited development of low-carbon

[15] T. Bruckner, I. Bashmakov, Y. Mulugetta et al.. Energy Systems. Chapter 7. Climate Change 2014. Mitigation of climate change. Summary for policy makers. Working Group III contribution to the Fifth Assessment Report of the IPCC. http://www.ipcc.ch/

electricity-, heat- and liquid fuel production technologies, 50% reduction in emission is achieved through successful “new” policies.

Formulation of short-term commitments to 2021-2025 or to 2021-2030 in the “soft” option may be borrowed from Presidential Decree No. 752 “On greenhouse gas emissions reduction” as maintaining the 2020 energy-related anthropogenic emission at 25% below the 1990 level (preferably relating to average annual emission over the commitment period). It is very likely that meeting this commitment will require both “current” and “new” policies; and this commitment will be met with guarantee through a large-scale application in this period of “vigorous” low-carbon development policies. In the “tough” option, the target may be formulated as follows: cap average annual emission in 2021-2030 at maximum 70% of the 1990 level.

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Section II

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Development of agreed scenario assumptions related to Russia's low-carbon social and economic development to mid-XXI century

1 Why is it important to agree upon social and economic development trajectories?

Long-term projections are essential to reveal serious problems that can be faced by the country in the future and to make preventive decisions to mitigate, if not address, these problems. Most economists, irrespective of their visions of Russia's future economic development, agree that it is important to support the development of scenarios, strategies, and programmes (S. Glaziev and G. Fetisov, 2013; E. Gurvich, 2013, V. Ivanter and M. Ksenofonov, 2012; E. Yasin, 2011). A comprehensive picture of the problems and a decision menu are a reliable basis for future decision-making, allowing it to avoid subjective assessments, enlarge the acceptable solution space, better forecast the consequences, and thus improve the decision-making process. The idea is not so much to have a consensus between various projection groups, but rather a variety of opinions underpinned by strong arguments. This would help avoid a situation when the government and economic agents receive unbalanced or erroneous information, and so development goals and objectives are inflated (A. Blokhin, 2012).

The need to change the economic development model; problems determined by a tough demographic situation; the inertia of economic systems that requires both early decision-making and assessing the long-term consequences thereof, are all factors that lead to the increasing number of projections of Russia's economic development as a whole and of its economic subsystems not only to 2030-2040 (Gurvich, 2013; RF Ministry of Economy, 2013; Uzyakov and Shirov, 2012; Makarov, Mitrova, 2013), but to 2050 and beyond (Bashmakov, 2011; Yasin, 2011; OECD, 2012; Kudrin and Gurvich, 2012; Vlasov et al., 2013; Sinyak, 2011; etc.).

The problem is now to avoid short-sightedness in decision-making. However, the vision of the future often builds on the analysis of the past and the present, and therefore it often happens that not so much the future is projected on the present, as the past is projected on the future. As part of the future becomes the past, the vision of the future is verified: some development trajectories that used to seem feasible turn out to be blocked, while others, that seemed either impossible or undesirable, become more probable. This means that the projections are to be (a) updated on a regular basis in order to allow for timely corrective action; and (b) compared in order to obtain a more comprehensive vision of the problem and possible solution space.

Comparability of projections depends on the assumptions, models, objectives, etc. After all, good decision-making is dependent on the possibility to compare the results of projections and to assess the degree of agreement in the expert community on the essential parameters of sustainable development and GHG emission control. Therefore, it is important that at least part of calculations be based on coordinated assumptions and that there be a possibility to estimate the degree of expert agreement which is determined by different concepts, analysis instruments, and scenario assumptions.

2 Approaches to the development of agreed trajectories of social and economic development

Development of GHG emission scenarios to 2050 and beyond should build on social and economic storylines, and the future is not unambiguous. These storylines are described in scenarios that include qualitative development parameters (concepts and drivers of future development: narratives, storylines) and a set of quantitative input variables, as well as other model parameters (ratios, equations, etc.). It is important that these storylines comprise all social and economic development options with minimal overlapping, yet the set of these concepts should be limited and representative. Then individual scenarios or families of scenarios allow for efficient structuring of this "option space". Combinations of input variables exponentially grow in number depending on both the number of variables and the number of trajectories for each variable. Formulating the storylines as mutually agreed combinations helps substantially reduce the number of scenarios while not affecting the comprehensive picture of the future.

Consumers of such storylines belong to one of the two groups: (1) decision-makers and experts in other climate issues (understanding of the assumptions under the projection results); and (2) the expert community involved in the assessment of the emission dynamics (using the storylines in their calculations) (Kriegler et al., 2012). Both for the first and the second group it is important that the scenario projections be comparable, so the scenarios should be (Van Vuuren et al., 2012; Kriegler et al., 2012; Bashmakov, 1987):

- mutually agreeable;
- comprising all social and economic development options;
- providing a brief, yet comprehensive description of the parameters and diversity of “concepts of the future”;
- limited in number and substantially different;
- comparable, obtained by individual expert groups with similar assumptions;
- flexible, structuring the analysis, yet not limiting the flexibility of the research groups, allowing it to develop additional scenarios and to assess the sensitivity of the results to additional assumptions or to modified assumptions.

There are a number of possibilities to address the problem of obtaining mutually agreed scenarios. One possible scheme was proposed by I. Bashmakov in 1987 as a “seven matrixes method”. The idea of the method is to follow the analysis loop: formulating assumptions related to the natural, technology, economic, social, and political trends → development of a matrix of scenarios (the first matrix) → calculations using the basic macroeconomic variables model (the second matrix) → then, by one branch, analysis of change in the economic status of major social groups (the third matrix) → and analysis of change in the alignment of domestic political forces (the fourth matrix) → by the other branch, assessment of change in the country’s position in the global economic cooperation (the fifth matrix) and assessment of change in the country’s position on the international arena (the sixth matrix). Both branches close the analysis loop on the solution matrix (the seventh matrix), where each major problem is assigned to possible solutions and the parameters of which are then compared to the parameters of the scenario matrix. On this basis judgments are made, whether or not the assumptions or the analysis results are controversial and how probable this or that scenario is. This approach allows it to close the loop of direct and reverse relationships between natural, technology, economic, social, and political factors, to apply the principles of complexity and development in the assessments, and above all to reduce the degree of uncertainty through rejecting unfeasible trajectories and to form a basis for the assessment of likelihood of the remaining social and economic development options. Therefore, the space of social and economic development options becomes better shaped and substantially shrinks.

This approach expands the field of vision of economists, who are often narrow-focused on relevant areas, and urges to more carefully formulate initial hypotheses and check them for comparability. Only after such analysis is accomplished, the assumptions may be viewed as mutually agreed. This approach requires good cooperation between economists, engineers, mathematicians, sociologists, political experts. To a full extent this approach has not been implemented so far either in Russia or abroad. However, papers that use similar approaches increasingly grow in number in Russia (Bashmakov, 2009; Bashmakov, 2011; Gurvich, 2013; Yasin, 2013; Blokhin, 2012; etc.)[16]

The assumptions should include:

- institutional and management change (degree of long-term orientation and ability to timely detect and address problems; effective goal attainment; democratic or autocratic management methods, etc.) varying between effective leadership with broad national support and week institutions, instability, fragmentation, lack of integration;
- public values evolution vector: preference to keeping the status-quo or to the future; to consumption or environmental balance; to cooperation or conflict;
- technology change: substantial, transformation, "green", market penetration rate and steadiness.

As to the economic change (fast, moderate or slow growth), it can either be an input variable or defined in the model, depending on the model structure. The basic factors that determine the levels of economic activity are specified in the concepts of economic development models.

3 Concepts of the future

Most contemporary long-term economic projections for Russia to 2030 and beyond formulate alternative storylines underlying scenario assumptions and macroeconomic parameters. Obviously, these storylines are only described in broad brush strokes. Some experts pay more attention to them (Bashmakov, 2009; Gurvich, 2013; Yasin, 2013; RF Ministry of Economy, 2013), others less (Yzyakov and Shirov, 2012). The task of this section is to specify a limited number of substantially different storylines and assess their relation to the parameters of future economic development.

I. Bashmakov (2011) considers four groups of scenarios:

- **"Russia's Gods' favourite",** with the most favourable for our country assumptions about oil and gas production, oil price evolution, improved economic performance;
- **"Oil&gas optimism",** a group of scenarios with the same optimistic assumptions about oil and gas production, yet with less favourable hypotheses relating to the productivity growth in the non-oil&gas sector;
- **"Hydrocarbon depletion",** a group of scenarios that assume that oil production will peak in the coming years and go down thereafter, while gas production will peak in 2016-2030 also followed by a decline;
- **"Effective renovation":** assumptions from the "Hydrocarbon depletion" scenarios relating to the hydrocarbons production go for this group, too; however a hypothesis is accepted that the economic growth model will change driven by improved productivity.

However, a point is made in this paper, that with Russia's current cultural tradition which can be described by the formula: *yearn for survival by separate individuals, who tend to address only tactical problems and have a very vague idea of what awaits them in the future* (Bashmakov, 2008), and with the basic values best described as *high priority of security and defense provided by the state and low rank of novelty, creativity, freedom, self-reliance and risk* (Margun and Rudnev, 2010), it is difficult to form potent coalitions for timely modernization. And without modernization it is impossible to completely implement even the catching-up development

[16] For example, A. Blokhin, 2012, makes a point that the analysis should focus not on sectors, but on key agents who can become subjects of the relevant change.

potential, let alone transition to the technological development that requires innovation environment and culture, including democratization, minimization of corruption and bureaucracy, and competitiveness in all spheres.

E. Yasin (2011) specifies three different storylines:

- **Top-down modernization,** or inertial development in the framework of the "mistrust triangle" with the corners state-business-society. Making up for the passivity of business, the state will increase its share in the economy, so the overall efficiency will decline. Everyone will be trying to avoid risks, so the planning horizon will become shorter, the business activity will drop, corruption will grow up, competition will decline, and in the end either this policy will have to change, or stagnation is inevitable. We are currently at the beginning of this process. If we go along this development trajectory, GDP growth rate may drop to 1-3% per year;
- **Bottom-up modernization**, development of a "trust triangle" within 4-5 years through the employment of liberal democracy, development of innovative economy and implementation of institutional reforms to substantially reduce corruption and enhance democratic public control. This development trajectory may lead to 3-4% GDP annual growth rate;
- **Pessimistic scenario.** Oil prices keep at USD 50-60 per barrel for 20 years potentially leading to a development trajectory similar to the one that started after the 1986 oil price drop, which heralded the demise of the Soviet system.

E. Yasin (2011, 2013) believes that bottom-up modernization would be the best option, because no modernization is possible through directives, no matter how high-ranking the source is (Mau, 2012). Let us make a point, that top-down modernization is possible, as long as the government has revenue sources that are independent from the business and society (oil and gas revenues), and the role of these sources will be sustainably decreasing.

The RF Ministry of Economy (2013) considers three major scenarios:

- **Conservative scenario** does not imply any transition to a new development model and is characterized by active modernization primarily in the energy sector and in the raw materials sector against relative lag behind in the other sectors. Economic modernization primarily aims at the use of imported technology and knowledge. Average annual GDP growth rate in 2013-2030 is 2.5%.
- **Moderate-optimistic scenario** (to replace the innovative scenario) is characterized by additional innovative impulses; enhanced investment vector of the economic growth; development of advanced transport infrastructure, competitive cutting-edge production and knowledge-driven economy, and modernization of the energy sector. Economic growth is primarily driven by innovations. Priority is given to the development of economic institutions that protect property rights, promote market competition, reduce investment risks and administrative barriers, to the development of new companies and a focus on the business performance enhancement; improvement of public services and public administration. Average annual GDP growth rate is around 3.5% in 2013-2030 corresponding to the global economic growth rate.
- **Target (uprated) scenario** is characterized by boosted growth rates, increased saving rate, development of a large non-raw-materials export sector, and accelerated reforms to improve the business climate and to intensify foreign capital inflow, active use of national savings, and increased public spending for the development of social, energy, and transport infrastructure. Average annual GDP growth rates grow up to 5-5.3%, increasing the share of the Russian economy in the global GDP to 5.8% in 2030. Acceleration of growth is partially determined by the assumption that the population

will grow to 151.4 mln. people by 2030. This option implies significant growth of the corporate sector and households' debt, as well as substantial increase in the foreign debt and negative current account balance underlying growing sensitivity of the Russian economy to external shocks.

In other words, the RF Ministry of Economy actually recognizes that the desirable 5% GDP annual growth by 2030 in the target scenario is only possible through the highly improbable population growth and at the price of undermined sustainable growth beyond 2030. Therefore, only the first two scenarios by the Ministry of Economy are feasible, although obviously, the Ministry can hardly ignore the innovation top-down scenario in its vision of the future.

V. Ivanter and M. Ksenofontov (2012) believe that increased to 6-7% average annual GDP growth rate in the coming 10-20 years is one most important macroeconomic factor to determine transition to the innovative development and address the new industrialization problem. Referring to the Chinese and Indian experience they suggest a **"constructive"** development scenario, which implies that the saving rate will grow up to 35% by 2020 and gradually decline thereafter[17]. The authors suggest using the budget surplus[18] and accelerated credit development to increase the saving rate. They point out the need for a rational compromise between the policy of reforms and sustaining the stability as a method of reducing investment risks.

In their analysis of economic growth potential in Russia M. Uzyakov and A. Shirov (2012) consider two scenarios with primarily economic (technocratic) input parameters:

- **Inertial scenario:** as limitations related to the working-age population, infrastructure, and access to the natural resources exacerbate, economic growth will be slowing down, current structure of the economy will be preserved, along with the key structural and spatial disproportions. Average annual GDP growth rate equals 2.9% in 2011-2030. In this scenario, the storylines are the same as the picture of the present and the past;
- **Domestically-oriented investment scenario** suggests aggressive economic policy measures, basically in the existing institutional environment ("**constructive**" scenario, in the terms used by V. Ivanter and M. Ksenofontov), and saving rate increased to 35% by 2020. However, it is not clear, which exactly measures, on what institutional basis, and by whom are to be implemented, so that the ratio of consumption and savings in Russia's economy could change so dramatically[19]. In other words, this scenario is not supplemented with a set of explicit storylines that should be able to allow for the acceleration of average annual economic growth to 5.1% in 2011-2030.

A menu of options that allow it to substantially increase the saving rate and speed up the economic growth is suggested by S. Glaziev and G. Fetisov in their "**economic miracle**" concept (2013). They believe that it is market dogmas that have been hampering economic development in recent years, namely: "artificial" budgetary rules, the state's abandonment of enterprise ownership and price control leading to "growth without development". Let us make a point here that all these "dogmas" did not play any role during the recession of the 80'es, when there was

[17] OECD (2012) expects such saving rate in 2020 only in the developing economies, whereas in the industrialized countries it is expected close to 17%. In the developing countries, the saving rate will drop to this level by 2050. In China and India, it will go down to 20% by 2040.

[18] However, any substantial positive balance of the consolidated budget can hardly be expected in the coming few years or until 2050, and so this source is difficult to use. See Bashmakov (2011) and S. Vlasov, E. Deryugina, Yu. Vlasov (2013).

[19] Let us make a point that the saving rate in 2012 was 22%, while excess savings were 6.2%. In other words, even with a full use of all savings, the saving rate would only equal 28% versus required 35%. Given projected reduction in excess savings, increase to 35% by 2020 is only possible subject to a substantial decline in the share of consumption in GDP or to a large increase in foreign borrowings.

no growth or development whatsoever. After 2009, the budgetary rules substantially weakened[20], the role of state in the economy significantly increased, and monopoly prices have been under government control; all that, however, did not keep Russia from "crawling" into a new stagnation period in 2013. In order to implement the "economic miracle" concept (or the "breakthrough strategy") aiming at 7% GDP annual growth through 1.5-fold increase in the saving rate (up to around 35%) and at 15% annual fixed capital investment growth, S. Glaziev and G. Fetisov (2013) suggest the following measures: develop a strategic (indicative) planning system to integrate projections with up to 50 years time horizon; reduce the tax load on any type of innovative and high-technology activities; provide depreciation and property tax benefits to enterprises; expand loans to the real sector of economy; institute mandatory insurance of deposits held by physical persons with banks; stabilize the real ruble exchange rate; develop cooperation in the framework of the Eurasian Economic Community.

E. Gurvich (2013) considers three scenarios that should respond to the post-recession economic growth slowdown:

- **no response or weak response** (inertial scenario). The Government keeps pursuing the inefficient and wasteful government spending policy and/or attempts to restore economic growth through measures that affect the core of the existing economic system or the balance of interests. This option requires little effort, yet is fruitless and risky, because, among other things, Russia will not be able even to maintain its position in the global economy. Attempts to spur economic growth through palliative measures while maintaining large government spending are the most real and serious danger for the Russia's economy in the years to come. GDP growth rate in 2011-2030 is 2.1-3.1%, depending on the oil price evolution;
- **passive response** suggests adaptation of the economic and social policy to the expected economic slowdown and oil rent reduction (for example, through the rejection of unnecessary government spending and improved effectiveness of the remaining expenditures); ensures moderate yet safe development. It requires that the authorities and elites cut their ambitions and reject populism, transit to a rational social spending policy, reject costly "status" projects that do not promote economic development, lay off part of public employees, transit to more thrifty military and foreign policies[21];
- **active response** requires profound, albeit politically difficult, institutional reforms to address basic problems faced by the country (unprotected property; excessive government and quasi-government sectors; excessive economic regulation; uncontrolled officials) through a radical improvement of the quality of governance. The author believes, that only this scenario allows for a better position in the economic development rating of countries. Institutional progress helps increase the saving rate and improve the investment efficiency. Improved quality of state scales up annual economic growth rate by 0.8-1.1%, and so GDP growth rate increases to 2.9-4.2% in 2012-2030, depending on the oil price evolution.

E. Gurvich estimates probability of institutional progress at 15-20% with high oil prices and at 30-35% with cheap oil. The logics underlying this estimate is as follows: only a combination of three factors (reduced ability of officials to lay hands on the oil and administrative rent; increased dependence of officials' economic might on the situation in the non-oil&gas sector; and growing public discontent with the reduction or very slow growth of incomes) can force both the government and the society take real action towards modernization. This means, that

[20] For more detail see: Lebedinskaya (2012); Kudrin (2013); Vlasov, Deryugina, Vlasova (2013); Kudrin. Kommersant. 17.07.2013.

[21] Let us make a point that only a recession can justify transition to such policy. Otherwise the government will not be able to make this transition without substantial loss of support by population.

scenarios with launched institutional reforms should be assigned with a certain time lag to scenarios with low oil prices in order to partially make up for the economic growth slowdown.

OECD (2012) highlights, that a 3-fold economic development gap between Russia and the U.S. in 2011 (estimated based on PPP GDP per capita in 2005 prices) is determined by the fact, that human capital (per employee) in Russia is 1.3 times lower, than in the U.S., factor productivity is twice lower, and fixed assets are 1.2 times lower. Catching up by the first two parameters should become the major economic growth driving force. The 2000-2011 reduction in the economic development gap between Russia and the U.S. was by 82% driven by improved factor productivity in Russia, albeit more attributed to structural shifts in the economy, than to technological progress[22]. OECD (2012) believes that in the industrialized countries productivity factor will contribute 1.3% to the GDP annual growth to 2060 versus 2.3% in Russia. The growth of this parameter is to a large extent determined by the level of competition in domestic and international markets and the factor productivity gap with the U.S. OECD experts think that successful reforms and maintaining the structural balances can spur Russia's annual GDP growth from 2.3% in 2011-2060 (3% in 2011-2030 and 1.3% in 2030-2060) to 2.7% (3.6% in 2011-2030). Unlike many Russian experts, who see the saving rate increase as an important catalyst for economic growth, OECD sees the major growth source for Russia in the factor productivity increase. Entov and Lugovoy (2013) believe that factor productivity increase can contribute 0.7-1.7% to Russia's GDP growth in 2011-2020, which is below the OECD estimates. In its October 2013 projection, the RF Ministry of Economic Development estimates factor productivity increase potential at 1.3-2.6%, including 0.8-1% through catching-up development (Ministry of Economic Development, 2013a).

The accomplished analysis provides grounds for a systematization of scenarios (Table 1) with a wide range of possible GDP growth rates split into 4 zones:

Table 1. Classification of long-term economic development scenarios for Russia

Authors	Projection horizon	Average annual GDP growth rates			
		less than 1%	2-3%	3-4%	5% or more
I. Bashmakov (2011)	2010-2050	Hydrocarbon depletion	Oil&gas optimism	Russia's Gods' favourite	
				Effective modernization	
E. Yasin (2011)	2010-2050	Pessimistic scenario	Top-down modernization	Bottom-up modernization	
M. Uzyakov and A. Shirov (2012)	2011-2030		Inertial scenario		Domestically oriented investment scenario
RF Ministry of Economy (2013)	2013-2030		Conservative scenario	Moderate-optimistic scenario	Facilitated scenario
S. Glaziev and G. Fetisov (2013)					Economic miracle
E. Gurvich (2013)	2011-2030	Passive response	Weak response	Active response	
OECD (2012)	2011-2060		Improved factor productivity		
R.M. Entov and O.V. Lugovoy (2013)	2011-2030		Low	Moderate and High	

Sources: Bashmakov (2011); Yasin (2011); Uzyakov and Shirov (2012); RF Ministry of Economy (2013); Glaziev and Fetisov (2013); Gurvich (2013); Entov and Lugovoy (2013).

[22] R.M. Entov and O.V. Lugovoy believe that factor productivity in Russia contributed 55% to the GDP growth in 1998-2008 (Entov and Lugovoy, 2013).

All long-term scenarios can be split into several different storylines.

"Dynamic growth". These scenarios assume sustainable GDP growth at a rate faster than 5% per year through the "top-down modernization" by the innovative scenario (that implies dynamic renovation of fixed assets, energy efficiency and labour productivity improvements, yet reduction in capital productivity), and so requiring/assuming a radical increase in the saving rate. These scenarios imply dynamic economic restructuring. The risks involved by these scenarios are related to a bloated public sector and excessive regulation of economy, which are incompatible with the economic efficiency improvement, as proved by the evidence of all countries with centrally planned economies. Besides, the risks include fast debt growth, which is incompatible with sustained dynamic economic growth, as proved by the experience of countries with market economies.

