Center for energy efficiency – XXI

Russia's carbon neutrality: pathways to 2060

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CONTRIBUTORS

Igor Bashmakov
General Director
CENEf – XXI

Vladimir Bashmakov
Legal Advisor
CENEf – XXI

Konstantin Borisov
Leading Researcher
CENEf – XXI

Maxim Dzedzichek
Leading Researcher
CENEf – XXI

Alexey Lunin
Leading Researcher
CENEf – XXI

Irina Govor
Senior Research Fellow
Yu.A. Izrael Institute of Global Climate and Ecology

Table of contents

Introduction

There is an opinion both among the skeptics and the optimists, that there is currently no room for long visions of Russia's economic and decarbonization future. However, all of the countries need a future and visions of the future. As correctly stated in the "Back to the future" movie, 'The *future* isn't *written* yet'. Matt Myklusch in his "Jack Black and Imagine Nations" makes it even stronger: "The future is not written. It lies in the choices you make. Our future is ours to decide. Always". To decide on our future, we need a map of pathways that lead to the desired future statuses. To map these pathways, we need to climb a high tree in the thick forest to see what is around us and which directions are available. The time horizon for this study is 2060, so there are about forty years ahead. The history can give us a feeling of what may happen in the next forty years. Forty years ago (in 1982) there was USSR ruled by Brezhnev and the Russians had no vision, that in 10 or 20 years' time they would live in a very different country. In other words, extrapolation doesn't always help. One has to have imagination.

Visions of a low carbon future are important, as they affect Russia's economy, fuels and basic materials exports to the global and regional low carbon markets, where low carbon footprint is becoming critical, while carbon price mechanisms undermine the competitiveness of carbon-intensive products. The future of carbon-intense markets is not bright, in contrast to high-tech products and services in the emerging trillions-of-dollars-worth low carbon markets, which Russia needs to penetrate. Any development should rely on the least-costly technology solutions. It is expected that in the 2020s and 2030s low carbon technologies will become less costly, than the traditional processes. Producers and countries which will be lagging behind will lose the economic development momentum. Many sectors and industries need long-term visions when making investment decisions to avoid having their assets stranded. Any family with children need long-term visions on the potential futures ahead.

Russia has pledged for 2060 carbon neutrality. However, the pathways to this goal are yet to be explored. This is challenging – partly due to the lack of long-term models for the whole economy and for the key sectors working on the time horizon beyond 2050. Therefore, expert and policy-making communities have to stop in 2050, with only intuition and blind search prompting whether carbon neutrality is attainable in the mist of the 2050s.

The first task, which this study was seeking to achieve, was to further develop CENEf-XXI's model set to extend the time horizon and improve the technological and costs details by sectors. The overall goal was to better capture the effects of key mitigation options, and the potential effects of global low carbon transition and the restrictions that followed Russia's military operation. This model set is presented in Chapter 2.

The initial purpose of Chapter 3 was to assess the systemic impacts of low carbon transition on the global scale and of Russia's key trade partners on Russia's economic development depending on the selected pathways, breaking down this assessment into the effects on traditional Russia's exports and on its potential to penetrate the emerging low carbon markets. After February 24th, this purpose was modified to also capture long-term impacts of the strong and escalating sanctions.

One lesson from the future is that there is no business-as-usual for the decades to come; instead, business-as-unusual needs to be in the focus. For Russia, there will be no business-as-usual even in the short- and medium-term. The task was to develop visions to embrace the range of uncertainty which greatly increased after February 24. Three sets of scenario storylines were developed to cover the abruptly widening uncertainty zone to draw the pathways which may bring Russia to carbon neutrality in 2060: *4S – Stagnation*, *Sanctions*, *Self-Sufficiency*, which may be alternatively titled *Forward-to-the-Past* (as the opposite to the *Back-to-the-Future*); *4D – Development Driven by Decarbonization and Democratization*, which opens the door for Russia to return to the global economy; *4F – Fossil Fuels for Feedstock*, which builds upon *4D* and allows Russia to use its fossil fuel resources for non-energy use. The story lines for these pathways are described in Chapter 4.

The next three chapters – five, six and seven – present the results of model runs for each alternative conceptual pathway to assess the trajectories towards carbon neutrality and the costs and benefits associated with different low-carbon development pathways. Contributions from different sectors (power and heat generation, industry, transportation, buildings, agriculture, waste management, LULUCF) to the carbon neutrality perspective were assessed, and – building on this evaluation – recommendations were developed for potential sectorial policy goals and instruments.

Like we always do in our papers, key findings of the study are given in Chapter 1 – kind of a summary for policy makers titled "Russia's carbon neutrality: bumpy pathways to 2060. Key findings".

This research was led by Igor Bashmakov and done by V. Bashmakov, K. Borisov, M. Dzedzichek, and O. Lunin with participation from O. Lebedev. I. Govor of Yu. A. Izrael Institute of Global Climate and Ecology was responsible for modeling GHG emissions from the waste sector.