"Moderate extensive growth". Development along this group of trajectories is possible with a successful "top-down modernization" by the innovative scenario, through substantially larger oil&gas revenues, but with an account of restrictions related to the saving rate growth. With a favourable situation in the hydrocarbon markets and improved factor productivity it is possible to attain 3-4% sustainable annual GDP growth. The risks related to the dominating role of economic regulation against the background of passive business community and so to the dominating role of the state in the economy are preserved. Factor productivity (workforce productivity, energy efficiency) growth is lower, than in the next family of scenarios, as determined by lower competition pressure.

"Moderate intensive growth". These scenarios imply modernization to radically improve the quality of governance, to promote dynamic investment activity and to improve factor productivity through reduced monopolization and state interference with the economy. In these scenarios, 3-4% annual growth of GDP is possible even with a less favourable situation in hydrocarbon markets, through the improved performance of the economy, reduced corruption, development of the private initiative and medium- and small business, and therefore flow of investments into less capital-, energy-, and material intensive sectors. It is not so much the growth rates, as the growth quality that makes this family of scenarios different from the previous group.

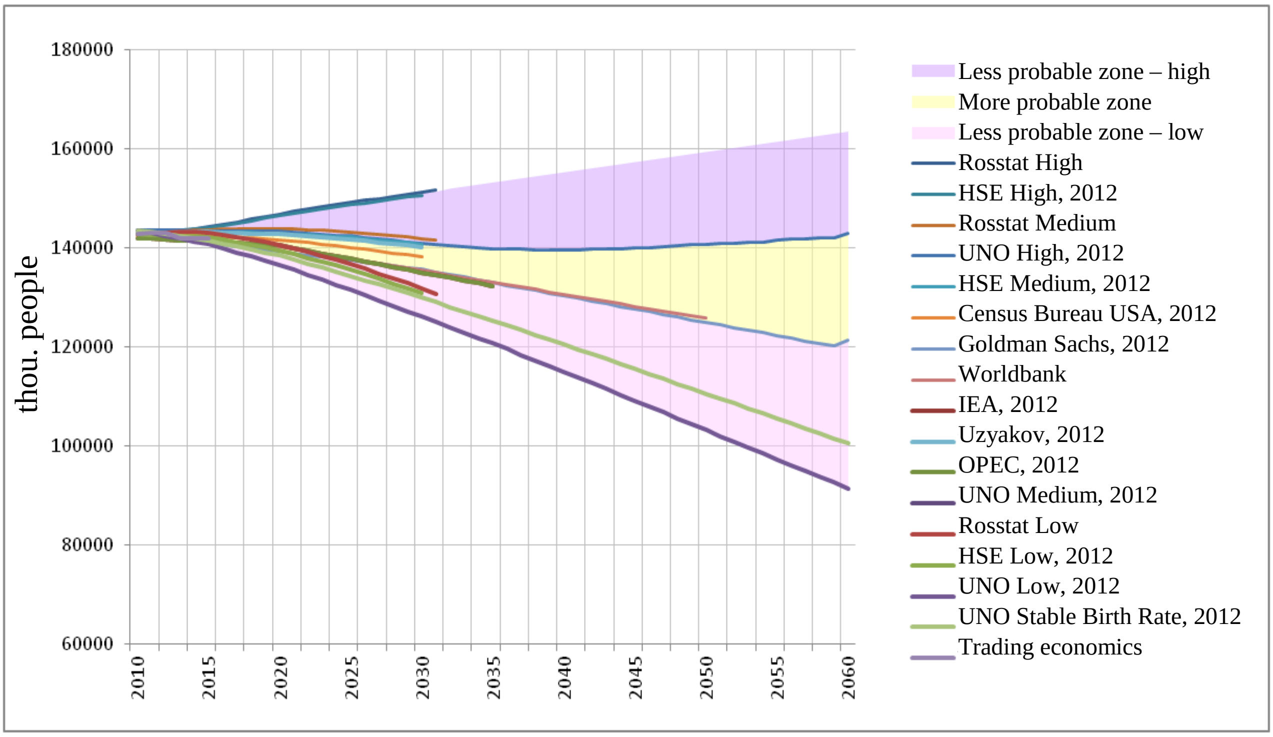
"Slow growth". Maintaining the current model of political, social, and economic development, given depleted sources of growth and inability to make a transition to a new development pattern; adaptation of economic and social policies to the reduced oil rent and lack of mechanisms to allow for a capital flow from the raw materials to other sectors. At the turn of the 40'es, development by this model may lead to the "magic skin" economy, i.e. sustainable reduction in GDP and inability of the improved economic performance to make up for the employment reduction and capital intensity increase. (Bashmakov, 2011).

The major drivers of the GHG emission include: population growth and structure; economic growth and structure; technology development and penetration rate (including low-carbon technologies); objectives and intensity of emission control policies. For Russia, it is important to add here changes in the global economy evolution and in domestic energy markets.

4 Demographic parameters

Demographic parameters are normally input variables in all models. In a number of global scenarios there is no direct correlation between population growth and emission dynamics (Van Vuuren et al., 2012), because it is mediated by the economic growth parameters and aggressive emission control policies. Russia has already entered the "ageing century" (Kudrin and Gurvich, 2013). Only two projections (by Rosstat, 2012, and IDEM HSE[23]) assume that population may grow by 2030-2031 to 151-152 mln. people, if the birth rate goes up (Fig. 1). However, most projections agree that the population in Russia, which has got into the "ageing trap" (Kudrin and Gurvich, 2013), will be going down.

Figure 1. Russia's population evolution projections to 2060



Most pessimistic scenarios (low scenario and stable birth rate scenario (UN, 2012)) assume that by 2060 population may drop to a level below 100 mln. people. In other words, the next 50 years may manifest the dawn of the "ageing-of-the-dying-off-population" era. The consequences of this development trajectory may include: demand structure shifts determined by the population age structure; evolution of savings volume and structure (reduction in savings that makes it difficult to increase the saving rate); reduced labour supply and hard-to-achieve increase in the labour productivity; growing demand for public financing, because public spending per elderly person is larger, than per working age person; growing demand for pension funds (Kudrin and Gurvich, 2012).

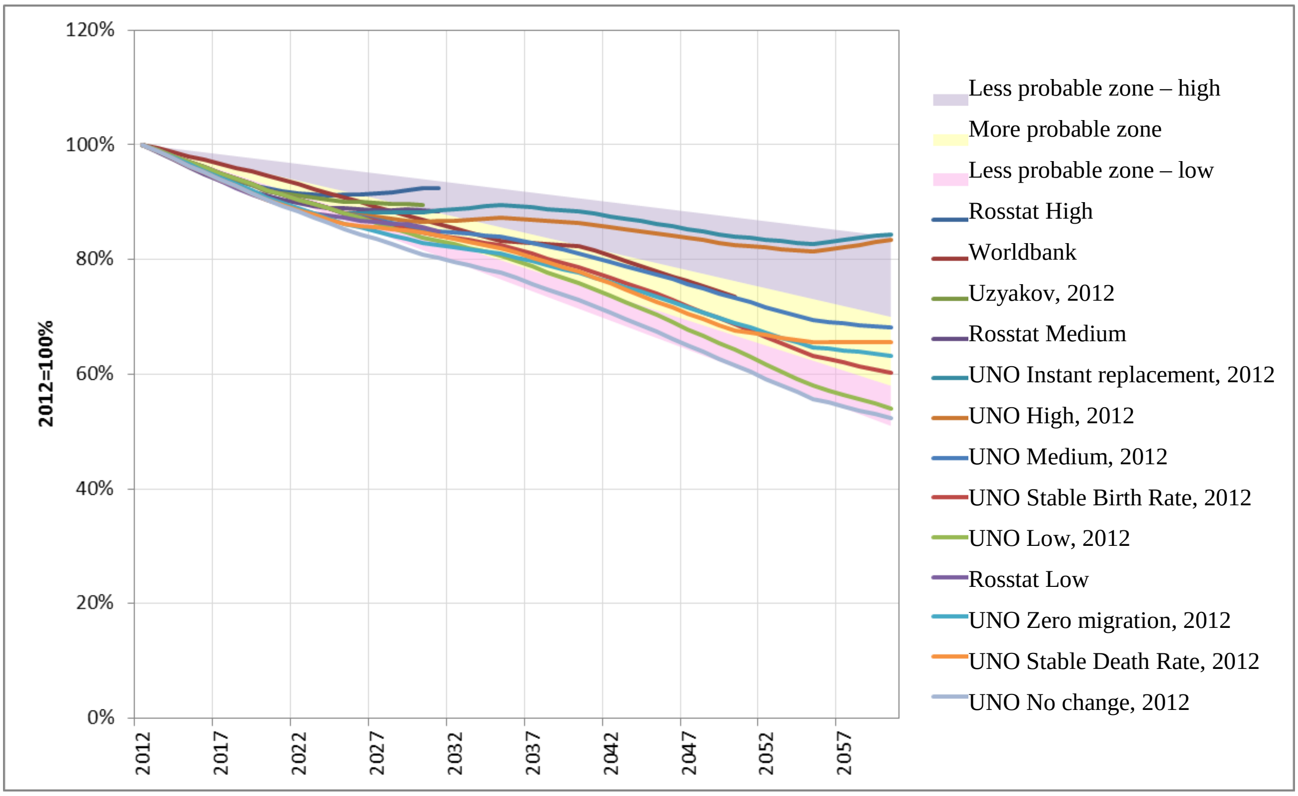
The population evolution uncertainty zone can be split into three segments:

- less probable upper zone: stabilization at a level around 140 mln. people, or population growth;
- more probable zone: between the population stabilization and drop to around 120 mln. people by 2060;
- less probable lower zone: population drop to below 120 mln. people by 2060.

[23] According to M. Denisenko (2012). Russia's population to 2025. *Pro et Contra*, July – October, 2012.

As far as the working age population is concerned, projections depend on the definition of working age. Therefore, comparisons were made not between the absolute values, but between the evolution parameters. All projection groups agree that the working age population will be decreasing, but they differ in their estimates of this decrease (Fig. 2). Until 2020, annual reduction rate is 0.6-1.3%, and working age population annually drops by 860-1,240 thousand people.

Figure 2. Russia's working age population evolution projections to 2060



Working age population evolution zone may be split into three segments:

- less probable lower zone: 1-1.3% annual reduction;
- more probable zone: 0.6-1% reduction;
- less probable upper zone: 0.3-0.6% annual reduction.

According to OECD (2012), Germany, Japan, Poland, and China will face similar demographic problems, yet for Russia the problem will be more pressing and impossible to address without raising the retirement age, which is difficult because the electoral importance of retired people will grow up from current 37% to nearly 50% in 2050 (Kudrin and Gurvich, 2012). In Russia, the demographic load of the elderly people (the ratio of retired people to the working age population) is expected to grow up 2.3-fold by 2050.

5 Economic growth rates and proportions

Models usually use GDP as the macroeconomic activity indicator. This is definitely not a perfect indicator of sustainable development, giving birth to numerous alternative concepts and aggregated economic development indicators: green growth, green economy, green national product, true savings, true progress, human development potential index, gross national happiness, better life index, shrinking economy, comprehensive prosperity index, etc.[24] Many of these indicators are not impeccable in terms of showing the evolution of real market situation or factor productivity and require assessments of a large bulk of additional information. Therefore, GDP keeps dominating in macroeconomic models, and GDP per capita is usually used for comparisons. Given shrinking population, it may become the major, instead of an auxiliary, indicator. In Russia, it was also suggested that the non-oil&gas GDP evolution be used as the major macroeconomic indicator (Bashmakov, 2006).

The saving and accumulation rates are very important macroeconomic proportions. The "economic miracle" concept builds on the assumption that the saving rate in Russia can grow up from the current 21-22% to 35% by 2020[25]. S. Glaziev and G. Fetisov (2013), as well as M. Uzyakov and A. Shirov (2012) and, to a smaller degree, the RF Ministry of Economic Development (2013), believe that such saving rate growth is (a) possible, and (b) will catalyze the economic growth. This assumption does not take into account the specific features of oil production economies or their limited absorption capacity. As soon as their absorption capacity is exceeded, capital intensity grows up driven by an imbalance of the capital and other production factors evolution, and the growth of prices for investment goods accelerates. Therefore, evolution of the investment load of the economy (the ratio of gross investment in fixed assets in current prices to the non-oil&gas GDP in the baseline year prices with a 1 year lag[26]) is a more adequate indicator of the investment activity in oil producing economies, than the saving rate growth (Bashmakov, 2006a). Calculations made by the author show, that growth of the saving rate in GDP from 22% to 35% in 2013 would contribute 1.5-2.5% to the acceleration of GDP growth; 27% to the investment goods additional price growth in 2013 alone and 50% to cumulative price growth by 2020; 10% to the consumer price growth in 2013 and 46% by 2020. In other words, nearly the entire effect of the radical growth of the saving rate turns into inflation within several years[27], and additional GDP growth is minimal (saving rate elasticity of real GDP growth is only 0.03).

The OECD projection highlights, that ageing of population is the major factor driving the saving rate down in all countries, and very dynamically in China and India (to 18-20% by 2040). The OECD average reduction in the saving rate determined by this factor is 5% of GDP by 2060, and in the non-OECD countries ageing of population, along with others factors (better access to loan financing, growing social spending, etc.), is responsible for 5-40% reduction in the saving rate (OECD, 2012). With an account of all these factors, maintaining the saving rate in Russia at 20-22% until 2050-2060 may be viewed as a success, as this rate will keep close to the average global value until 2030, will exceed it thereafter and will remain above the saving rate in the

[24] For more detail see A. Atkisson. 2012. Life Beyond Growth. Alternatives and Complements to GDP-Measured Growth as a Framing Concept for Social Progress. 2012 Annual Survey Report of the Institute for Studies in Happiness, Economy, and Society – ISHES (Tokyo, Japan); and also the proceedings of OECD Global Forum on Measuring Well-Being for Development and Policy Making. New Delhi, India. 16-20 October 2012.

[25] Current saving rate in Russia is higher, than in the industrialized countries (14-17%), close to the global average (22-23%), but far below those in China (around 50%) or India (30-35%). The saving rate in the non-oil&gas sector (around 25%) is higher, than in the oil&gas sector or than the cross-sectoral average.

[26] Unpreparedness of the Russian investment machine building for a substantial investment growth was demonstrated in papers by A. Kornev (2012, 2013).

[27] M. Uzyakov and A. Shirov (2012) highlight that rising prices for investment goods contribute 50% to the saving rate increase.

OECD countries on the entire 50 years' horizon. In view of the above, it is not clear, which factors may possibly drive it up to 35%.

Given 35% saving rate, it is difficult to achieve 7% annual GDP growth even if the capital intensity remains at the current level. And the capital intensity will be growing (Uzyakov and Shirov, 2012), and the more the absorption capacity of the economy is exceeded, the faster the growth (Bashmakov, 2006). OECD assumes that capital intensity of transition economies (excluding the cost of fixed assets in the residential sector) will be growing until 2020-2030 and stabilize thereafter. In export-oriented economies, such as Canada or Australia, capital intensity will not only grow faster, but will stabilize at a level nearly 1.5 times higher, than in other industrialized countries. This means that the saving rate growth and the fixed assets increase in Russia will not be able to simultaneously make up for the reduction in labour supply and neutralize capital intensity increase. Therefore, only human capital growth and improved factor productivity may become the sources of economic growth in Russia.

Correlation between the economic growth and technology may be diverse. Restorative growth in Russia was not accompanied by fast deployment of new technologies[28], unlike the fast investment growth in China. On the contrary, fast growth in Russia was accompanied by dynamic structural shifts towards less material- and energy-intense sectors, whereas in China the share of these sectors was going down. As to the perspective sectoral shifts, they are explored in detail in M. Uzyakov and A. Shirov (2012). Accelerated growth is possible through faster development of high- and medium tech sectors (2-3 times faster, than in the inertial scenario) and faster development of the service sector coupled with a very slow development or stagnation of the mining industry.

More than forty scenarios of long-term projections are shown in Fig. 3, and they substantially differ in terms of perspective economic growth estimates for Russia. To a large degree determined by different storylines (Table 1), these differences lead to a wide range of GDP growth multiplicity: between 1.5 and 10 by 2050 and 14 by 2060. Most projections agree that GDP growth rates will be declining with time. A due account of this trend is taken while breaking up GDP growth projections by groups of scenarios (Fig. 4).

The GDP evolution uncertainty zone consists of three segments:

- "Slow growth" (less probable lower zone): growth to 2% in 2013-2030, to 1% in 2031-2050, and no growth after 2050;
- "Moderate growth" (more probable zone): 2-4% growth in 2013-2030, 1-3% growth in 2031-2050 and up to 2% growth after 2050;
- "Dynamic growth" (less probable upper zone): 4% and faster growth in 2013-2030; 3% and faster growth in 2031-2050; and 2% and faster growth beyond 2050.

[28] Entov and Lugovoy estimate that growth in production capacity load was responsible for 36% of GDP increase in 1998-2008 (Entov and Lugovoy, 2013).

Figure 3. GDP growth rate projections for Russia to 2060

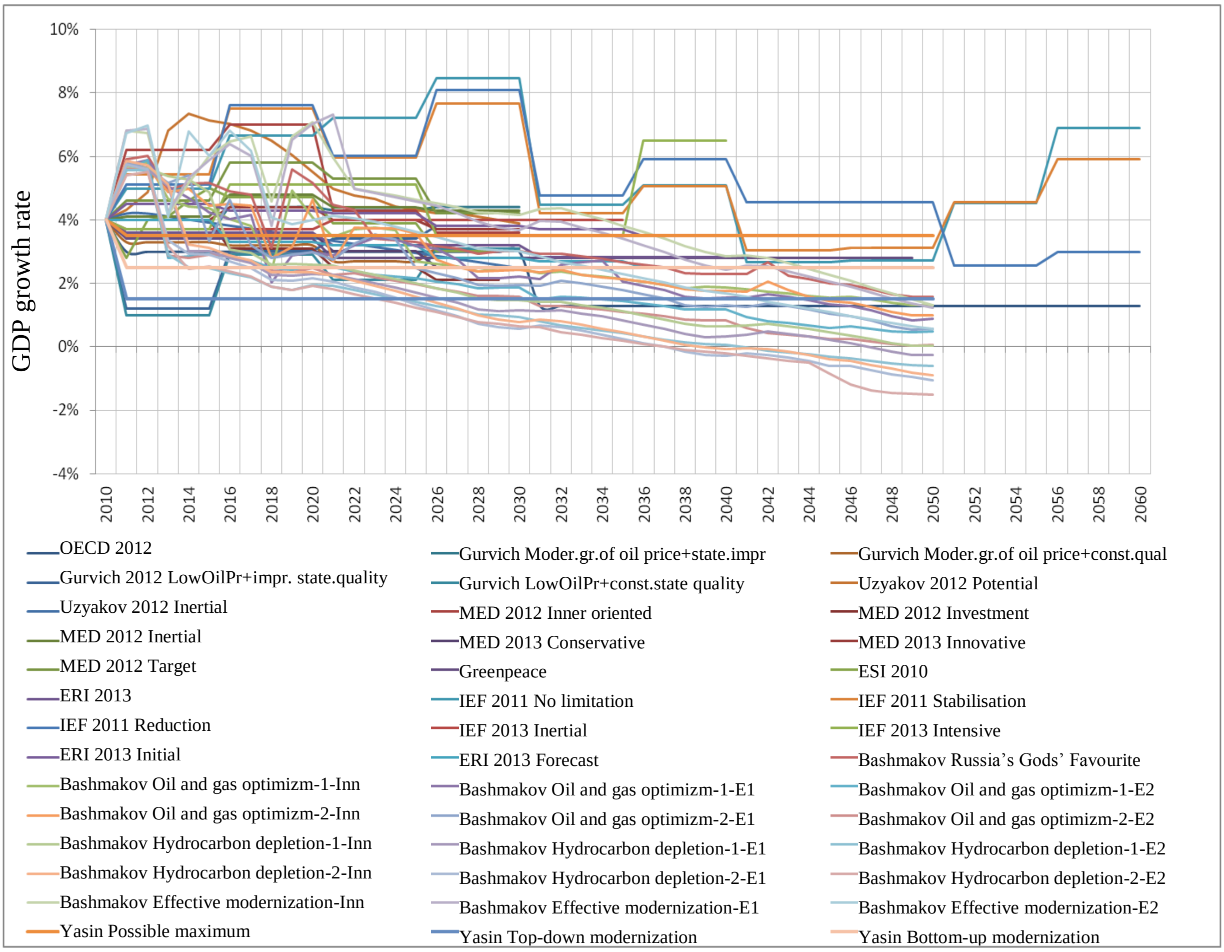
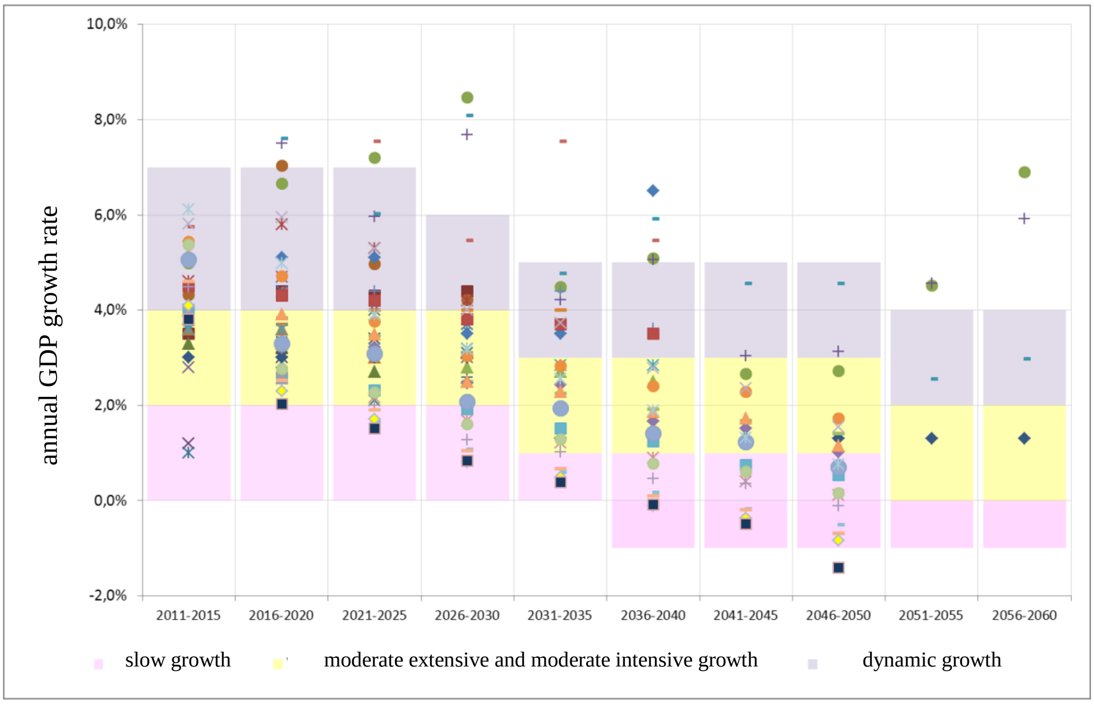


Figure 4. Breaking up GDP growth rate projections for Russia to 2060 by groups of scenarios



6 Oil&gas sector development

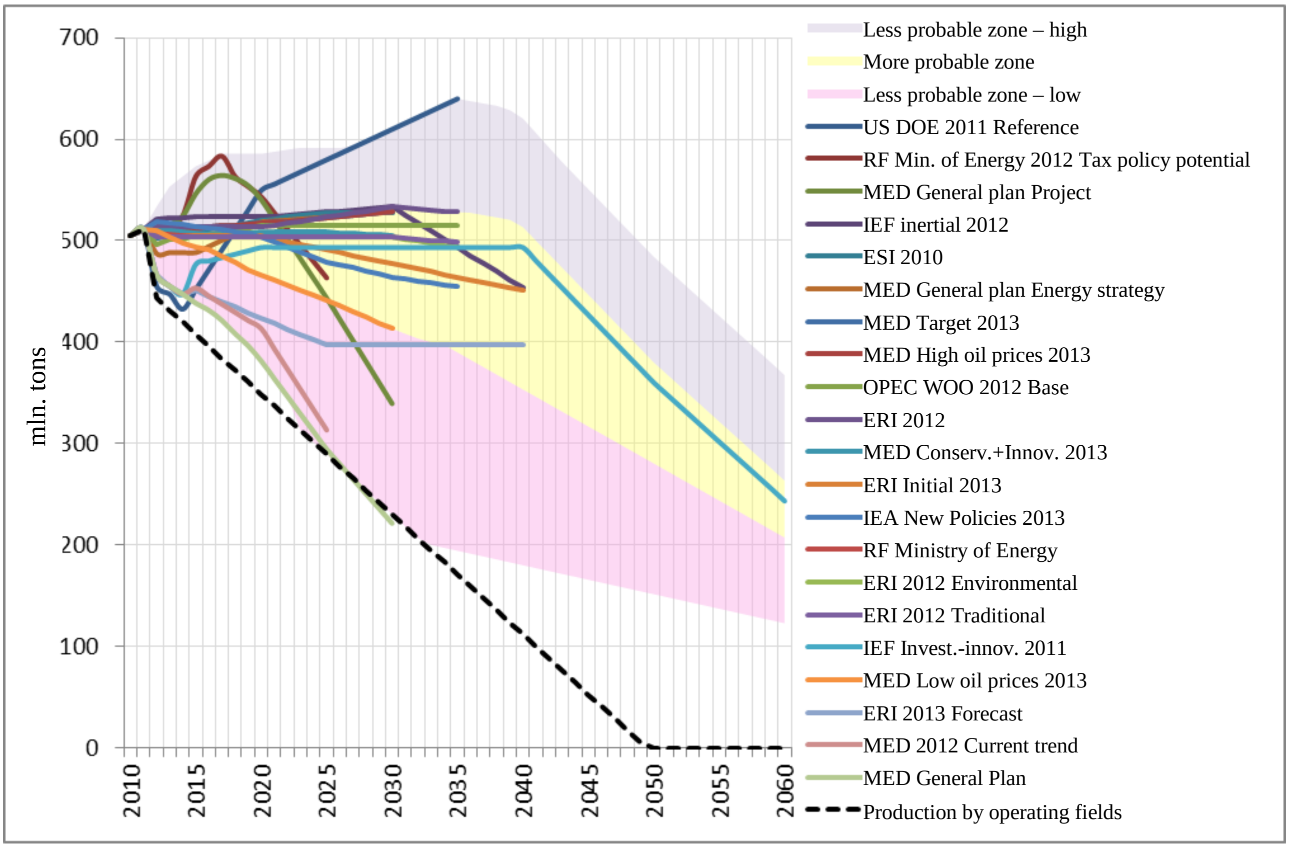
In Russia, economic growth parameters very much depend on the situation in its oil&gas sector, which was responsible for 24% of the entire 2012 GDP. Economic growth rate uncertainty is largely determined by uncertainties related to oil, gas, and petroleum production and export and price evolution.

In terms of **crude oil production** in Russia, most projections agree that it has peaked or is about to peak and a decline will follow. The projection by the U.S. DOE (2011) alone is standing out of this logic (Fig. 5). The other scenarios differ in: (a) the peak level (520-540 mln. t); and (b) the steepness of decline after the peak.

Three uncertainty zones related to crude oil production are considered:

- less probable lower zone: production drop to 230-420 mln. t by 2030, to 140-280 mln. t in 2050, and to 120-210 mln. t in 2060;
- more probable zone: between production drop to 420 mln. t and a peak at 540 mln. t by 2030 with the following decline to 280-380 mln. t in 2050 and to 210-285 mln. t in 2060;
- less probable upper zone: production growth beyond 540 mln. t by 2030 followed by a drop to 380-490 mln. t in 2050 and to 285-390 mln. t in 2060.

Figure 5. Oil production evolution projections for Russia to 2060



A. Lukyanov (2013) views oil production peak as a function of marginal capital investment efficiency (discounted income to capital investment increase ratio). The higher capital intensity and the rate of return requirements to new oil deposits or to the current production level, the lower possible production peak. With sound assumptions about marginal capital investment efficiency, production will not exceed 550 mln. t; and only with very soft capital investment efficiency requirements and practically unlimited investment leverage possibilities the peak may be expected at 700 mln. t by 2033, which is very close to the US DOE estimate (2011). A. Lukyanov also shows potential oil production decline trajectories to 2050 after the peak. With tough requirements to capital investment efficiency oil production drops to 260 mln. t in 2030 and to 150 mln. t by 2050. This corresponds to the lower range value of the less probable lower zone. With a 700 mln. t peak, production shows a fast decline to 300 mln. t by 2050.

The sum of oil production under each of the four curves bounding three uncertainty zones in Fig. 5 plus oil reserves required to sustain the 2060 production level for another 10 years equals 13.6; 21.4; 26.7 and 32.4 bln. t respectively. As of January 1, 2012, Russia's officially declared oil reserves of A+B+C1 categories equaled 17.8 bln. t and of C2 category 10.2 bln. t[29]. This means that overall reserves (and assessments thereof do not take into account oil production rate of return[30]) are not sufficient to sustain production under the less probable upper zone. Proved and 'yet-to-find' reserves (with a high probability of finding) are enough to sustain only production trajectories in the less probable lower zone. If the production trajectories of the more probable zone are to be implemented, at least 10 bln. t of oil are to be transferred from the 'yet-to-find' to the 'proved' reserves category. This is in line with the oil reserves increase plans in Russia to 2030. Probability of such developments is close to 50%.

Most projections estimate oil export to 2030 in the range between 150 and 260 mln. t, and in 2040 at 150-220 mln. t. However, if domestic oil consumption grows by 2050 from the current 116 mln. t to 180-200 mln. t, then in 2050 this scale of oil and petroleum products export will be possible only with crude oil production of at least 330-420 mln. t, which falls into the more probable zone.

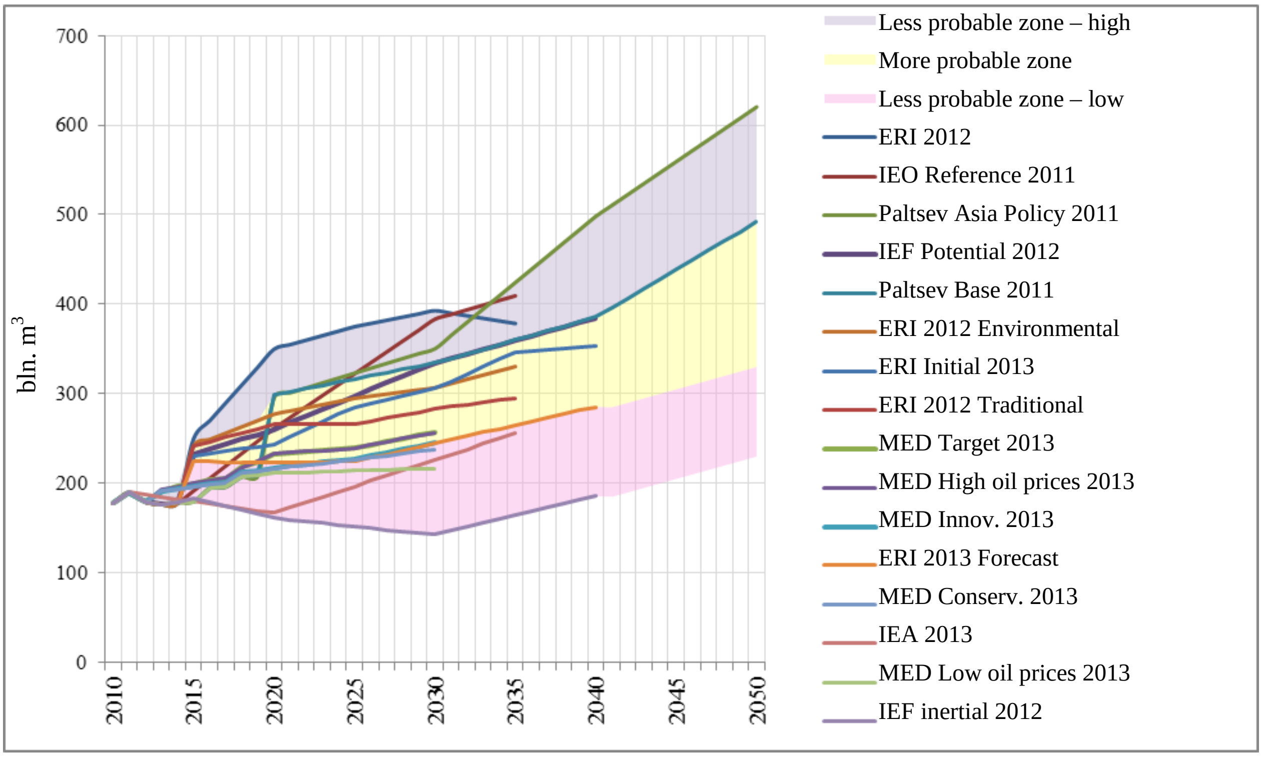
Gas production in the next few years will be determined by the excessive supply in the international markets. Besides, reduction, stabilization or a very slow growth of domestic natural gas consumption in Russia to 2020 is possible. However, in the longer term, most projections see a potential for a substantial increase in natural gas exports by Russia (Fig. 6). The highest estimates of this potential are shown in S. Paltsev (2011). Shale gas revolution, dynamic development of renewable energy and resulting shifts in the energy balance sheets of regions that are potential consumers of Russian gas continuously verify these estimates. For example, the Shtokman field, which, according to the "Energy Strategy" was supposed to produce around 70 bln. m^3 of gas in 2030, "will be developed by the future generations"[31].

Long-term projections show three possible zones of production dynamics (Fig. 7):

- less probable lower zone: from gradual reduction in gas production to 630 bln. m^3 to stabilization at 700 bln. m^3 in 2030; further reduction to 570 bln. m^3 or stabilization at 700 bln. m^3 in 2050 followed by a production drop to 460-620 bln. m^3 by 2060;
- more probable zone is bounded from below by the trajectory of production stabilization at 700 bln. m^3 to 2050 and further reduction to 620 bln. m^3 by 2060, and from above by production increase to 850 bln. m^3 in 2030 and maintaining this level until 2050 with further reduction to 800 bln. m^3 by 2060;
- less probable upper zone: production growth beyond 780 bln. m^3 by 2020, beyond 850 bln. m^3 in 2030-2050, and beyond 800 bln. m^3 in 2050-2060.

[29] RBK. 12.07.2013.
[30] According to BP, Russia's proved oil reserves were 11.9 bln. t as of the end of 2012 (BP, 2013), and according to the U.S. Geological Service, Russia's 'yet-to-find' oil reserves are between 3.4 bln. t with 95% probability, 9.8 bln. t with 50% probability and 20.4 bln. t with 5% probability. In other words, proved and 'yet-to-find" reserves sum up to 15.3-32.3 bln. t.
[31] http://ejnews.ru/articles/2013/06/03/Gazprom_ostavit_SHtokman_potomkam_12255.

Figure 6. Natural gas export evolution projections for Russia to 2050



The sum of natural gas production in 2011-2060 under each of the four curves bounding three uncertainty zones in Fig. 7 plus gas reserves required to sustain the 2060 production level for another 15 years equals 38; 44; 53 and 63 trln. m^3 respectively. As of January 1, 2012, Russia's estimated natural gas reserves of A+B+C1 categories equal 48.8 trln. m^3 and of C2 category 19.6 trln. m3[32]. This means, that overall reserves are only just enough to ensure production level under the less probable upper zone. According to BP, Russia's proved natural gas reserves, as of the end of 2012, were 32.9 trln. m^3. According to the U.S. Geological Service, Russia's 'yet-to-find' natural gas reserves are between 8.8 trln. m^3 with 95% probability and 67 trln. m^3 with 5% probability. In other words, proved and 'yet-to-find' reserves (with a high probability of 'finding') are sufficient to ensure only production trajectories in the less probable lower zone. If other production trajectories are to be implemented, at least 20-30 trln. m^3 of 'yet-to-find' gas reserves are to be explored and gradually shifted to the 'proved' category. Probability of such developments equals 40-50%.

One most important parameter of the oil&gas sector and the entire Russia's economy are **oil prices**, which Russia cannot really affect (Bushuev, Konoplyanik, Mirkin, 2013). Long-term oil price projections are driven by four factors:

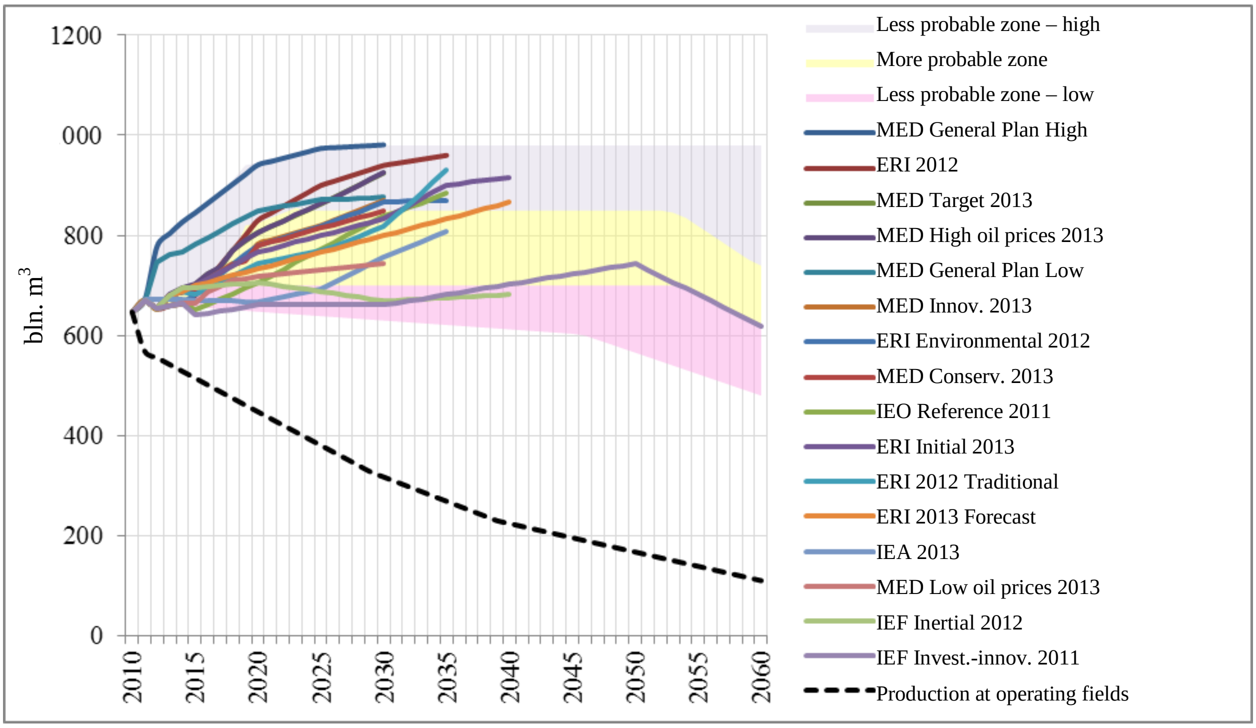
- upper range values and evolution of oil price fluctuations (concept of limited effective demand, or marginal production costs of alternative liquid fuels);
- lower range values and evolution of oil price fluctuations (Saudi-Arabian deficit-free budget price – 50-100 USD/barrel, – or current traditional oil production costs – 10-40 USD/barrel)[33];
- trajectory turning points from levels close to the upper range values to the lower range values and vice versa;

[32] RBK. 12.07.2013.

[33] For more detail about upper and lower limits to oil price fluctuations see Chapter 4 (authored by A. Konoplyanik) in Bushuev, Konoplyanik, Mirkin, 2013.

- U.S. inflation rate evolution and USD exchange rate fluctuations related to the most important currencies.

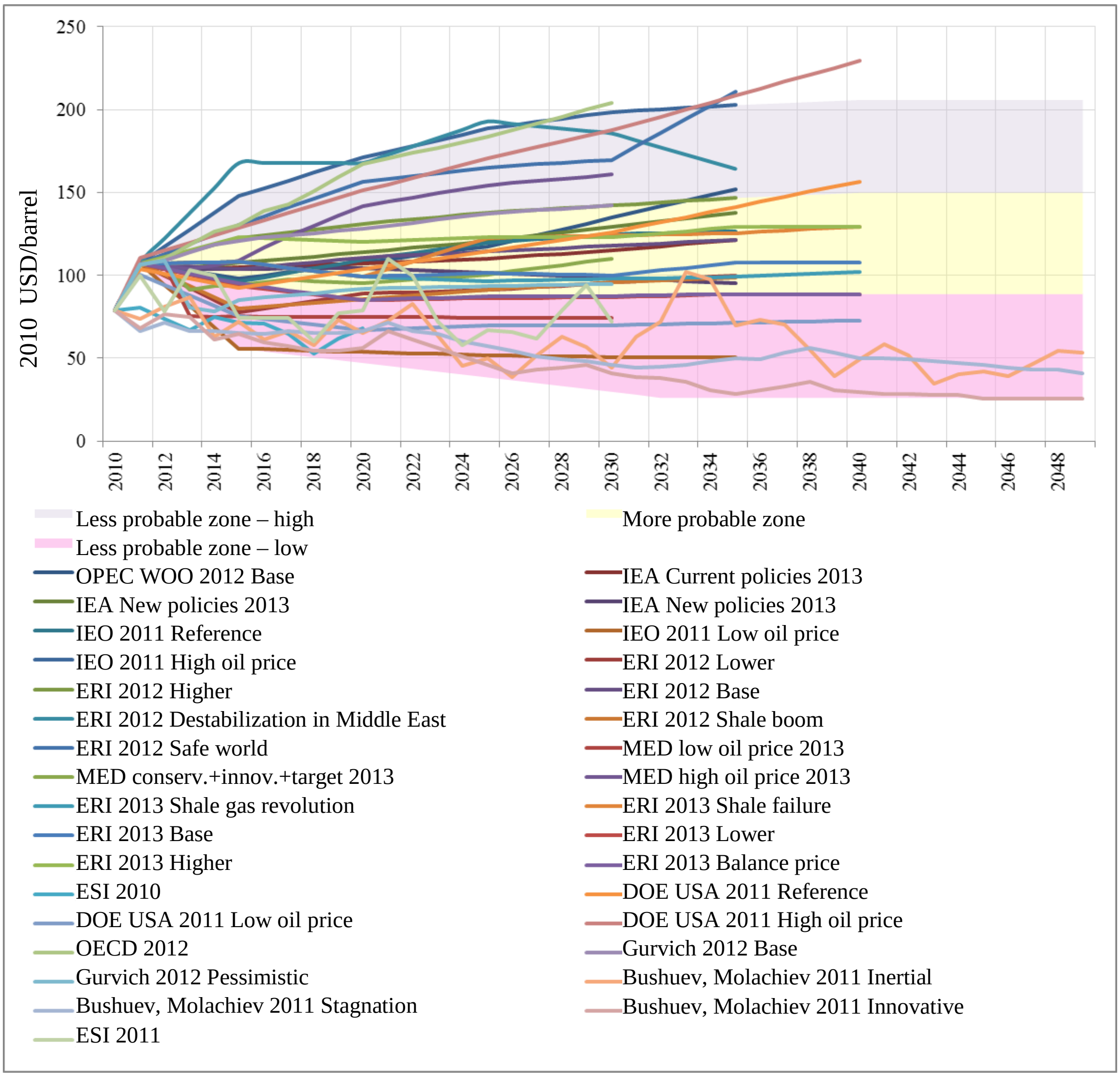
Figure 7. Natural gas production evolution projections for Russia to 2060



In the 70'es and 80'es, the general concept was that the price of various types of synthetic oil sets a limit to the oil monopoly price growth. However, during that period traditional oil from OPEC (a group of countries with least oil production costs), rather than synthetic oil, played the role of the marginal oil supplier. Only recently non-traditional oil started to play a noticeable role in the global liquid fuel balance. This concept was challenged by a theory stating that monopoly oil price growth is restrained by effective purchasing power, providing that possibilities to reduce oil consumption are limited due to its critical importance to sustain production growth (Bashmakov, 1988; Bashmakov, 2006a). According to this theory, monopoly price growth limit is reached, when a monopoly can no longer increase revenues by raising the price; and this happens when the ratio of the cost of consumed energy resources to the GDP goes beyond the 10-11% energy affordability threshold[34]. This concept allowed it to formulate a hypothesis in 2006 (which proved correct), that oil prices much above 100 USD/barrel (in 2006 prices, which is equivalent to 115 USD/barrel in 2013 prices), are not sustainable and cannot last for any long period (Bashmakov, 2006a).

[34] In 2008 in the U.S., this share came close to this limit: 9.9% (EIA, 2013), in the EU it went beyond and reached 12%, in China exceeded 10.5% (IEA, 2011). This put an end to the oil price growth. Gas and coal price reduction in the U.S. brought this share down to 8.3% in 2010. In the EU, high share of energy costs was one reason that determined economic stagnation, and in China, it determined economic growth slowdown. Getting back to the energy and oil affordability zone put an end to the oil price decline in many countries.

Figure 8. Oil price evolution projections to 2060



Evolution of energy affordability upper range value depends on the reduction in global GDP energy intensity (1.9% until 2030) and average energy price growth (in constant prices) determined by improved energy quality for end-users (at 2% per year)[35]. Therefore, the share of energy costs in the global GDP is about maintained (2% annual price growth minus 1.9% annual energy intensity reduction; IEA, 2013). Since the share of oil in the energy balance may be expected to annually decline by about 1%[36], oil price cap may decrease by 2030 to 102 USD/barrel in 2010 prices, and by 2050 to 88 USD/barrel. If GDP energy intensity decrease is any slower, it will keep at around 100 USD/barrel in 2010 prices. If we assume that average annual inflation rate is 2%, then the upper range value of oil price fluctuation will grow up to 200 USD/barrel by 2030 and to 225 USD/barrel by 2050. Practically all projections in Fig. 8 stay below these upper range values.

Marginal costs of alternative liquid fuels production may be assessed as non-traditional oil production costs (shale oil, heavy oil, bitumen, oil (tar) sands and extra-heavy oil that are trapped in sedimentary rocks – according to different sources, in the range of 50-85 USD/barrel) plus tax and required rate of return (70-100 USD/barrel, in all). With an account of inflation, by 2050 this

[35] For more detail see Bashmakov, 2007. This is determined by the growing share of better quality, yet more expensive, energy carriers, for example, electricity.

[36] Not percentage points, but 1% share reduction. I.e. if the share in this year is 32%, next year it will be 31.7%.

would be equivalent to 175-190 USD/barrel and will fall into the upper less probable zone, whereas the lower value of this range correlates to the current production cost of 75 USD/barrel.

The upper range value of the more probable oil price evolution is equal to the Saudi-Arabian deficit-free budget price (85-110 USD/barrel in 2012; Bushuev, Konoplyanik, Mirkin, 2013). It about corresponds to the evolution of marginal costs of alternative liquid fuels production. The lower value in this range corresponds to the price of about 90 USD/barrel with further growth to 110 USD/barrel by 2050. Finally, the lower value in the less probable lower zone corresponds to the oil price of 50 USD/barrel until 2030 with further inflation-induced growth. This is close to the price that can be set based on the current costs of traditional oil production (10-40 USD/barrel) with an account of tax and required rate of return. This range corresponds to the prices that underlie project financing in traditional oil production.

While the historical oil price evolution has a cyclic pattern and is highly unstable, most long-term oil price projections display flat trajectories for its future evolution (Fig. 8). This can be partially explained by existing confidence that it is impossible to project either levels or the turning points in the oil price evolution, especially now that oil has become an object of financial speculations with less than 1% of real delivery deals in the total stock-exchange deals (Bushuev, Konoplyanik, Mirkin, 2013). However, there are other opinions, too (Bashmakov, 1988; Bashmakov, 2006; Bushuev and Molachiev, 2012). It is important to identify the turning points from the levels close to the upper range values towards the lower range values and vice versa. In his book “World Energy: Lessons of the Future” published in 1992[37] the author formulated the following findings that were amply confirmed by practice: global export oil price will not go beyond the 1985 level until 2000; then the increasing pressure on the resource potential in the oil sector will inevitably bring the price up; the upward trend in relative oil price growth is not unavoidable, we ended up with a new center of long- and short-term price fluctuations instead; the amplitude of these fluctuations may be quite substantial[38].

Unfortunately, there is no cycle theory in place that would allow for a reliable assessment of perspective cycles in the oil price evolution, which are determined by the interaction of Kondratiev’s long waves (50-60 years), Kuznets’ cycles (15-20 years), medium-term business cycles (7-12 years), and even solar cycles (ESI and ERI, 2013). However clearly, with oil price staying high for a long time, some production capacities become excessive, as determined by changes both on the demand and supply sides, and this creates prerequisites for oil price decline. And vice versa, oil price staying low for a long time creates prerequisites for further growth. Therefore, along with flat oil price evolution scenarios it is worth while considering cyclic evolution scenarios, similarly to what the RF Ministry of Economic Development (MED) did for 2011 scenarios. Following the MED logic, oil price is expected to peak in 2016-2017, 2023-2025, and further in 2034-2036 and 2043-2046. In the projection by V. Bushuev and A. Molachiev (2012), it peaks in 2021, 2032-2033, 2041, and 2050. Generalizing, 9-11 year cycles may be identified starting from 2021. Such cyclic projections can be tied to a certain range if the trend – center of oscillation – falls into one of the three zones. Vulnerability of Russia’s economy to oil price variations makes analysis of cyclic price evolution extremely important[39].

[37] Bashmakov, 1992.

[38] Estimated 2020 oil price in this paper (in current prices) is 54-88 USD/barrel, falling into the less probable lower zone.

[39] For example, D. Shapot and V. Malakhov, 2012, found out that oil price variation elasticity of GDP growth monotonously declines from 0.36 with 20% price drop over three years to 0.33 with 10% drop, to 0.32 with 10% price rise and to 0.21 with 20% price rise. In other words, this elasticity is quite significant, yet asymmetric.

7 GHG emission control policies: variety and aggressiveness

All GHG emission control policies can be split into two groups:

- frameworking or enabling policies affect evolution and structure of economic growth, population, industrial output, housing construction, inflation parameters, etc.;
- policies that promote energy efficiency, energy security, and GHG emission control:
  - technical progress in energy efficiency improvements in energy transformation and end-use processes;
  - energy prices;
  - carbon tax or carbon price in emission trading markets;
  - fuel substitution in various sectors;
  - nuclear energy production;
  - hydro energy production;
  - energy production from renewable sources;
  - heat generation by thermal power plants (TPP);
  - heat generation by nuclear plants;
  - heat generation from renewable sources;
  - biofuel production;
  - share of natural gas losses;
  - share of gas flaring;
  - share of coalmine methane utilization;
  - carbon capture and storage.

Specific energy policies may not necessarily aim at GHG emission control, but rather at the improvement of energy efficiency and energy/environmental safety, reduction in polluting substances emissions, yet have a substantial indirect GHG emission reduction effect.

It is not only the set of measures that matters, but also how they are packaged and how aggressively implemented. In order to attain ambitious GHG emission control goals, some energy policies may be implemented more intensely, becoming special climate policy measures. Then they may provide indirect effects related to the improvement of energy efficiency / energy and environmental safety.

Globally, an approach that couples global warming evolution and intensity of emission control policies is used (Van Vuuren et al., 2012; Kriegler et al., 2012). For Russia, it hardly makes sense to couple agreed social and economic policies development trajectories with the warming levels, since the warming will be determined by efforts taken by all countries. However, it does make sense to compare these development trajectories with GHG emission evolution trajectories for Russia to 2050 and beyond, as rated by emission control ambitions (Bashmakov, Myshak, 2013).

The list of specific GHG emission control policies and combinations thereof is pretty long, so there are sufficient possibilities for attaining GHG emission control policy goals, but not for a compact classification of these policy packages. Therefore, GHG emission control policies may classified by allocating individual policies to one of the three groups (IEA, 2013):

- **"current measures"** include policies adopted by regulations and already in use as of summer 2013, with verification as required to attain the specified targets. These policies partially include the provisions of the "Integrated implementation plan of the Russian Climate Doctrine to 2020" approved by the RF government on 25.04.2011;
- **"new measures"** include policies which would allow it to keep emission at a level at least 25% below the 1990 level[40]), including measures specified in the "Integrated Plan", but not launched yet. They may be launched before 2020. These include: development and deployment of economic instruments for GHG emission control; implementation of additional energy efficiency policies, primarily in the industrial sector; implementation of measures aiming to develop renewable and nuclear energy and cogeneration; improvement of fuel efficiency of vehicles; promotion of passive buildings construction;
- **"vigorous measures"** measures aiming at a profound reduction in GHG emissions in relation to the baseline and sustaining the emission at a level at least 50% below the 1990 level, including electrification of automobile transport and substantial growth in hybrid car park; transition to a larger-scale construction of passive buildings; deployment of carbon capture and storage in the electricity and industrial sectors; substantial increase in the carbon tax rate or more stringent emission restrictions introduced to increase the carbon price in emission trading markets.

These policies are applicable to any one of GDP growth rate evolution range (Fig. 4).

8 Development of a matrix of scenarios

Each of the uncertainty zones in the evolution of the above variables consists of three segments: less probable upper zone (H), more probable zone (M) and less probable lower zone (L). Generally, development of scenarios may involve most diverse combinations of these zones. Four storylines are enough to structure the social and economic development options, if these storylines comprise all social and economic development options with minimal overlapping, and on the other hand, substantially limit the set of scenario families. In Table 2, each storyline is assigned with an uncertainty zone of critical scenario variables.

Table 2. Scenario families matrix*

Basic input variables for scenarios	Storylines (concepts of the future)			
	Dynamic growth	Moderate extensive growth	Moderate intensive growth	Slow growth
Population	H	M	M	L
GDP**	H	M	M	L
Factor productivity growth determined by technological progress	High (3-4% per year)	Moderate (1-2% per year)	Better than moderate (2-3% per year)	Low (0.5-1% per year)
Oil production	H	M	M	L
Natural gas production	H	M	M	L
Oil price	H	M	M	L
Emission control policies	current policies	current policies	current policies	current policies
	new policies	new policies	new policies	new policies
	vigorous policies	vigorous policies	vigorous policies	

* H – less probable upper zone; M – more probable zone; L – less probable lower zone.

** If GDP is specified in the model, GDP growth parameters are not input variables.

Source: Author.

[40] Complying with Presidential Decree No. 752 dated 30.09.2013 "On greenhouse gas emissions reduction".

“Dynamic growth” is possible subject to extremely high saving rate, comparatively high labour supply and savings excess, and therefore, high oil&gas revenues. A very dynamic resource efficiency improvement will be needed to provide resources required for such growth. Combination of all factors from the less probable upper zone reduces the integral probability of this family of scenarios.

On the other pole there is a “Slow growth” family of scenarios with a combination of scenario variables from the less probable lower zone. According to E. Gurvich, such development trajectory (“economy of apathy and stagnation”) may within several years lay a basis for reforms that are required to ensure institutional progress and transition to bottom-up modernization.

Two options with values from the more probable zone – “Moderate extensive growth” (“top-down modernization”) and “Moderate intensive growth” (“the confidence triangle”) – differ only in the assumptions related to the efficiency of major production factors. The second option, which is more competition-driven, assumes faster efficiency improvement.

Two options are possible while developing the marker-scenarios, i.e. most representative scenarios for each group. Since the entire range of control input variables is split into three zones, either the extreme range values (4 in all) or average range values (3 in all) may be used in calculations. It is suggested to go for the second option, yet not necessarily with the average values, but with any values that fit into this range; and if the evolution is cyclic, then with any values with a trend that fits into this range. Such approach allows it to well enough structure the social and economic development options without strangling the research groups by too tight universal marker-scenarios.

Combination of the major options for control input variables with the implementation of GHG emission control “current policies” would allow it to obtain estimates of the baseline emission trajectory for each of the four families of scenarios. Thus, there are four baseline scenarios, one for each family. Four more scenarios are obtained while assessing the effectiveness of the “new measures”. Assessment of contribution made by “vigorous measures” builds on the assumption that there will be neither determination, nor resources available to implement the “vigorous measures” under the “slow growth” (“economy of apathy and stagnation”) family of scenarios. Therefore, 11 potential groups of scenarios are developed. It is not mandatory for each research group to develop the entire set. Besides, each research group may develop a set of additional scenarios, where combinations of input variables may differ from those shown in Table 2.

9 Scenario analysis goals

Comparison of GHG emission scenarios that was made earlier (Bashmakov and Myshak, 2013) allows it to specify the agenda for additional research related to GHG emission projections for Russia and assessment of the effectiveness of various additional climate policies and energy-related GHG emission control instruments:

1. Assessment of the concept of “natural” absolute upper limit to GHG emission growth in the absence of specific climate policies. Is there such absolute limit? If yes, what is it? Why can’t it be exceeded?
2. Is it possible to verify correlation between climate policies and improvement of energy efficiency and economic effectiveness? Is there a synergy of effects and how significant is it?
3. What are direct and indirect effects of individual policies and Russia’s energy-related GHG emission control instruments?
4. How much can GHG emission be reduced to 2050 and beyond with (at no cost to the economic growth) in relation to the 1990 level?

5. Does GHG emission control hamper economic growth? If yes, then starting from what level of limitation?
6. What is the "solution space"? Which policies provide the largest emission reduction effect at least cost, no matter which cost metrics used?
7. In what sequence and schedule, and how aggressively should special policies and instruments to control energy-related GHG emission in Russia be launched?

10 Cost metrics for GHG emission control measures

One basic question to be answered using the scenarios is: what may be the costs of GHG emission control strategies? Cost metrics are needed to answer this question.

GDP annual or cumulative loss or individual consumption loss (in relation to the baseline scenario) is often used for this purpose. However, no account is usually taken of possible reduction of climate change-induced damages, or of indirect effects related to the reduction of environmental protection costs or to health improvements. These effects may be accounted for, if such macroeconomic indicators as green national product, human development index, cumulative (comprehensive) prosperity index, etc. are used in models instead of GDP; however, this is not the case so far.

Cost assessments of environmental protection measures normally build on the assumption that these measures do not contribute to GDP, and neither avoided damage or indirect benefits are monetized. Such assumption gives grounds to a point that these investments are infinitely capital intense and lead to economic growth loss in relation to an alternative investment strategy with a finite capital intensity. However obviously, in a country with limited male life expectancy environmental improvements lead to larger workforce supply and so may provide additional growth resources.

Additional (in relation to the baseline) cumulative investments or costs are another indicator (giving rise to a question related to the assessment and aggregation by sectors and by years). They can be associated either with loss, or with additional economic growth.

Marginal cost of emission reduction required to attain the emission control goals is one more indicator. It is expressed as price per ton of $CO_{2\text{-eq}}$. However, it rather reflects the emission price or emission tax rate, than the cost of emission control measures. This latter is obtained as the marginal abatement cost function.

In full economic models, GDP is either assessed or verified with an account of impacts provided by emission control policies. Obviously, primary energy demand volume and patterns modify the economic environment (resource restrictions, affordability and prices; energy supply investment scale and structure, incremental capital intensity of individual energy supply options). GDP reduction in relation to the baseline scenario is determined by the assumption that resources are used with maximum efficiency. However, this assumption is incorrect, if resource distribution mechanisms are imperfect (or inadequately reflected in the model), or if there is substantial government interference and/or high monopolization and poor public administration. Therefore, there are policy options that can both provide emission reduction and spur economic growth.

In partial economic models, GDP is not an endogenous, but an input variable. They often "assume" that: more stringent emission control policies involve additional costs and GDP growth reduction; lower economic activity makes emission reduction easier; lower economic activity is accompanied by slower deployment of new technologies (Van Vuuren et al., 2012). None of these "assumptions" are fundamental truth, all need to be proved and may turn out incorrect. Therefore, the finding related to the hampering role of the transition to a low-carbon economy is, in fact, not a finding, but rather an assumption embedded into such models.

In practice, it is not emission control parameters, but other input assumptions and other factors that dominate in determining economic growth parameters. With this in mind, the impact provided by climate policy on GDP is negligible (Van Vuuren et al., 2012). In other words, erroneous or successful economic policies in other sectors may result in far larger GDP loss (or increase), than GHG emission control measures. For example, recent developments, including “shale gas revolution”, and resulting regional energy price evolution have lead to diverse shifts in the energy balances of individual world regions, affecting both competitiveness and economic growth to a far larger degree, than any earlier emission control policies. The same goes for the debt crisis: growth incentives in the early 21st century, to the detriment of the future, substantially hampered economic development 10 years later.

For the sake of projection results comparability it is best if similar cost metrics are used. For example, assessment of GDP evolution (in percent), which does not require that all indicators are given in comparable prices, but leaves open the question related to the GDP baseline value. Another example is losses of average annual GDP growth. If GDP losses are set at 2% by 2050, then losses of average annual GDP growth will be only 0.05%. Speaking about, say, 2% losses, it is important to remember, that Russia’s annual military spending exceeds 4.4% GDP (SIPRI, 2013), and inability to reduce external factor vulnerability along with earlier economic mistakes cost Russia nearly 8% GDP in 2009, while in many countries the losses were much smaller.

For cumulative costs, it is advisable to follow IPCC and use 5% discount rate and assess costs as the ratio of cumulative discounted additional (incremental) investments to cumulative discounted GDP (or consumption). Then cost metrics would be better comparable.

Finally, another approach is possible, the one that was used by IEA (2013a): identification of a set of additional emission control measures that do not reduce GDP, because additional costs of low-carbon technology development are compensated by reduced costs of production, fuel purchase, and environmental protection. IEA came to a conclusion, that reduction in global energy-related emission by 2020 by 3.1 Gt $CO_{2\text{-eq}}$ (10% of the 2012 emission, or 80% of reduction required to cap the global warming at $2^{o}C$) is possible without GDP losses.

Therefore, in order to ensure comparability of scenario projections and models, it is best to go beyond carbon price and provide assessments of relative GDP or individual consumption evolution, discounted incremental costs of emission control in relation to GDP. While comparing various costs metrics it is important to remember, that GDP deviations may be somewhat more prominent, than consumption deviations, and either of them may be more prominent, than the ratio of emission control costs to GDP.

11 Input and output parameters for comparison and database development

In order to compare scenarios, it is important to have basic assumptions and results documented. Certain parameters may be input variables in some models and endogenous variables in others.

Minimal requirements to the scenario database development include the following scenario parameters:

- macroeconomic variables:
    - population;
    - number of employees;
    - GDP;
    - oil production;
    - natural gas production;
    - oil price;

- emission control policies:
  - evolution of GDP energy intensity and other parameters of technical efficiency improvement in energy transformation and end-use;
  - primary energy demand;
  - consumption of basic fuels;
  - nuclear energy production;
  - hydro energy production;
  - electricity production from renewable sources;
  - heat generation by thermal power plants;
  - heat generation by nuclear plants;
  - heat generation from renewable sources;
  - biofuel production;
  - share of natural gas losses;
  - share of gas flaring;
  - coalbed methane utilization;
  - carbon capture and storage;
  - energy prices;
  - carbon tax or carbon price in emission trading markets;
- Evolution of energy-related GHG emission[41], total (mln. t $CO_{2\text{-eq.}}$), including:
  - fossil fuel GHG emission, total (mln. t $CO_{2\text{-eq.}}$), including:
    - CO_2;
    - CH_4;
    - N_2O;
    - other GHG;
  - GHG emission from process leaks and emissions, total (mln. t $CO_{2\text{-eq.}}$), including:
    - CO_2;
    - CH_4;
    - N_2O;
    - other GHG;
  - GHG emission from other anthropogenic sources[42], total (mln. t $CO_{2\text{-eq.}}$), including:
    - CO_2;
    - CH_4;
    - N_2O;
    - other GHG;
- Costs of emission control policies:
  - relative change in GDP;
  - relative change in individual consumption;
  - discounted incremental costs (including benefit increase) of emission control;
  - discounted incremental costs (including benefit increase) in relation to discounted GDP.

[41] As defined by IPCC.
[42] Providing they are included in the model.

Obviously, not all inputs and outputs include the whole set of these parameters. For example, the set of GHG emission sources may vary in different models. It is important to the maximum possible degree reflect this information, leaving blanks where unavailable.

Information is provided for 1-year intervals. Models with large time intervals provide data for every 5 or 10 years.

For better comparability and simplicity, it is suggested that data related to fuel and energy consumption are provided in tce, to electricity consumption in bln. kWh. Cost information is best provided in 2012 prices with corresponding Rosstat deflators or price indices, so that parameters that are provided in other years prices could be expressed in 2012 prices.

With these data obtained, a database of GHG emission projection scenarios to 2060 can be developed, and building on this structured information projections and findings can be compared. The projection database would allow for the projection results to be used not only by the research groups, but also by other experts and decision-makers. Each modeling group may decide for itself, which data it would be willing to make public.

12 Uncertainty parameters

Individual scenarios and families of scenarios do not have equal probabilities. Scenario likelihood assessment is based on the consistency of assumptions and results. Such assessment may include a number of criteria. I. Bashmakov (2009) used three:

- sufficiency of the resource base to sustain oil, gas, and coal production (see Section 7 *Fuel and energy production and consumption*);
- energy price evolution and energy affordability for consumers (with the growth of energy bills to GDP ratio far beyond 10%, economic growth slows down or even terminates, see Bashmakov, 2007);
- potential change in Russia's position in global energy markets (change in export revenues to a level when assumptions about GDP growth or other macroeconomic variables become inadequate).

Other criteria are also possible. Each one of them allows it to: assess the probability of fossil fuels production levels as set in the scenarios, or the possibility to maintain high economic growth rates with various options for energy price growth or changes in Russia's position in global fuel markets. An integral assessment by these three and possible additional criteria allows it to estimate the likelihood of each of the four families of scenarios. It may be provided quantitatively, although there may be not sufficient grounds for such quantitative assessments. The same goes for the assessment of the reliability of basic findings related to the costs of emission control policies.

Qualitative assessments of the reliability (confidence) of results, similar to those made by IPCC, are possible: very high confidence (more than 90% probability); high confidence (more than 80%); moderate confidence (more than 50%); low confidence (20% or lower); and very low confidence (10% or lower). Or three levels of confidence instead of five may be involved: high, moderate, and low. These levels are set by every research group at its own discretion.

Each result obtained by each research group may be accompanied by an assessment of expert community agreement. Four levels of expert community consent may be involved: low (consent of less than 33% of the groups that have submitted their results), moderate (consent of 33-67% of the groups), high (consent of more than 67%), and very high (unanimous consent). Therefore, each finding of the comparative analysis of the projection results will be supported by both individual assessments of practicability and expert community agreement regarding the critical parameters of sustainable development and GHG emission control policies. This should help decision-makers form their attitudes towards the most important parameters of sustainable development and GHG emission control policies. It will also help identify the “gaps” in the knowledge and reveal the need for further analysis to obtain more reliable results.

13 List of research groups that took part in the project

5 Russian and 2 foreign expert groups took part in the project.

Russian organizations:

- Center for Energy Efficiency;
- Institute for Economic Forecasting of the Russian Academy of Science;
- Energy Research Institute of the Russian Academy of Science;
- The Russian Presidential Academy of National Economy and Public Administration;
- Economic policy institute (Gaidar Institute);

Foreign institutions:

- International Energy Agency;
- Massachusetts Institute of Technology. The MIT Joint Program on the Science and Policy of Global Change.

Exchange of projection results between expert groups will allow it to lay the grounds for an ongoing forum to discuss long-term perspectives for Russia’s economic, energy, and environmental development, similar to the Energy Modeling Forum created in 1976 in Stanford University[43]. At the beginning, EMF annual conferences were a platform to discuss energy development and environmental aspects of the U.S. alone; at a later stage it turned into an international forum. In Russia, a different evolution is possible: from energy development and environmental aspects on the federal level to regional projections. This project may lay the grounds for a Russian energy modeling forum.

[43] http://emf.stanford.edu/

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Section III

Center for Energy Efficiency (CENEf)

Igor Bashmakov

Low-carbon social and economic development scenarios for Russia to 2050

1 Maths of the future: analysis instruments and logics

Many countries have set, in this or that form, their national greenhouse gas (GHG) emission reduction targets for 2020. The EU has committed to reduce its emission in 2020 by 20% of the 1990 level. In 2013, the U.S. have committed to reduce their emission by 17% over 2005-2020[44]. Attention of governments and experts from industrialized countries is increasingly focused on possibilities to substantially reduce anthropogenic GHG emission by mid-XXI century, and they come up with a finding that this is feasible, both technically and economically. In the Roadmap for moving to a competitive low-carbon economy by 2050 adopted in 2011, the EU sets the target of reducing emission by 80% by 2050 with intermediate objectives of 40% by 2030 and 60% by 2040.

Russia has already achieved not only 20%, but even 30% emission reduction[45]. However, the problem of complete neutralization of emission growth is yet to be addressed. The estimate of GHG emission growth in 2011 (6.7%) provided in the National Inventory Report set off alarms[46]. Such growth poses a potential threat to complying with Presidential Decree No. 752 "On greenhouse gas emissions reduction", which sets the goal of maintaining the emission below 75% of the 1990 level (25% reduction).

Can Russia reliably comply with Presidential Decree No. 752 and ensure absolute reduction in its GHG emission in the coming years or will the emission keep growing for a while? What can be the "price" of such reduction? What can be Russia's commitments to 2030 and 2050? Can it reduce its emission by 50%[47] or more? Answers to these and similar questions are not obvious, but they are important, especially before the new round of negotiations on the new global agreement which is to (may) be signed in 2015.

Since a great number of interacting factors in very large and complex systems "resources-technologies-economy-energy-environment-society" are to be taken into account, and these factors are distributed both spatially and temporally, such analysis is normally made using large and complex mathematical models that help develop projection scenarios. This paper presents the results of estimates obtained through a system of imitation models developed by the author. ENERGYBAL-GEM-2050, an imitation model based on the concept of Integrated Fuel and Energy Balance (IFEB), is the core of this system. It helps estimate integrated annual energy balances, as well as balances for individual energy sources to 2050. The model allows it to evaluate a large number of parameters, including consumers' energy spending and capital investments. Major factors of demand functions include: indicators of economic activity in individual (46) sectors; energy prices; weather, capacity load; technology parameters. The model integrates a block of three GHGs (CO_2, CH_4 и N_2O) emissions from all sectors.

RUS-DVA-2050 is a two-sector economic development imitation model. Oil&gas sector includes production, refinery, transportation and sales of crude oil, petroleum products, and natural gas. Non-oil&gas sector (the rest of the economy) produces one product. The model integrates the following blocks: GDP, overall demand, balance of payments, consolidated budget, and prices. The model has a one-year step and a projection horizon to 2050.

Besides, the system incorporates a set of models for individual energy consumption sectors, including electricity sector, heat supply sector, industrial sector, transport, public and

[44] In other words, 2020 emission will be only 2% below the 1990 level.

[45] For a detailed analysis of the 1990-2010 emission dynamics and drivers see (I. Bashmakov, A. Myshak. 2012).

[46] This estimate needs verification. CENEf estimates the 2011 emission growth at 3.5%. In 2012, according to CENEf, the emission was not growing, while in 2013 it declined.

[47] Complete implementation of the technical potential of three GHG emissions reduction (basically through energy efficiency measures) would allow it to bring down the emission to 46% of the 2010 level, or to 31% of the 1990 level (Bashmakov and Myshak, 2012).

commercial, and residential sectors. This is a system of lower-level models that allows for a detailed presentation of modernization processes in these sectors and then for the identification of aggregated technology parameters of energy demand functions for ENERGYBAL-GEM-2050. A set of sectoral models is used to assess the effectiveness of a large variety of energy efficiency policies and their impacts on the evolution of the production technology mix. This allows for quantitative assessment of the effectiveness of various energy efficiency measures in individual sectors. Sectoral models also have a one-year step and a projection horizon to 2050. RUS-DVA-2050, ENERGYBAL-GEM-2050, and the models for individual sectors are running as a comprehensive system.

The logic of the analysis follows the agreed scenario assumptions. This project included calculations on the system of models by all 11 scenarios: for all combinations of 4 economic development trajectories and 3 sets of emission control policies, excluding vigorous policies with slow GDP growth. The following abbreviations are used in the text below to distinguish between the scenarios: CP – "current" policies; NP – "new" policies; VP – "vigorous" policies; Dyn.Gr. - dynamic growth; Mod.Int.Gr. – moderate intensive growth; Mod.Ext.Gr. – moderate extensive growth; Sl.gr. – slow growth.

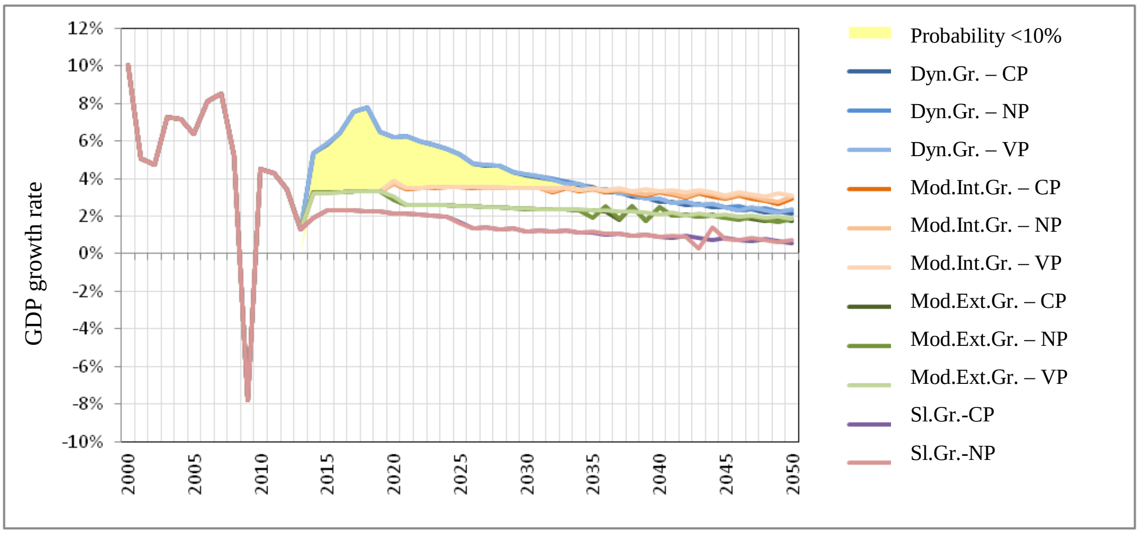
Analysis of the modeling results for each scenario allows it to understand the degree of compatibility with the initial assumptions and to see if they are (in)consistent. The likelihood of each scenario was estimated by seven criteria: sufficiency of oil and gas reserves; overall productivity improvement possibilities; energy affordability; possible change in Russia's position in the global oil and gas market; and the probability of launching emission control policy packages.

2 Major calculation results obtained for individual scenarios

"Dynamic Growth". These scenarios assume sustainable GDP growth at a rate faster than 5% per year through the "top-down modernization" by the innovative scenario (that implies dynamic renovation of fixed assets, energy efficiency and workforce productivity improvement, yet reduction in capital productivity), and so requiring/assuming a radical increase in the saving rate. These scenarios imply dynamic economic restructuring. The risks involved by these scenarios are related to a bloated public sector and excessive regulation of economy, which are incompatible with the economic efficiency improvement, as proved by the evidence of all countries with centrally planned economies. Besides, the risks include fast debt growth, which is incompatible with sustained dynamic economic growth, as proved by the experience of countries with market economies.

In its "boost" scenario, the RF Ministry of Economic Development assumes that fixed capital saving rate growth to 32% increases GDP growth rate to 8.1-8.2% in 2017-2018 (Fig. 1) with subsequent decline to 3.6% by 2030, averaging to 5.3% annual growth over 2013-2030 (RF Ministry of Economic Development, 2013). For no one year to 2050 a faster than 5% GDP growth rate was obtained through the RUS-DVA model runs through a significant (up to 32-35%) increase in the saving rate. The reason is that a large part of the additional investment demand cannot be effectively absorbed by the Russian investment complex and spurs inflation, while contributing just insignificantly (around 1% per year) to the acceleration of the economic growth. In reality, a substantial acceleration of GDP growth is possible through a radical increase in the overall factor productivity and subsequent cost reduction, rather than through the saving rate increase.

Figure 1. GDP growth rates for individual scenarios



Source: the author

This scenario assumes that nuclear energy production will grow up to 255 bln. kWh in 2030 and to 304 bln. kWh in 2050; hydro energy production to 236 and 281 bln. kWh respectively, geothermal energy production to 7 and 17 bln. kWh, and energy production from other renewable sources to 25 and 107 bln. kWh.

In the “Dynamic Growth – Current Policies” scenario:

- GHG emissions dynamically grow up to 83% of the 1990 level (by three GHGs) and to 78% of the 1990 level (by CO_2 alone) in 2020, primarily driven by extremely high economic growth rates, which are not compensated even by 4.2% (average over 2013-2020) energy intensity reduction determined, above all, by the dynamic structural shifts in the economy. Moderate development of “green” technologies, that is possible on the 2020 horizon, is not able to noticeably hamper the emission growth either;
- as the economic growth slows down, GHG emission increase rates decline. However, by 2050, the emission equals 3,170 mln. t $CO_{2\text{-eq}}$., which is 17% above the 1990 level, and does not peak yet (albeit showing less than 0.7% annual growth rate in the latest years).

This scenario is virtually unlikely, because:

- GDP growth rate increase to 5.3% per year on average over 2013-2030 and above 8% over 2017-2018 (Fig. 1) is possible only through the overall factor productivity increase to 4% on average in 2015-2021 and with a peak above 6% in 2017-2018. Such increase exceeds the contribution made by this factor in 1998-2008, and “manifold” exceeds the estimates made by many experts[48]. It is not clear, which factors can so drastically spur the overall factor productivity growth on the 2017-2018 horizon, since the RF Ministry of Economic Development itself views the period to 2020 as the internal restructuring interval. Capacity load growth, which was one critical factor behind the economic boom of the early 2000’es, is expected to play a much smaller role in the future;
- a substantial labour inflow along with a dynamic improvement of its quality are needed to ensure high economic growth rates. However, in most projections labour is fast declining. The RF Ministry of Economic Development forecasts 2-2.8% annual labour

[48] The estimate by O. Lugovoy and R. Entov (2013) is 0.7-1.7% to 2020, by OECD 2.3% by 2060. The estimate by the RF Ministry of Economic Development is 1.4-2.8% on average over 2013-2030.

productivity growth over 2010-2030. Therefore, 5.3% GDP growth is only possible with at least 2.5% per annum employment growth, while employment is expected to decline;

- overall natural gas production in 2013-2050 is 33 trln. m^3; reserves required to maintain production at the 2050 level for 30 more years equal 60 trln. m^3, which exceeds proved reserves (32 trln. m^3, according to the BP) and reserves by A+B+C1 categories (49 trln. m^3). Such cumulative levels of gas production can be supported by reserves with maximum 85% probability;
- driven by fast growing domestic demand and slow growing domestic gas prices, potential export of Russian gas shows dramatic decrease after 2029, and even with production growth to 920 bln. m^3 over 2040-2050, Russia becomes a net importer of natural gas in the late 40'es (gas import increases to 128 bln. m^3 in 2050). With slowly growing domestic gas price, gas industry revenues decline as the share of gas sold domestically grows, and so the financial base required to achieve such high production levels shrinks. In order to avoid this scenario, gas prices are to be increased (to 630 $/1,000 m^3), so that domestic demand would decline to offer at least 100 bln. m^3 for export in 2050. However, with so high domestic gas price it might make more sense to import natural gas;
- overall oil production in 2013-2050 is 17.6 bln. t, and oil reserves required to maintain production at the 2050 level for 10 more years equal 21.4 bln. t. This is more than proved oil reserves (11.9 bln. t) and estimated reserves by A+B+C1 categories (17.8 bln. t). Such production levels can be supported by reserves with not more than 47% probability;
- with oil production decline after 2030 driven by growing domestic demand for liquid fuel to 2035 (with subsequent demand saturation), oil export drops by 2050 to 204 mln t (41% of the 2013 level), and export of petroleum products to 35 mln. t (50% of the 2013 level);
- reduction in the oil&gas export substantially increases the role of the oil&gas sector in guaranteeing the budget and currency stability. Non-oil&gas export is to double by 2021 and grow faster, than at 5% per year, until 2050. The share of oil&gas revenues in the GDP declines to 4% in 2050.

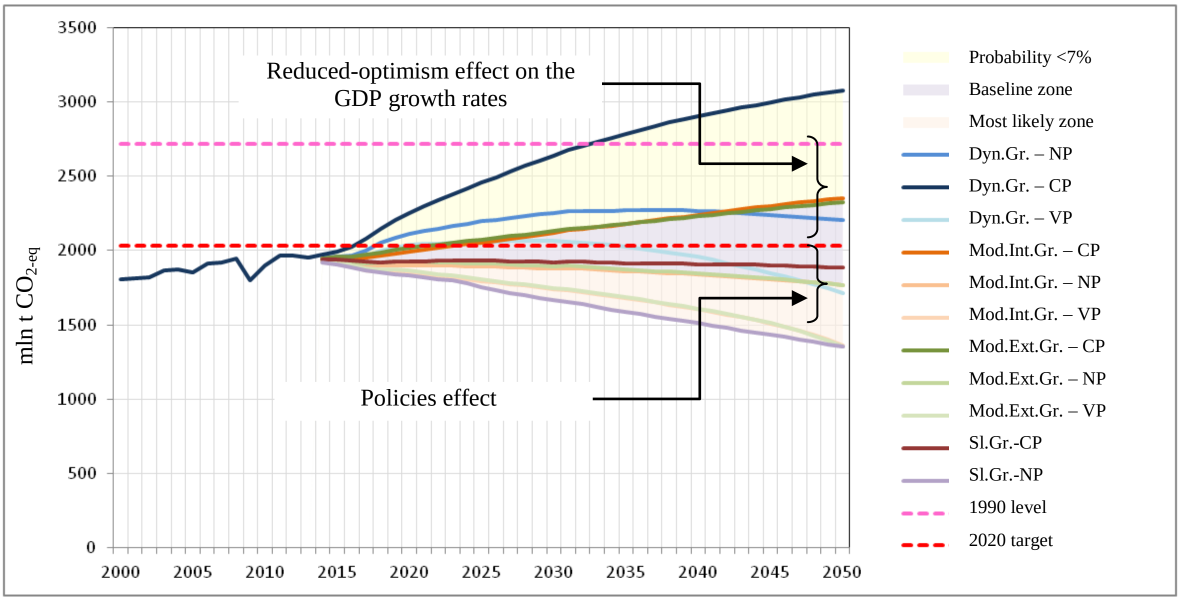
Summing up the estimation of probability for the "Dynamic Growth – Current Policies" scenario, it is **very unlikely**. Obviously, the RF Ministry of Economic Development does not remove this scenario from its projections list solely to honour the memory of the optimism in the "Concept for long-term development to 2020", which is now a thing of the past.

The "Dynamic Growth – Current Policies" scenario is a modification of the "Dynamic Growth" scenario, which assumes growth of domestic gas price by 2050 to 630 $/1,000 m^3 in order to maintain gas export at 100 bln. m^3 in 2050. Then emissions of three GHG show a less substantial growth by 2050 – to 3,080 mln. t $CO_{2\text{-eq}}$. (13% above the 1990 level), approaching the saturation (peak) level and growing up only at 0.5% per year in the latest years (Fig. 2). However, like mentioned above, this scenario is very unlikely (not more than 7% probability).

"Dynamic Growth – New Policies". It is very logical to assume that in a scenario with substantial acceleration of technological modernization processes a much more dynamic energy efficiency improvement is observed in all sectors. These premises were added to the assumptions. It was further assumed, that modernization and dated capacity retirement rates in the industrial sector will double, and these processes will deploy best available technologies (BAT); that in the buildings sector, building codes will dynamically improve, and in 2050 specific energy consumption by new buildings for space heating purposes will drop to 27% of the 2013 level. The efficiency of electricity and heat production and transmission will also considerably improve.

Spurring technological energy efficiency through "new" policies aiming to promote technological innovations more correlates with the logic of the "uprated" scenario with a substantial inflow of foreign capital and advanced technologies. In this scenario (Fig. 2), in 2020 emissions of three GHG equal 78% of the 1990 level (or 72% for CO_2 alone). Accelerated deployment of energy efficiency technologies increases the role of energy efficiency and develops a significant emission control potential. GHG emission grows much more slowly, and, as new energy production and use technologies are deployed, peaks in 2037-2038 at 2,274 mln. t $CO_{2\text{-eq}}$. (three GHG), which is 13% below the 1990 level (or 18% for CO_2 alone). By 2050, the emission is 19% below the 1990 level. Therefore, even in the "Dynamic Growth" scenario with integrated "new" policies energy-related GHG emission peaks at the turn of the 40'es and starts declining thereafter.

Figure 2. Energy-related GHGs emissions trajectories for individual scenarios



Source: Author

"Dynamic Growth – Vigorous Policies". In order to compensate the impact provided by fast economic growth on the emission evolution, deployment of "green" energy generation technologies is to be spurred through "vigorous" policies. "Vigorous" policies have not been adopted yet, while the time allowed for policy development and obtaining a tangible result by 2020 is running out. Therefore, this scenario aims at reducing GHG emission on a longer time horizon: to 2050. The set of "vigorous" policies includes:

- incentives for accelerated replacement of the cross-industry equipment (electric motors; air compression systems; lighting and ventilation equipment; steam supply systems; electric equipment; etc.);
- incentives for further development of nuclear and renewable energy production: growth in electricity production by nuclear plants to 262 bln. kWh in 2030 and to 422 bln. kWh in 2050; by hydro power plants to 248 bln. kWh and 328 bln. kWh respectively; by geothermal plants to 19 bln. kWh and 54 bln. kWh; and by other renewable energy sources to 58 bln. kWh and 422 bln. kWh, with respective electricity tariff growth;
- introduction of carbon tax, effective from 2016, in the amount of 10 USD/t CO_2 with subsequent gradual increase to USD 90 by 2040 and to USD 140 by 2050;

- development of carbon capture and storage technologies, starting from the moment when the carbon tax rate exceeds 58 USD/t CO_2, with the volume of carbon storage growing up to 55 mln. t CO_2 by 2050.

In the "Dynamic Growth – Vigorous Policies" scenario:

- in 2020, emissions of three GHG equal 75% of the 1990 level (69% for CO_2 alone)[49];
- GHG emission peaks in 2028 at 76% of the 1990 level (70% for CO_2 alone);
- by 2050, emissions of three GHG, driven by vigorous policies, decline to 63% of the 1990 level, and CO_2 emission to 53% of the 1990 level.

Deployment of low-carbon technologies, accelerated through "vigorous" policies, allows it to substantially hamper emission growth (Fig. 2). "Vigorous" policies result in a considerable reduction in domestic natural gas consumption and, therefore, in natural gas export growth to 420 bln. m^3 in 2030 and to 480 bln. m^3 in 2050, subject to maintained high production levels (920 bln. m^3 in 2030-2050). In most long-term projections (by IEA, BP, ERI, etc.), Russia's natural gas export market niche is limited to 350 bln. m^3 in 2030-2035. If we view this export volume as the maximum value, then natural gas production peak (864 bln. m^3) will be achieved in 2035 followed by gradual decline to 790 bln. m^3. Along with other effects, this will allow it to reduce capital investment in the development of the gas industry by 11 trln. rubles (in 2013 prices). This effect alone covers 65% of additional investment demand (17 trln. rubles in 2013 prices) by "vigorous" policies.

Summing up the analysis of the "Dynamic Growth" family of scenarios, the following findings may be highlighted:

- if radical acceleration of technological modernization (including dynamic improvement of energy efficiency in all sectors and fast development of renewable energy sources) is viewed as the basis for such growth, GHG emission peaks in the 20-30'es (depending on how aggressively low-carbon technologies are promoted). In 2020, emissions of three GHG equal 75-83% of the 1990 level;
- technological modernization allows it to cap domestic natural gas consumption growth and so to reduce the gas industry investment demand through additional investments in low-carbon technologies;
- the "uprated" economic growth scenario is exceptionally unlikely, as this scenario is not supported by the necessary resources or sources of growth.

"Moderate Extensive Growth – Current Policies". Development along this group of trajectories is possible subject to a successful modernization financed from substantially large, albeit slowly growing (even declining in the 40'es), oil&gas revenues, and with an account of restrictions related to the saving rate growth possibilities and effects[50]. Development under this scenario implies gradual oil production decline to 332 mln. t by 2050, gas production increase to

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[49] Let us make a point that CENEf's estimates of three energy-related GHG are 2.5% above the data for 2011 in the National Inventory Report. This difference is observed over the whole period of 2000-2011. By 2011, it somewhat reduced, after the National Inventory methodology had been improved, including as suggested in (Bashmakov and Myshak, 2012). Therefore, estimates for 2020 are somewhat lower, if GHG emission evolution projections are based on the data from the 2011 National Inventory Report.

[50] With the saving rate gradually growing to 26% by 2020 and then showing slow and smooth decline, GDP only grows up by 1.8% by 2050. If the saving rate grows to 30% by 2020 and then shows smooth decline, GDP grows up by 3% in 2050, or less than at 0.1% per year. Acceleration of the inflation rate by 5-8% per year to 2020 and beyond and fast devaluation of ruble (or, with ruble exchange rate control, strengthening of ruble and falling costs of import, and so lower competitiveness of Russian goods) can become a negative result of fast growing saving rate. Growth of the overall factor productivity (labour productivity, capital, and energy efficiency) is a larger contributor to the economic growth, than the growth of the saving rate.

777 bln. m^3 by 2030 with subsequent stabilization at this level, and nominal oil price growth to 162 USD/barrel by 2030 and to 248 USD/barrel by 2050. All this manifests replacement of the recent economic growth model driven by continuously growing oil&gas revenues, with a model that implies sustainable reduction in the role played by oil&gas revenues in the GDP, in the budgetary system, and in the foreign trade balance.

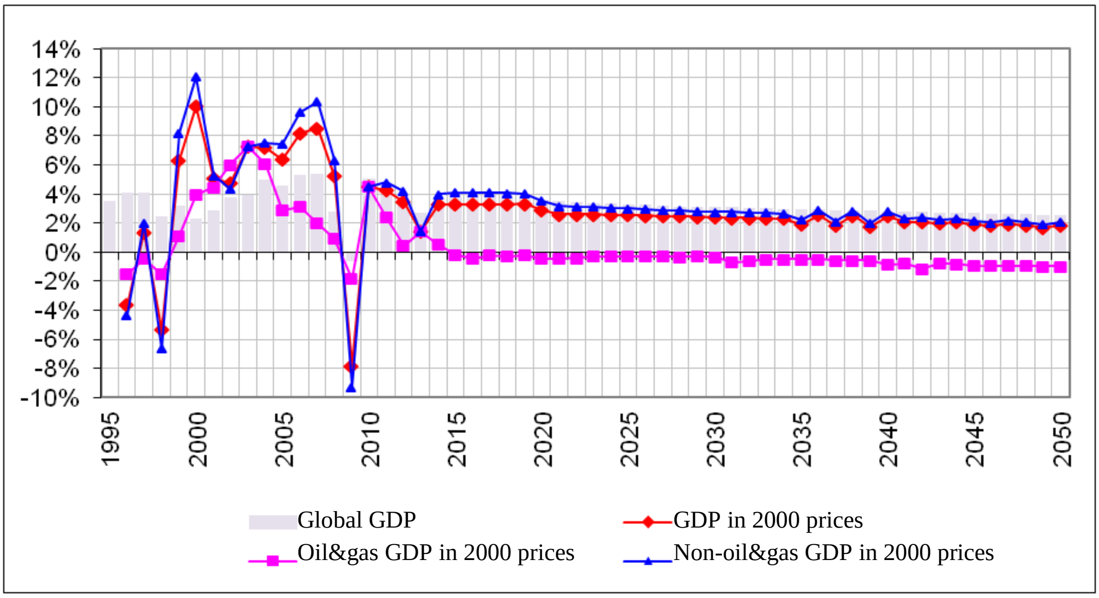
With a favourable situation in the hydrocarbons markets and moderate success in the factor productivity improvement it is possible to achieve 3-4% sustainable annual GDP growth in Russia (the rate close to the global trend) for the next few years with subsequent reduction to 2-3% (Fig. 3).

The set of "current" policies includes:

- measures to spur energy efficiency improvements under the RF federal programme "Energy efficiency and energy sector development";
- growth of electricity production by mini-hydro plants and from renewable sources;
- growth of electricity production by nuclear plants;
- partial substitution of liquid fuel with natural gas in the transport sector;
- reducing gas flaring to 5% by 2015 (by 2017 sounds more realistic) and enhancement of coalbed methane utilization.

Measures aimed at increasing electricity production from renewable sources and partial substitution of liquid fuel with natural gas in the transport sector were adopted in spring 2013. In compliance with Subprogramme 6 "Promotion of renewable energy sources" of the RF Federal programme "Energy efficiency and energy sector development" enforced by Government decree No. 512-r dated 03.04.2013, the share of electricity production from renewable sources in the total electricity production (excluding production by hydro plants with more than 25 MW installed capacity) is to grow up to 2.5% due to the commissioning of 5.9-6.2 GW capacities. The RF Government decree No. 449 dated 28.05.2013 "On the mechanism to provide incentives for renewable energy in the wholesale electricity and capacity market" specified the mechanisms to be deployed to attain the target. Electricity production in 2020 may equal 1,100-1,200 bln. kWh. If the share of renewable sources is 2.5%, around 30 bln. kWh will be produced from renewables, and the increase in production over 2013-2020 will equal nearly 18 bln. kWh. Since this measure was launched before mid-2013, it was classified as a current policy. The same goes for the RF Government decree No. 767-r dated 13.05.2013, which requires that a substantial part of public transport and road service transport (up to 50% in large cities and up to 10% in small cities) be transferred to compressed gas by 2020. Depending on whether or not minivans are included, natural gas consumption by the above vehicles may grow up to 1-3 mln. tce by 2020. Development of the CNG filling stations network will also contribute to the promotion of natural gas use by light- and heavy-duty vehicles and agricultural transport. Analysis of impacts provided by these measures, which were launched in the first half of 2013, takes into account a possibility of only partial compliance with the targets set for 2020. Raising energy prices has temporally fallen out of the list of measures, because so far no decision has been made related to the slowdown of natural gas, electricity, and heat price growth.

Figure 3. **Evolution of GDP and its components in Russia to 2050 in the "Moderate Extensive Growth – Current Policies" scenario**

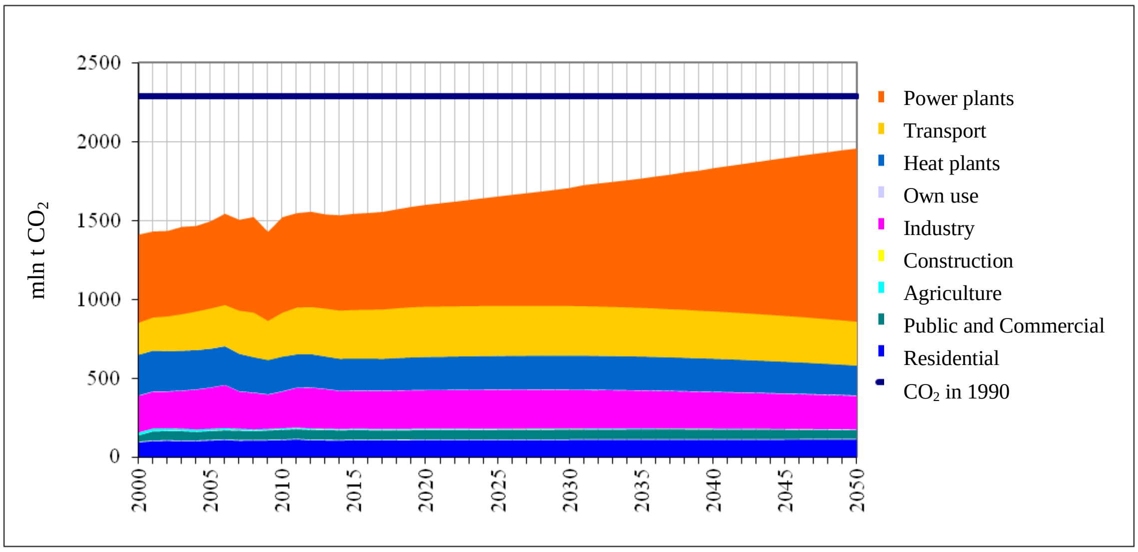


Source: estimated by author

In the "Moderate Extensive Growth – Current Policies" scenario (Fig. 2):

- GHG emission shows growth and in 2020 equals 74% of the 1990 level (for three GHG) and 70% of the 1990 level (for CO_2 alone), driven by the economic growth which is not compensated by either energy intensity reduction (it only drops by 23% over 2007-2020 versus the 40% target), or deployment of low-carbon electricity generation technologies;
- until 2050, emissions of three GHG keep growing and reach 2,323 mln. t $CO_{2\text{-eq}}$., which is 14% below the 1990 level (17% for CO_2 alone). The emissions grow primarily in the electricity sector (Fig. 4).

Figure 4. **Structure and evolution of energy-related CO_2 emission in the Moderate Extensive Growth scenario**



Source: estimated by author

With moderate extensive growth, even current policies and even if only partially implemented allow it to maintain GHG emission in 2020 at 26% below the 1990 level, meeting the requirements of Presidential Decree No. 752 "On greenhouse gas emissions reduction". As the economic growth slows down, GHG emission growth rates also decline. However, the same goes for the energy intensity reduction rates (including energy intensity reduction driven by the decreasing role of structural shifts), whereas the share of non-fuel electricity generation even drops from 34% to 31% in 2020-2050. This does not let carbon intensity reduction completely compensate the contribution made by the economic growth. However, in 2049-2050, GHG emission only grows at 0.3% per year and approaches the absolute maximum point.

Economic growth estimates obtained using the RUS-DVA model are quite close to those in the moderate-optimistic scenario by the RF Ministry of Economic Development. Total natural gas production over 2013-2050 equals 28.7 trln. m^3, reserves needed to maintain production at the 2050 level for another 30 years are 51.9 trln. m^3. With 95% probability the reserves are sufficient to maintain these cumulative natural gas production levels. Russian gas export drops to 113 bln. m^3 by 2050 driven by domestic demand growth (primarily in the electricity and automobile transport sectors).

Total oil production over 2013-2050 equals 16.7 bln. t, and reserves needed to maintain production at the 2050 level for another 10 years are 20.1 bln. t. With maximum 50% probability the reserves are sufficient to maintain these oil production levels. In other words, there is a need for programmes aimed at petroleum products substitution in the transport sector. Given oil production decline beyond 2030, oil export drops in 2050 to 74 mln. t (32% of the 2013 level). Driven by growing until 2035 domestic demand for liquid fuel (with subsequent saturation), export of petroleum products declines to 149 mln. t (76% of the 2013 level), but then, as natural gas use by the transport sector increases, starts growing and by 2050 accounts for 149 mln. t, which is slightly above the 2013 level.

There is a wide set of policies which can improve economic growth and slow down oil&gas export decline, and at the same time substantially reduce GHG emissions.

"Moderate Extensive Growth – New Policies". In this scenario, technological modernization rates increase through additional ("new") policies. However, both the set of measures and implementation commitment may be limited. The set of "new" energy efficiency policies which can generate 150 mln. tce in additional energy savings by 2020 includes[51]:

- long-term target agreements to deploy best available technologies and attain the energy efficiency targets in electricity and heat generation and transmission and in the railway and pipeline transportation;
- long-term target agreements under the "500-500" programme, which can bring 160 mln. tce in cumulative energy savings by large energy-intense industries over 2013-2020 and 500 mln. tce over 2013-2030;
- "white certificates" in the industrial, public, and residential sectors;
- promotion of the ESCO mechanism in the public, residential, and industrial sectors;
- energy efficiency labeling for typical industrial and transport equipment and appliances and making buildings codes more stringent in terms of energy efficiency;
- increasing share of multifamily and public buildings that undergo capital refurbishment and expanding the list of mandatory energy efficiency measures included in the capital refurbishment programme;
- energy efficiency programmes for low-income households ("Warm House" and "Cheap Light");
- energy efficiency labeling for equipment and buildings and subsidies for purchasing and/or construction of efficient equipment/buildings;

[51] For more detail see (Bashmakov, 2014). Many of them are specified in the Minutes No.4 dated 22.11.2013 of the meeting of the Presidium of Presidential Council for economic modernization and innovative development.

- subsidies for SME to promote the development and implementation of energy efficiency programmes;
- incentives to promote purchase of hybrid and small cars;
- programme for energy utilities in isolated areas;
- government procurement of energy efficient office equipment, appliances, and vehicles.

In the “Moderate Extensive Growth – New Policies” scenario (Fig. 2):

- GHG emissions evenly decline to 71% of the 1990 level in 2020 and to 1,769 mln. t $CO_{2\text{-eq.}}$ in 2050 (35% below the 1990 level for three GHG, or 41% below the 1990 level for CO_2 alone);
- contribution made by the economic growth is completely compensated by the reduction in GDP energy intensity (27% reduction over 2007-2020). Primary energy demand shows only 4% growth by 2050. Non-fuel electricity generation technologies allow for emission stabilization and subsequent declining trend;
- the role of electricity sector in the emission structure sustainably grows.

Additional investments in energy efficiency allow for a substantial increase in the natural gas and petroleum products export potential without any production growth. Therefore, “new” policies not only do not hamper GDP growth, but even slightly accelerate it by 2050. The alternative might be reduced oil and gas production and resulting reduction in production costs.

The following questions remain unanswered: can GHG emission be substantially reduced by 2050 (to, say, 50% of the 1990 level), through which measures, and at what price.

“Moderate Extensive Growth – Vigorous Policies”. The package of “vigorous” policies includes:

- rejection of the electricity net export increase strategy (20 bln. kWh cap);
- promotion of nuclear and renewable energy development: growth of electricity generation by nuclear plants to 255 bln. kWh in 2030 and to 373 bln. kWh in 2050; by hydro plants to 248 bln. kWh and 313 bln. kWh respectively; by geothermal plants to 19 and 54 bln. kWh respectively; and growth of electricity generation from other renewable sources to 48 and 318 bln. kWh;
- carbon tax effective since 2016 in the amount of 10 USD/t CO_2 with subsequent gradual increase to 60 USD in 2040 and to 90 USD in 2050;
- raising energy prices in correlation with accelerated deployment of non-fossil electricity sources and introduction of carbon tax (price for electricity generated from fossil fuels will rise by 10% and for heat by 16% in 2050, as driven by the carbon tax);
- development of carbon capture and storage technologies starting from the moment when the carbon tax rate exceeds 58 USD/t CO_2 with subsequent growth of carbon storage to 19 mln. t CO_2 in 2050;
- increasing production of biofuel for partial substitution of petroleum products in the transport sector (3 mln. tce in 2040 and 34 mln. tce in 2050).

In the “Moderate Extensive Growth – Vigorous Policies” scenario (Fig. 2):

- GHG emissions sustainably decline on the entire time horizon to 2050 when they equal 50% of the 1990 level (41% for CO_2 alone). In other words, technically and economically it is possible to halve emissions in 2050 in relation to the 1990 level;
- in 2020, emissions of three GHGs equal 69% of the 1990 level (64% for CO_2 alone).

Since 2041 onwards, reduction in carbon intensity becomes a more important factor, than reduction in energy intensity. Additional investments in the development of low-carbon technologies allow it to more substantially, than in the previous scenario, expand natural gas and petroleum products export without increasing production levels, and so reduce capital costs in the oil&gas sector by 6 trln. rubles in 2013 prices.

"Moderate Intensive Growth". In the "Moderate Extensive Growth" family of scenarios it is assumed that by 2020 institutional measures will enhance the role of competitiveness in the economy, improve the effectiveness of programmes aimed at the improvement of labour productivity and of return on invested capital, as well as at the reduction in material- and energy intensity, and so double the contribution of the overall factor productivity (from 1% per year on average in the extensive growth scenario to 2% in this scenario). All the other assumptions of the three previous scenarios remain. In the scenario with "vigorous" policies, carbon tax rate grows up to USD 130 by 2050.

In this case GDP growth rate is on average 1% per year higher, than in the extensive growth scenario (Fig. 1); energy intensity declines faster driven by both larger contribution of structural shifts and accelerated modernization of equipment. Ultimately, despite much more dynamic economic development, emissions of three GHG in scenarios with "current", "new", and "vigorous" policies are hardly any different from similar trajectories in the moderate extensive growth scenarios: in 2050 they deviate around 30 mln. t $CO_{2\text{-eq.}}$ (Fig. 2).

"Slow Growth – Current Policies". This scenario implies maintaining the current political, social, and economic development model, given depleted sources of growth and inability to make a transition to a new development pattern; adaptation of economic and social policies to the reduced oil rent and lack of effective mechanisms to allow for a capital flow from the raw materials to other sectors. The RF Ministry of Economic Development calls this scenario, which implies declining GDP growth rates (2.5% on average over 2013-2030, yet dropping to 1.6% by 2030), conservative. Extrapolation of GDP growth slowdown in the 30-40'es shows that this development pathway may lead to nearly zero growth at first, and then to the development of the "magic skin" economy, i.e. sustainable reduction in GDP and inability of the improved economic performance to make up for employment reduction and capital intensity increase (Bashmakov, 2011).

This scenario builds on the assumption that population will shrink to 119 mln. people in 2050; factor productivity growth determined by technological progress will be slow (0.5% per year); oil production will reduce to 230 mln. t in 2050; natural gas production will be maintained in the range 670-690 bln. m^3 on the whole time horizon to 2050; and oil price will be growing slowly to 186 USD/barrel in the mid-century. With these assumptions, RUS-DVA model runs show that oil&gas GDP drops following oil production decline trend, while non-oil&gas GDP slowly grows (at 1.7% per year over 2011-2050). Ultimately, Russia's GDP growth rates drop by 2030 to 1.2%, and by 2050 to 0.6% and lag well behind the global economic growth rates (Fig. 1). GDP evolution is even more depressing, than in the conservative scenario by the RF Ministry of Economic Development. The share of oil&gas GDP in the overall GDP drops from 22% in 2013 to 16% in 2020, 12% in 2030, and 9% in 2050.

In the "Slow Growth – Current Policies" scenario (Fig. 2):

- GHG emissions grow up, and in 2020 equal 71% of the 1990 level for three GHGs and 67% of the 1990 level for CO_2 alone. Therefore, even current policies and even if only partially implemented allow it to comply with the Presidential Decree "On greenhouse gas emissions reduction";
- on the entire time horizon emissions of three GHGs do not exceed the 2012 level (1,969 mln. t $CO_{2\text{-eq.}}$). Emissions show growth primarily in the electricity sector;

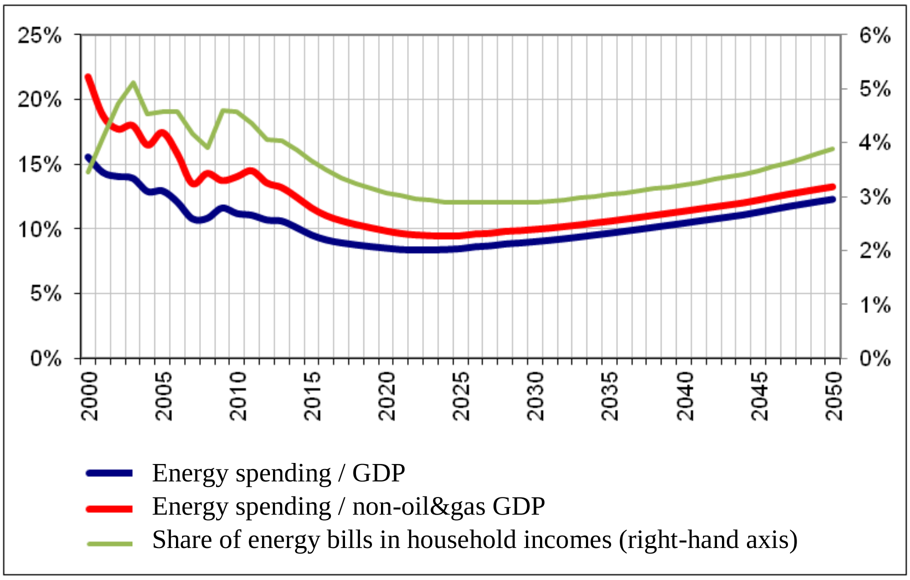
- population reduction and energy efficiency improvement are the major contributors to the reduction in emissions.

Analysis of the scenario assumptions and projection results shows that this scenario is very inconsistent. In the “Slow Growth – Current Policies” scenario:

- total natural gas production over 2013-2050 equals 25.8 trln. m^3, and reserves required to sustain production at the 2050 level for another 30 years are 45.9 trln. m^3. With 95% probability these cumulative gas production levels can be supported by reserves;
- Russian gas export peaks in 2030 (at around 280 bln. m^3) and then slowly declines to 192 bln. m^3 in 2050 driven by growing domestic demand, primarily in the electricity and automobile transport sectors;
- total oil production over 2013-2050 equals 15.7 bln. t, and reserves required to sustain production at the 2050 level for another 10 years are 18.9 bln. t. With maximum 62% probability these production levels can be supported by reserves;
- given declining oil production and growing domestic demand for liquid fuel, oil and petroleum products export drops by 2050 to 137 mln. t, even if natural gas use in the transport sector shows substantial growth.

After the energy spending to GDP ratio and the energy spending in the non-oil&gas sector to the non-oil&gas GDP ratio, as well as the share of household energy bills in household incomes have declined by 2020, these indicators start growing, and in the 40’es go beyond the energy affordability thresholds (Fig. 5) hampering the economic development. In other words, without “new” policies, even such low economic growth rates are not feasible, because the share of energy costs grows driven by extremely slow modernization and reduces the competitiveness. Therefore, a possibility for implementing a wide set of policies to improve economic growth is, in fact, a possibility for sustaining the economic growth.

Figure 5. Energy spending to income ratio



Source: Author.

“Slow Growth – New Policies”. This scenario assumes that technological modernization is spurred through “new” policies, primarily in energy efficiency improvement (see above). Because of smaller investment activity, the implementation scale for policies that are related to new construction is not as large, as in dynamic and moderate growth scenarios. In the “Slow Growth – New Policies” scenario:

- GHG emissions peak in 2012 with subsequent decline:
    - in 2020 to 1,830 mln. t $CO_{2eq.}$, which is 33% below the 1990 level for three GHGs (37% for CO_2 alone);
    - in 2050 to 1,353 mln. t $CO_{2\text{-}eq.}$, which is 50% below the 1990 level for three GHGs (57% for CO_2 alone);
- contribution made by per capita GDP growth to the emission growth is compensated in spades by the reduction in population and energy intensity (the latter shows 24% drop over 2007-2020 and 53% drop in 2050);
- primary energy demand goes down on the year-to-year basis, and even moderate development of non-fossil electricity generation technologies increases the share of these technologies to 50% by 2050;
- in the electricity sector, CO_2 emissions show decline at first, followed by a slow growth in the 40'es.

Additional investments in energy efficiency allow for a substantial increase in natural gas export. In 2050, gas export equals 317 bln. m^3, which is 125 bln. m^3 more, than in the "Slow Growth – Current Policies" scenario. Improved energy efficiency practically keeps energy spending to GDP ratio and energy bills to household income ratio within the energy affordability intervals throughout the whole period.

Therefore, even if policy implementation is limited to the "new" policy package alone, leaving the "vigorous" policies untapped, 50% reduction in emission (in relation to the 1990 level) can be attained.

Additional investments in energy efficiency technologies in the "Slow Growth – New Policies" scenario allow for natural gas export increase without raising gas production levels.

3 Comparison of model runs by 11 scenarios

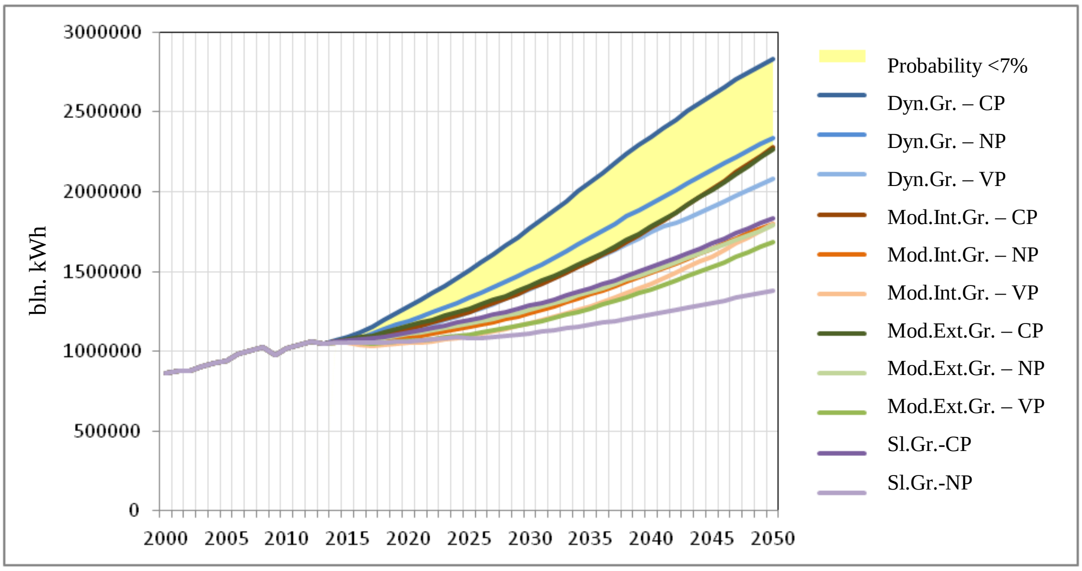
It was not GHGs emission control that hampered economic growth; vice versa, economic growth slowdown, determined by entirely different reasons, and re-evaluated economic development perspectives became a manifold contributor to the reduction in upper range values of future GHGs emission. Over 6 years (2008-2014) post-recession review of economic development perspectives lead to the reduction in maximum GHGs emission estimates for 2050 by 1,300-3,600 mln. t $CO_{2\text{-}eq.}$ (for analysis of emission projections see Bashmakov and Myshak, 2014). This is comparable to, or substantially above, the 2013 emission.

It is very likely, that by 2060 energy-related emission of three GHGs will peak at a level at least 13% below the 1990 emission. Development under scenarios with "current" policies forms a baseline, which does not reach the 1990 value before 2050 (Fig. 2). In 2020, except in the very unlikely "uprated" scenario, it is possible to attain the targets specified in Presidential Decree No. 752. This would require improved implementation of "current" policies" and launching some "new" policies. It is very likely that in scenarios with "new" policies GHG emissions will not exceed 65% of the 1990 level in 2050. In scenarios with "vigorous" policies GHG emissions drop in 2050 to 50% of the 1990 level.

Primary energy demand will be slowly growing. In most very likely scenarios, primary energy demand shows not more than 1% annual growth over 2013-2050. In scenarios with "new" and "vigorous" policies, the growth is 0.3% on average, and in scenarios with slow growth primary energy demand may start declining. Russia is close to switching to a trajectory with constant or even declining primary energy demand; the trajectory which OECD countries have been following for nearly a decade (IEA, 2013) and are expected to follow until 2035 (IEA, 2013a).

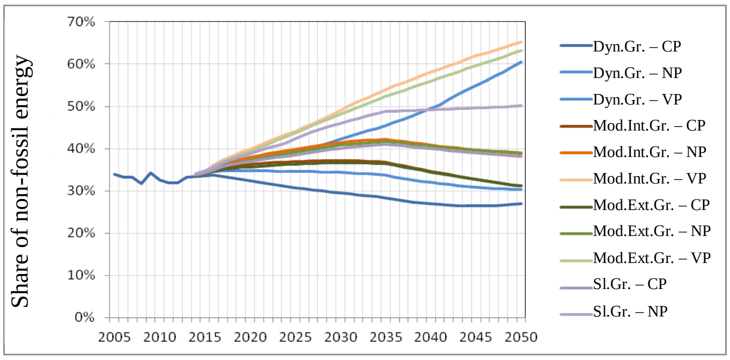
Electricity consumption will be growing slowly until 2020 and somewhat accelerate thereafter. It is virtually certain, that average annual growth in electricity consumption will equal 0.8-2.2% over 2013-2050. This rate is higher, than electricity consumption growth rates expected in OECD countries (0-0.6% per year, IEA, 2013). However, until 2020, in Russia, too, electricity consumption will be growing very slowly, at 0.2-1.2% per year, and by 2020 cumulative growth will equal 1,050-1,200 bln. kWh (Fig. 6). Only beyond 2020, as the major sectors are electrified, fuel gets more expensive, and "green" and nuclear electricity generation technologies develop, electricity consumption growth will accelerate. The share of primary energy used for electricity generation sustainably grows in all scenarios, same as the share of the electricity sector in the structure of fossil fuel emission.

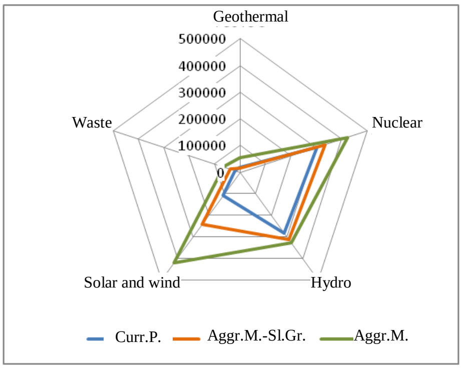
Figure 6. Evolution of electricity consumption in individual scenarios



Source: estimated by author

Figure 7. Evolution of the share of low-carbon electricity sources in the electricity generation mix (a) and application scale in individual scenarios (b)





a

b (2050, mln. kWh)

Source: estimated by author

The share of electricity produced from low-carbon sources is a function of both electricity consumption evolution and low-carbon sources development. In 2000-2013, this share was not growing and remained in the range 33-35%. In 2050, depending on the electricity demand evolution and progress in the development of nuclear and "green" generation, it may drop to 31% in scenarios with "current" policies, fall in the range 39-50% in scenarios with "new" policies, and grow to 60-65% in scenarios with "vigorous" policies (Fig. 7a).

In Russia, decision-making related to providing support for various types of low-carbon electricity generation does not build on economic or environmental, but rather on political (including defense) considerations. Global nuclear energy has been in recession for many years: the share of nuclear energy in the global electricity generation mix has been declining since 1996, in primary energy mix since 2002, and since 2006 absolute electricity generation by nuclear plants has been declining, too. All these trends have developed long before the Fukushima nuclear accident in 2011. In Russia, on the contrary, according to many official documents, there are plans for substantial expansion of nuclear plants construction both to substitute for retired capacity and to increase existing installed capacity to 29-35 GW in 2020 and to 45-50 GW in 2040. Nuclear plants construction plans are implemented slower, than expected[52], because of: much higher construction costs (growth from 1,000 USD/kWh of installed capacity to 6,000-7,000 USD/kWh over the last 10 years) (WNESR, 2013); depleted natural uranium reserves; accumulation of large amounts of spent nuclear fuel and of related utilization problems; lack of skilled staff; negative public opinion of nuclear energy development; and huge public investment demand, given growing Russian budget constraints.

In compliance with the RF Government Decree No. 705 dated 20.09.2008, 820 billion rubles from the federal budget were secured to support the Federal nuclear energy corporation Rosatom in 2009-2015. In compliance with the RF Government Decree No. 2375-R dated 17.12.2013 "On providing a subsidy in the form of property contribution by the Russian Federation to the development of the nuclear energy complex to the Federal nuclear energy corporation Rosatom from the 2013 funding", 80.6 bln. rubles were provided in 2013 to the Federal nuclear energy corporation Rosatom from the federal budget, including 22.45 bln. rubles to cover the costs of building nuclear power plants in other countries. In other words, the Russian federal budget provides subsidies for nuclear plants construction not only in Russia, but also abroad, and the amount of just one-year subsidy equals 10 years' federal energy efficiency spending.

Federal support for the development of electricity generation from renewable sources is considerably smaller. The RF Government Decree No. 449 dated 28.05.2013 "On the mechanism to promote renewable energy in the wholesale electricity and capacity market" sets the goal of increasing electricity generation to around 30 bln. kWh in 2020. As of today, Russia is lagging behind the globe, as in 2012 more than half of the entire generation capacity commissioned in the world was from renewable sources. However, this may significantly change to 2050. Therefore, these generation sources involve a larger uncertainty, than other sources (Fig. 7b). Specific investments in the construction of generation capacities on renewable sources are 2-5 times lower, than in the construction of nuclear plants, and unlike the latter, tend to decline. This makes them an attractive option, even despite the fact that the installed capacity load factor is 2-3 times lower.

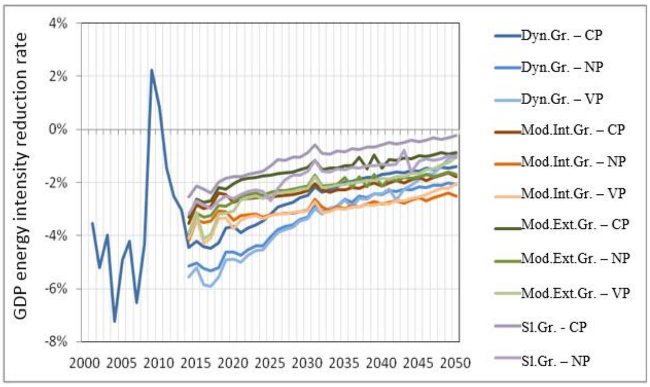
As the economic growth slows down, energy intensity reduction rates decline (driven by the reduced role of structural shifts and the narrowing gap with best available technologies), and deployment of low-carbon technologies becomes increasingly important for GHG emission reduction. GDP energy intensity reduction rates are determined by the scale of structural shifts in the economy: the faster the growth, the bigger the role played by structural shifts (Bashmakov and Myshak, 2011). As the economic growth slows down, the difference between the growth rates in energy intense and other sectors shrinks diminishing the contribution of structural shifts in the economy as a whole and in the structure of industrial output. As technologies are renovated and the energy efficiency gap with BAT narrows, further progress in reducing process energy consumption per unit of products, work or services becomes more difficult to achieve, and so the progress slows down. These two factors determine GDP energy intensity reduction slowdown (Fig. 8a) in scenarios with "current" policies to 1-2% per year (to

[52] Like, for example, with Baltiyskaya nuclear plant, when a construction project that had already been launched, was mothballed for lack of demand for electricity from this plant.

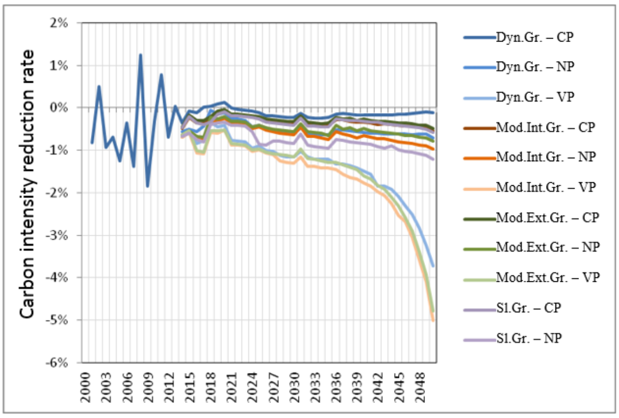
0.2% in the slow growth scenario); in scenarios with "new" policies to 1-2.5%; and to somewhat lower values in scenarios with "vigorous" policies, as determined by growing process needs of power plants that use carbon capture and storage technologies and by the growing share of nuclear energy[53].

So as to compensate the impact of GDP growth and ensure GHG reduction, it is important to accelerate the reduction in carbon intensity of primary energy to attain by 2030 the rates observed in 2000-2012 and much more dynamic rates thereafter (Fig. 8b). In scenarios with "current" policies, carbon intensity reduction rates do not go beyond 0.6% per year on the whole time horizon (1.2% per year in scenarios with "new" policies). Only in scenarios with "vigorous" policies the reduction rates dramatically accelerate in the end of the period to 3.7-5% per year.

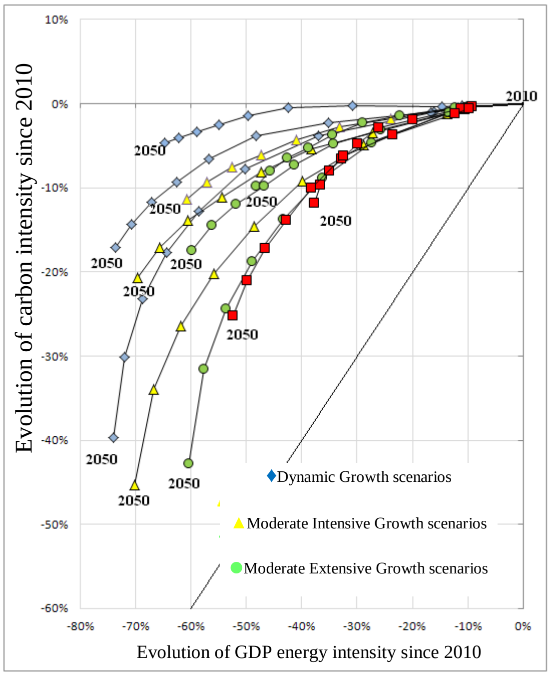
Figure 8. Evolution of GDP energy intensity (a), of carbon intensity of primary energy (b), and the ratio of these parameters evolution in individual scenarios (c)



a



b



c

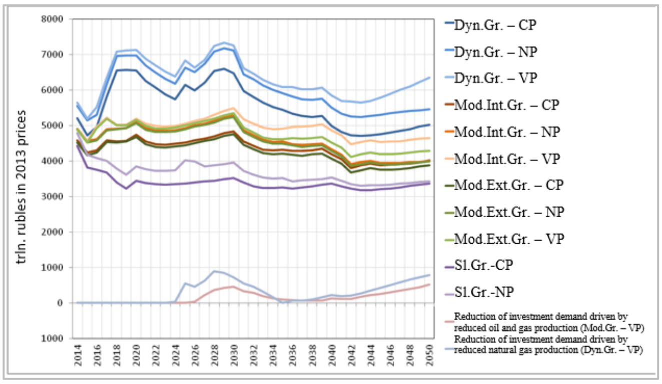
Source: estimated by author

Until 2030-2040, emission control is primarily realized through energy efficiency improvements; and beyond that time frame development of low-carbon generation brings down carbon intensity (Fig. 8c).

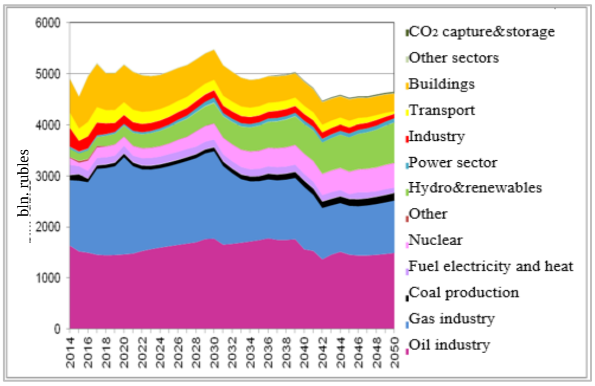
[53] IFEB takes account of nuclear plants according to the physical energy content method and building on the assumption that the efficiency of electricity generation from steam is 33%. In 2050, this is below the efficiency of fuel plants. Therefore, the growing share of nuclear plants, given this method of integrating nuclear energy in the energy balance, impedes energy intensity reduction.

Emission reduction measures cost less than 1% of GDP, do not hamper economic growth and, given foreign markets restraints for Russian hydrocarbons, allow it to reduce projected oil&gas production and, consequently, new deposit development costs. The volume and dynamics of capital investment in energy resource production and energy efficiency improvement largely depend on the fossil fuel production profile, development of fuel and low-carbon generation sources, and investments in energy efficiency. Overall capital investment over 2014-2050 equals 125-233 trln. rubles in 2013 prices. Investments in hydrocarbon production and transportation dominate in all scenarios (Fig. 9a) and provide a more substantial impact on the overall investment structure, than investments in low-carbon technology development or in energy efficiency improvement (Fig. 9b).

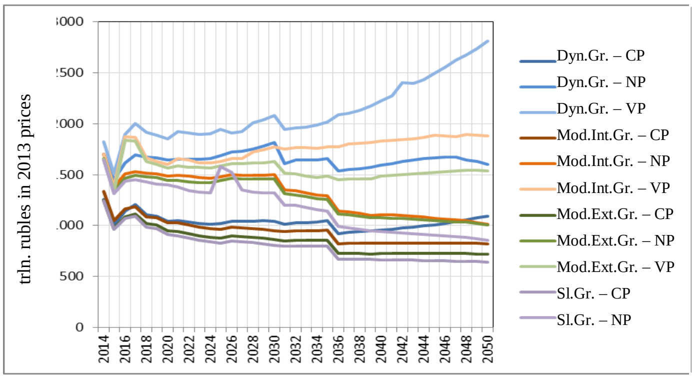
Figure 9. Parameters and evolution of capital investments in energy production and energy efficiency improvements



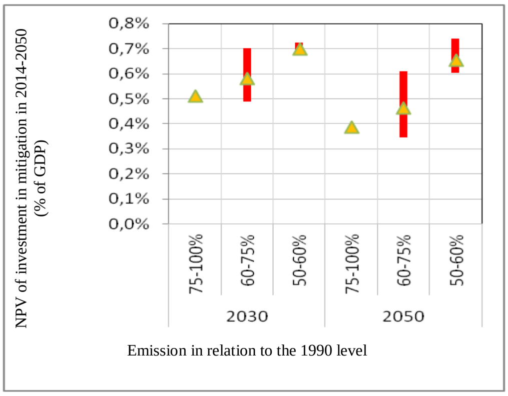
(a)



(b)



(c)



(d)

(a) Evolution of investments in energy production and energy efficiency improvements; (b) Structure of investments in the Moderate Intensive Growth scenario with "vigorous" policies; (c) Evolution of capital investments in the development of low-carbon technologies and energy efficiency improvements; (d) Evolution of the ratio of discounted capital investments to the discounted GDP, depending on the emission reduction (with 5% discount rate).

Source: estimated by author

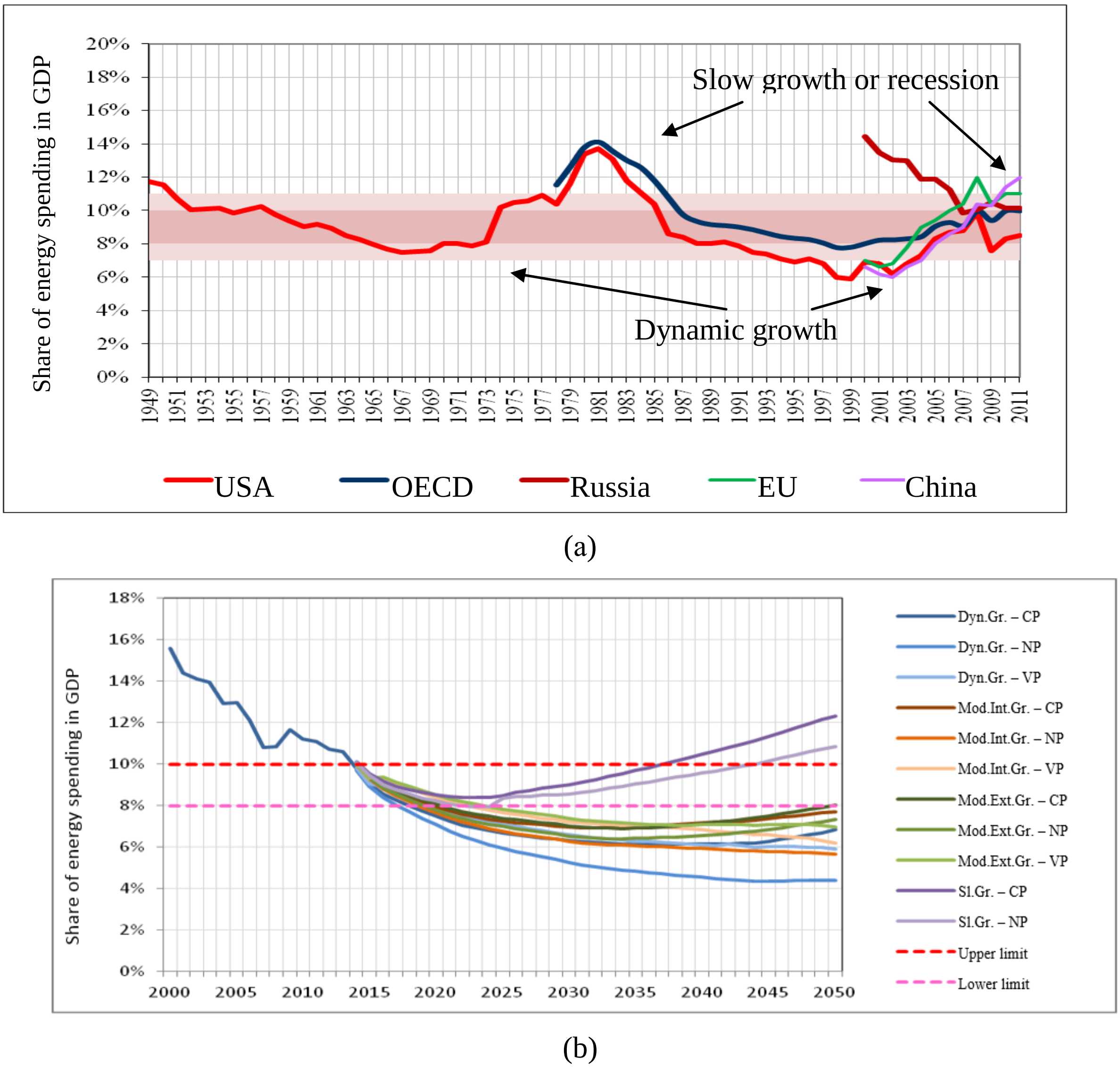
Investments in low-carbon technology development and energy efficiency improvement over 2014-2050 equal 30-78 trln. rubles in 2013 prices, depending on the scenario. Investment demand is determined by both economic growth rates and the aggressiveness of "new" and "vigorous" policies. The former cost 13-23 trln. rubles in 2013 prices, and the latter are 10-17 trln. rubles more costly. Additional total discounted capital investments are no more than 0.8% of the discounted GDP (Fig. 9d). Against the background of declining investment activity in the oil&gas sector (decline from 4.4% of GDP in 2013 to 0.8-1.2% in 2050) this offers an additional impulse to the economic growth.

Additional investments in low-carbon development and energy efficiency improvements offer possibilities for a significant increase in natural gas and petroleum products export without increasing production. Investment demand for low-carbon technology development and energy efficiency improvement is 6-10 times lower, than the capital costs of fossil fuel production and transport. Specific capital investment per unit of energy saved is 2-3 times lower, than per unit of low-carbon energy generation increase, and manifold lower, than specific capital investment in new hydrocarbon deposit development. In the 30-40'es, huge capital investments in the oil&gas sector will not even help maintain current production levels. Given limited export potential of Russian hydrocarbons, these capital investments can be substantially reduced: discounted reduction in capital investments in the oil&gas sector development may exceed 0.2-0.3% of the discounted GDP.

Deployment of "new" policies helps reduce the ratio of energy spending to GDP, whereas deployment of "vigorous" policies just slightly brings this ratio up, albeit keeping it at a lower level, than if only "current" policies are implemented. One of the laws of the energy base transformation (Bashmakov, 2007) goes, that the ratio of energy spending to the income (GDP, gross output) is very stable in the long-term, fluctuating in a very narrow range around very sustainable ratios (8-11% of GDP, or 4-5% of gross output). When energy price growth drives energy affordability far enough beyond the upper limit (threshold), unattainability of energy hampers economic growth. Similar energy affordability thresholds exist in individual sectors, too: in industry, in transport (2-4% of incomes), and in the residential sector (2-4% of incomes). They are universal both spatially (very close values for various countries at different levels of development) and temporally (sustainable over many decades, Fig. 10a). M. Grubb tested the "Bashmakov's constant" (energy spending/GDP ~ 10%) on an industrialized countries sampling and confirmed that this constant clearly manifests (Grubb, 2014). Inter alia, this proves the consistency of the "minus one" rule, which determines the long-term ratio of energy prices and energy efficiency. In countries where energy prices are relatively higher, GDP energy intensity is on average lower by the same value. In the long-term, 1% price growth results in 1% energy intensity reduction, as determined by the evolution of the technology used, behaviour, and economic structure.

In many scenarios with "new" policies (and slow energy price growth) and assumptions related to the substantial impact provided by factor productivity, energy affordability shows significant increase with time, spurring cost reduction and economic growth. However, after 2020-2025, this ratio goes far beyond the lower fluctuation range value bringing energy saving incentives down. The most radical drop of this ratio is observed in scenarios with dynamic and intense growth, which have relatively vague implementation perspectives. In the "Slow Growth – Current Policies" scenario, this ratio goes beyond the upper range value (10%) as soon as in 2037, and this becomes one reason why the growth cannot be accelerated. In this scenario, as well as in the other two families of scenarios, "new" policies help keep energy affordable.

Figure 10. Evolution of the energy spending / GDP ratio



(a) For various countries and groups of countries over 1949-2011; (b) For Russia in individual scenarios.

Source: estimated by author

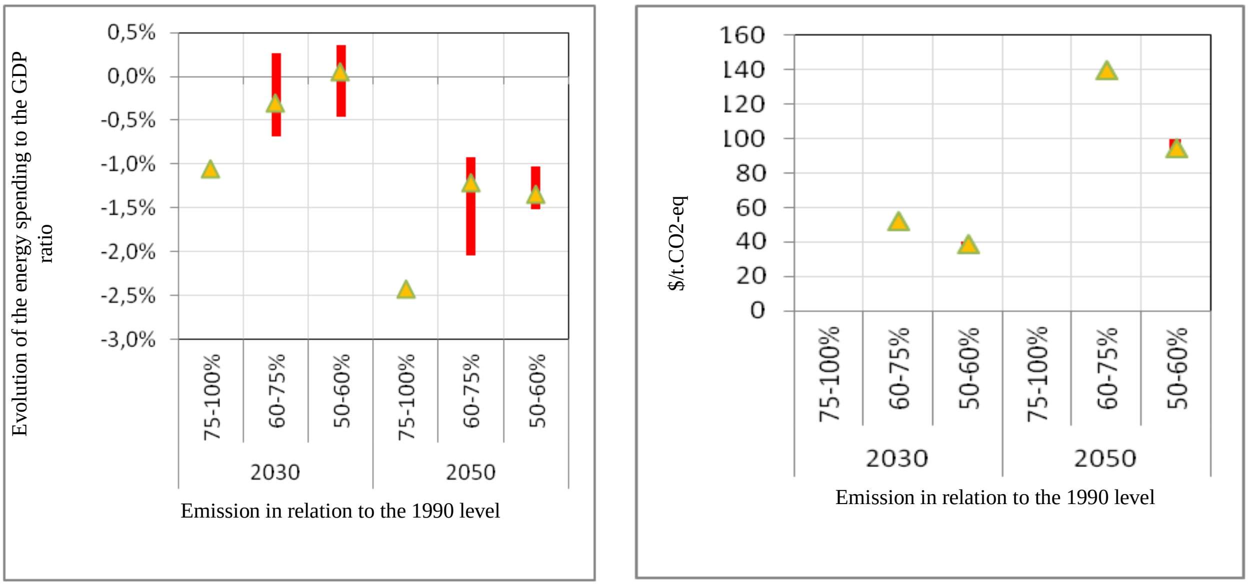
"New" policies that save energy at a cost lower than energy purchase price help reduce the share of energy spending compared to the "current" policies scenarios (Fig. 11a). "Vigorous" policies lead to a larger share of energy spending, although even with drastic emission reduction this share is lower, than with "current" policies alone. In other words, the costs of energy supply to customers do not go beyond the energy affordability thresholds even with GHG emission drop to 50% of the 1990 level. If motivation for energy efficiency improvements is to be preserved, energy prices in 2030 are to be approximately 30-40% higher, than those given in the IEA projection published in November 2013.

In scenarios with moderate growth, it is possible to reduce the emission to 50% of the 1990 level through the introduction of carbon tax, which is to grow up to 90-100 USD/t $CO_{2\text{-eq.}}$ in 2050. Carbon tax rate of 100 USD/t $CO_{2\text{-eq.}}$ in 2050 increases natural gas price for end-users by 54%, coal price 2.3-fold, electricity price by 10%, and heat price by 16%.

In dynamic growth and moderate intensive growth scenarios with "current" policies, if natural gas export is to be at least 100 bln. m^3, it is necessary to increase gas price by 60-120% going for a more substantial electricity tariff growth, than in the scenario with 140 USD/t $CO_{2\text{-eq.}}$ tax rate. With slow economic growth, there is no need to introduce carbon tax to reduce emission by

50%. The question here is, who will benefit from additional revenues: natural gas producers (from increased domestic gas price) or the government (from introducing the carbon tax). Depending on the tax collection method, carbon tax could bring 50-100 trln. rubles (in current prices) over 2016-2050, which is comparable to the low-carbon technology and energy efficiency investment demand.

Figure 11. Evolution of energy spending to GDP ratio as a function of GHG emissions reduction (a), and GDP reduction to the carbon price ratio (b)



(a) (b)

Source: estimated by author.

On average, 1 USD/t $CO_{2\text{-eq}}$. carbon price growth in 2050 brings emission down by 1.6 t $CO_{2\text{-eq}}$. through energy efficiency improvements and fuel substitution. As low-carbon technology development decisions are largely driven by non-economic considerations, it is difficult to accurately assess the impact provided by carbon price growth. With carbon price growth to 90-140 USD/t $CO_{2\text{-eq}}$. in 2050, the scale of carbon capture and storage technology deployment in Russia may be estimated at 19-55 mln. t $CO_{2\text{-eq}}$., or around 1-3% of the 2050 emission.

Analysis shows, that the highest likelihood is attributed to moderate extensive growth scenarios with “new” and “vigorous” policies and to slow growth scenarios with “new” policies, which correspond to the 2050 GHG emissions between 1,360 and 1,770 t $CO_{2\text{-eq}}$., i.e. 50-65% of the 1990 level[54]. “Dynamic growth” scenarios are virtually unlikely (Fig. 12a). Emission evolution assessments in these scenarios are purely illustrative and have no practical importance. To a somewhat smaller degree, same goes for the “Moderate Intensive Growth” scenarios. The “Extensive Growth – Current Policies” scenario does not guarantee sufficient natural gas volume for export.

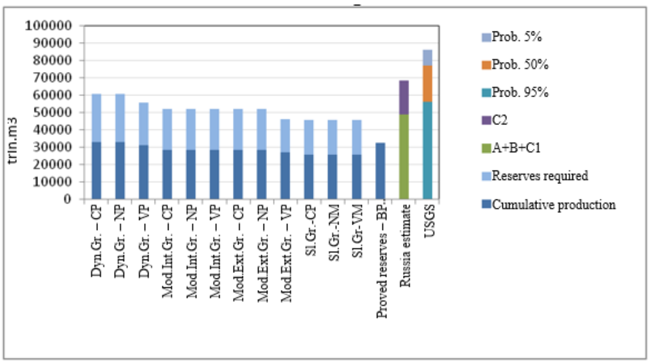
[54] Relative likelihoods of scenarios were assessed based on 7 independent criteria that were used to compare scenario results with relative assumptions (Fig. 50a). Since the criteria are independent, likelihoods were multiplied together. Relative likelihoods were obtained through dividing all the products by the maximum value obtained.

Figure 12. Analysis of relative likelihood of individual scenarios

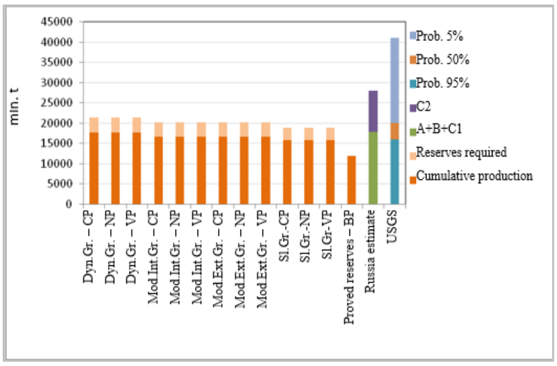
	Relative likelihood of scenarios	Gas resources	Oil resources	Factor productivity	Gas export	Export of oil and petroleum products	Share of energy spending	Policy implementation
DG-CP	4%	85%	47%	10%	25%	100%	85%	100%
DG-NP	7%	85%	47%	10%	75%	100%	70%	75%
DG-VP	4%	95%	47%	10%	100%	50%	86%	50%
MIG-CP	18%	95%	50%	50%	25%	75%	94%	100%
MIG-NP	47%	95%	50%	50%	75%	100%	83%	75%
MIG-VP	46%	95%	50%	50%	100%	100%	93%	50%
MEG-CP	35%	95%	50%	75%	25%	100%	95%	100%
MEG-NP	100%	95%	50%	75%	100%	100%	89%	75%
MEG-VP	72%	95%	50%	75%	100%	100%	96%	50%
SG-CP	62%	95%	62%	100%	50%	50%	100%	100%
SG-NP	93%	95%	62%	100%	100%	50%	100%	75%

0-20%	20-40%	40-60%	60-80%	80-100%

(a) Final relative likelihoods of scenarios estimated based on 7 selected criteria



(b) Estimated natural gas reserves sufficiency to maintain gas production levels



(c) Estimated oil reserves sufficiency to maintain oil production levels

Source: estimated by author

In most scenarios, natural gas production is adequately supported by resources (Fig. 12b), which is not at all true for oil production (Fig. 12c). Policy Implementation criterion integrates both determination to launch policies and expected policy effectiveness. By this criterion, likelihood goes down as the set of policies expands.

4 Eight basic questions and answers

The major findings of this study are presented below as answers to 8 basic questions related toGHG emissions evolution trajectories in Russia and assessments of the effectiveness of various energy-related GHG emissions control policies, as well as to one global question: what commitments can Russia make to 2030 and to 2050?

Question 1. The concept of "natural" absolute limit (peak) to GHGs emission growth in the absence of special climate policies. Is there such a peak If yes, what is it? Why is it impossible to go beyond? There *is* an absolute upper limit to Russia's energy-related GHG emission growth. It is very likely that even with "current" policies alone it does not exceed the 1990 emission, which was 2715 mln. t $CO_{2\text{-eq.}}$ This limit cannot be exceeded because (a) it is unlikely that high economic growth rates can be combined with slow innovations; (b) it is unlikely that fast growth of fossil fuel consumption can be combined with fast innovations; and

(c) because economic growth gradually slows down. It is very likely that the emission will peak in the 30’es or 40’es. Subject to the successful implementation of “new” policies, GHG emission will peak at a level below 75% of the 1990 emission.

Question 2. Is it possible to outline the relationship between climate policies and modernization / energy efficiency improvement of the economy? Are there synergies of the effects in addressing these issues and, if yes, how significant are they? Energy efficiency improvements are the basis for the reduction in production costs, improvement of the overall economic efficiency and sustainable economic growth. It is hardly possible to deploy just “current” policies to 2050, because it is important to address purely economic problems, such as: the conflict between fast growing liquid fuel / natural gas demand and stabilized or decreasing production and relevant reduction in the export potential; the challenge of supporting high production volumes with adequate oil and gas reserves; inadmissibility of natural gas export implosion or of Russia’s turning into gas importer. Until 2030-2035, substantial restraints to the emission growth will be a side effect of energy efficiency improvements. Beyond that period, the accent will shift from fossil fuels to low-carbon technologies of electricity-, heat-, and liquid fuel production. Therefore, reduced energy- and fuel demand allows it to control GHG emission and keep it at low levels. On the contrary, climate policies, such as carbon tax, spur energy efficiency and create a source of additional capital investments in energy efficiency improvements and low-carbon technologies.

Question 3. What are direct and indirect effects of individual special policies and instruments used to control Russia’s energy-related GHG emissions? It is possible to make a preliminary assessment of impacts made by specific policies aimed at energy-related GHG emissions control. For this purpose it is important to develop special models similar to those used in this study. Solely on this basis it is possible to make an integral assessment of the effectiveness of specific policies. The more sophisticated the models, the wider set of policies (and the more adequately) can be imitated through model runs. However, life is richer than any abstract scheme, and the devil is always in the detail of launching policies and mechanisms, so any model can provide only approximate estimates of the effects of specific policies.

Question 4. How much can GHG emission be reduced in 2050 and beyond in relation to the 1990 level, at no sacrifice of the economic growth? Practically to 50% of the 1990 level, subject to the commitment and ability to implement “new” and “vigorous” policies. As to the requirement to maintain the 2020 emission at 25% below the 1990 level, as specified in Presidential Decree No. 752 “On greenhouse gas emissions reduction”, it is very likely that it will be met.

Question 5. What is the cost growth profile in relation to the emission control commitments? Additional investments in low-carbon technologies and energy efficiency improvements do not exceed 1% of GDP. Given limited capacity of foreign markets to absorb Russian hydrocarbons that can be released for export through these measures, these additional investments are to a large degree neutralized by reduced costs of faraway deposit development and piping. Substantial energy savings generated by the deployment of “new” policies allow it to reduce the energy spending to GDP ratio, and of “vigorous” policies just slightly bring this ratio up, albeit leaving it far below the level typical for the deployment of “current” policies alone. If GHG emission in 2050 is to be below 50% of the 1990 level, it is important to introduce carbon tax and by 2050 to increase it to 90-140 USD/t $CO_{2\text{-eq.}}$ This would provide a smaller energy price escalation effect, than gas price increase in fast economic growth scenarios, which is required to cap domestic demand and avoid the metamorphosis of Russia into a natural gas importer.

Question 6. Does GHG emission control impede economic growth? If yes, then starting from which emission levels? The study has not revealed that introduction of GHG emission caps hampers economic growth (on the contrary, GHG emission control policies release additional hydrocarbons for export and so give a push to the economic growth). Inability to keep oil&gas GDP from a dynamic drop, or inability to improve the efficiency of economy and overall factor productivity and reduce production costs are much more important inhibiting factors. Against this background, potential positive or negative effects of emission control policies provide much (order of magnitude) smaller impacts. Additional capital investments in low-carbon technologies can hardly be viewed as loss of growth, because these investments have a much larger capital return, than substituted investments in the oil&gas complex development.

Question 7. What is the "solution space"? Which policies have the largest and least-cost emission reduction effect, no matter which cost metrics used? The solution space is pretty large. Priority should be given to cost-effective energy efficiency improvements, and in parallel a solid basis is to be laid for the future development of "green" generation. Then come more costly energy efficiency improvements and large-scale deployment of low-carbon technologies. There is an important bifurcation on this path: either to give a priority to renewable energy sources, or to focus on the construction of more nuclear power plants. In the recent years, renewable energy technologies have substantially progressed and become mature and cheaper, whereas construction of nuclear plants becomes increasingly more expensive. However, decision-making in favour of this or that option is more political, than economic.

Question 8. What is the order, intensity, and the time schedule for launching specific policies and instruments of Russia's energy-related GHG emission control? By 2015, it is important to strengthen the governance effectiveness for the implementation of already adopted "current" policies" and develop and launch "new" policies. These are mostly additional energy efficiency measures. At the same time, by 2020 it is critical to develop, discuss, and launch "vigorous" policies that are primarily aimed to support low-carbon technologies in electricity and liquid fuel production.

The major question is: what GHG emissions control commitments can Russia make to 2030 and to 2050? In the 2050 perspective, either "soft" or "tough" commitments are possible. "Soft" commitments include those that correlate with the upper boundary of the most probable emission evolution range dominated by energy efficiency measures, without introducing carbon tax or emission trading and without any significant support provided for the development of low-carbon technologies. "Tough" commitments include those that correlate with the lower boundary of the probable range. "Tough" commitments are determined by the dedication and ability to launch the two latter policy packages. Each commitment can be formulated as the level of emission in the last year of the commitment period, or as average annual emission over the commitment period (similarly to the commitments under the Kyoto Protocol).

"Soft" long-term commitments can be formulated as follows:

- cap the 2050 emission at maximum 75% of the 1990 level; or
- cap average annual emission in 2021-2050 at no more than 75% of the 1990 level.

These requirements are with guarantee met through successful implementation of both "current" and "new" policy packages. The risk of incompliance is solely related to the failure to launch "new" policies or to unbelievably fast economic growth. Depending on the emission profile, in some scenarios the first commitment, and in others the second commitment is more difficult to comply with. However, generally, the two formulations are pretty equivalent. Economic development cycles may somewhat "knock up" emission in this or that year, including in 2050, so the second formulation offers more flexibility in commitment compliance.

"Tough" long-term commitments can be formulated as follows:

- cap the 2050 emission at maximum 50% of the 1990 level; or
- cap average annual emission in 2021-2050 at no more than 67% of the 1990 level.

These requirements can only be met through successful implementation of a wide range of "new" and "vigorous" emission control policies, including carbon tax, which is to grow up to 90-100 USD/t $CO_{2\text{-eq}}$. in 2050 in Moderate Growth scenarios. These scenarios imply large-scale use of carbon capture and storage technologies. In Slow Growth scenarios, even with limited development of low-carbon electricity-, heat- and liquid fuel production technologies, 50% reduction in emission is achievable through successful "new" policies.

Formulation of short-term commitments to 2021-2025 or to 2021-2030 in the "soft" option may be borrowed from Presidential Decree No. 752 "On greenhouse gas emissions reduction" as maintaining the 2020 energy-related anthropogenic emission at 25% below the 1990 level (preferably relating to average annual emission over the commitment period). It is very likely that meeting this commitment will require both "current" and "new" policies; and this commitment will be met with guarantee through a large-scale application in this period of "vigorous" low-carbon development policies. In the "tough" option, the target may be formulated as follows: cap average annual emission in 2021-2030 at maximum 70% of the 1990 level.

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