Proofreading and translation of the report was done by Tatiana Shishkina, layout by Oxana Ganzyuk. Cover painting by Igor Bashmakov.

Igor Bashmakov

General Director

CENEf – XXI

Contacts: Tel. (499) 120-9209; Email: cenef@co.ru; website: https://cenef-xxi.ru**.**

1 Russia's carbon neutrality: bumpy pathways to 2060. Key findings

1.1 2060 carbon neutrality target

In October 2021, Russia set the carbon neutrality target to 2060.

Carbon neutrality does not mean a balance of sources and stocks across all GHG, but only for CO_2.

With a linear decline, net-CO2 emissions will cumulatively amount to 33.3 $GtCO_2$ in 2021-2060, which is 6.5% and 3.7% of the carbon budget to support the 1.5°C and 2°C global warming target respectively.

Retrospectively, Russia's GHG control commitments are as follows:

- **0% in 2008-2012** – Kyoto, 1997: Russia committed to not exceed its 1990 emission in 2008-2012 **(attained)**;
- **-25% by 2020** – Copenhagen, 2009: Russia committed to maintain its emission to 2020 below 75% of the 1990 level **(attained)**;
- **-20-25% by 2030** – Paris, 2015: Russia committed to maintain its GHG emission to 2030 at 70-75% of the 1990 level;
- **-30% by 2030** – RF Presidential Decree No. 666 of 4 November, 2020: Russia committed to limit its emissions to 2030 at 70% of the 1990 level;
- In spring 2021, the goal was set to ensure that cumulative net-GHG emissions in Russia to 2050 do not exceed those in the EU;
- **-80% by 2050** – Russia's low carbon development strategy to 2050 requires an 80% decline in net-GHG emission from the 1990 level and a 60% decline from the 2019 level. This is the only strategic document in Russia with a 2050 time horizon.

In order to judge on a possibility to attain the 2060 carbon neutrality target, long-term projections are required to capture the economic and technological evolution of the country and the effects of a variety of GHG control policies in the key sectors.

- Russian experts have a third of a century experience in GHG emission projections, yet not in forecasts beyond 2050.[1]
- Only in one of the scenarios considered Russia can expect to attain net-zero CO_2 emission before 2050.[2]
- Generally, such projections add confidence to the government's position in both climate negotiations and development of long-term decarbonization policies.
- To make informed decisions one has to estimate their potential long-term and systemic implications.
- Think tanks use comprehensive economic/energy/environmental models of various complexity to make calculations for their projections.
- The projections differ in macroeconomic assumptions, baselines, scopes of emission sources and GHG sinks, and also in the selection of projection tools.

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[1] The history of GHG emission projections for Russia is described in: Bashmakov, I.A., V.I. Bashmakov, K.B. Borisov, M.G. Dzedzichek, A.A. Lunin, A.D. Myshak. Russia on the path to carbon neutrality. Moscow, 2021.

[2] Ibid.

1.2 Projection tools

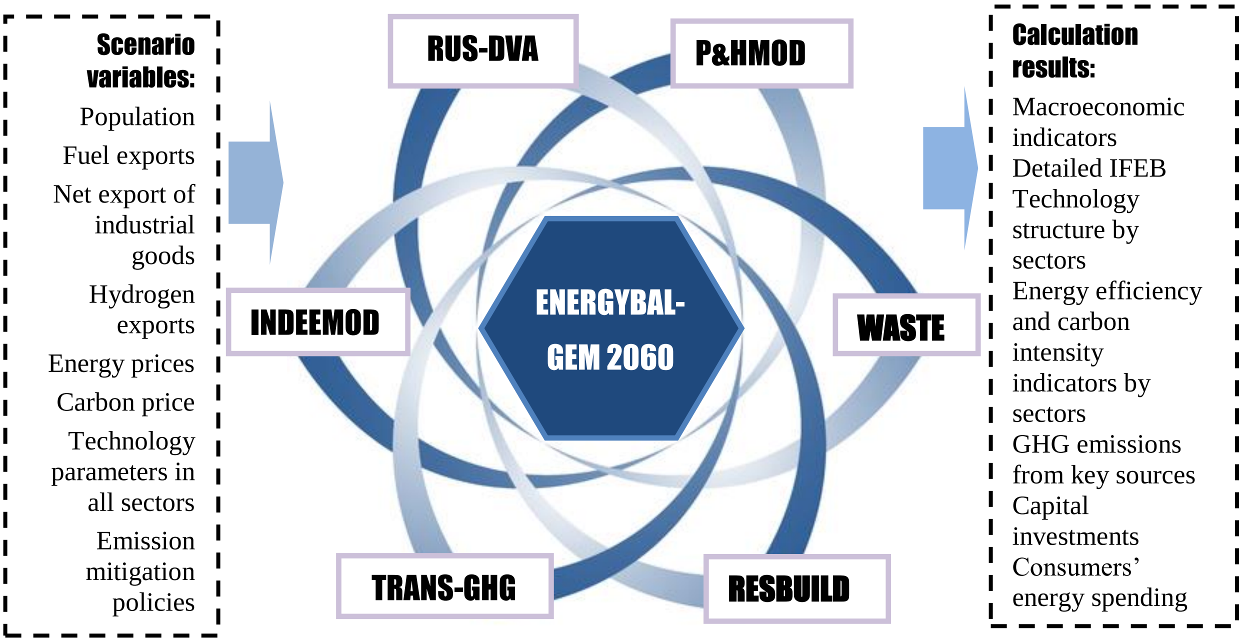
Projections are made using a set of interconnected models; their interplay is shown in Figure 1.1. The models are grouped around ENERGYBAL-GEM-2060, the core multisector model. Many of its parameters are identified using a 'cloud' of models developed by CENEf-XXI. The 'cloud' of models includes:

- macroeconomic model RUS-DVA (2 sectors – Oil&Gas and Non-Oil&Gas, 4 products, and 6 blocks);
- model for the power and heat sector P&HMOD (10 types of power and heat generation);
- model for industry INDEE-MOD (about 60 types of industrial products, technologies, and production processes);
- model for transport TRANS-GHG (9 transport modes plus 1-2 vehicles in each mode broken down by the fuels used);
- models for residential and public buildings RESBUILD and PUBBUILD. Part of the calculations for residential buildings were made using *EKR Assistant* model developed by CENEf-XXI for the RF Housing and Utility Reform Foundation; two types of residential buildings – multifamily and single-family – with 9 processes and equipment groups. PUBBUILD for 15 types of public and commercial buildings broken down into 5 processes;
- WASTE – a model for GHG emissions from the waste sector.

The model parameters are calibrated on 1995-2021 data.

- All of the models have a one-year calculation step and a projection horizon to 2060.
- Model runs for each scenario start from the RUS-DVA and ENERGYBAL-GEM 2060 pair. Then each sectorial model is run coupled with ENERGYBAL-GEM 2060 clockwise in Figure 2.1 to finish by getting back to the RUS-DVA and ENERGYBAL-GEM 2060 pair. It takes several iterations for each selected scenario.
- In all of the scenarios, LULUCF is the last resort option for Russia to meet its carbon neutrality goal by 2060.

Figure 1.1 The ‘cloud’ of models



Source: CENEf-XXI. The angle of incidence is not equal to the angle of reflection. Macroeconomic perspectives.

1.3 The angle of incidence is not equal to the angle of reflection

Global low carbon transition sets challenges, but also provides opportunities for Russia’s economic future. The balance will largely depend on the ability of the Russian government to recognize the scale of the challenge and to address it via effective policy packages. Until very recently, all these three calls for significant transformation were poorly met.

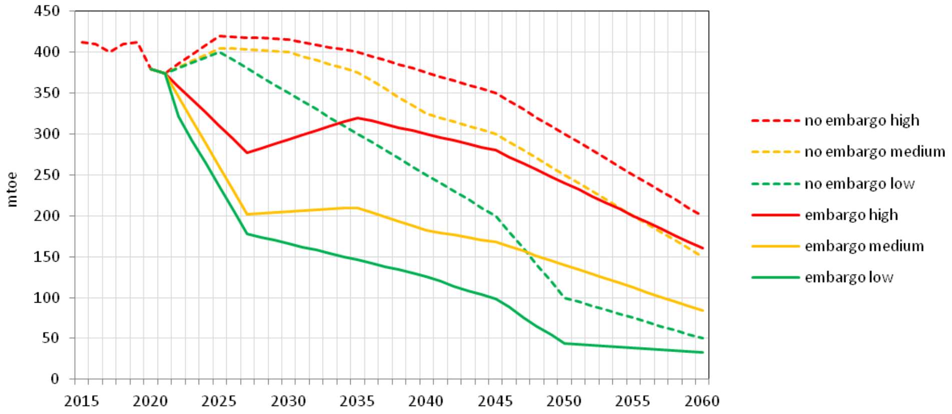
The potential to reach such balance substantially shrank after Russia’s military operation in Ukraine.

- The impacts of Russia’s key trade partners’ low carbon transition on Russia’s economic development depend on the decarbonization pathways that will be selected.
- The assessment of these impacts needs to be broken down into exploring the effects on:
  - ✓ Russia’s traditional exports (mostly fossil fuels and basic materials), and
  - ✓ the emerging low carbon markets.
- Russia’s economy is raw materials-based. Fossil fuels and raw materials production contributes 28-30% to the GDP, nearly two thirds to the industrial output, up to 40% to the federal budget, almost 25% to the consolidated budget, and nearly 75% to the export revenues.
- Therefore, if the “old” model of economic growth persists, the economic progress will largely depend on the potential to supply fuels and basic materials to Russia’s trade partners and to the domestic market in the decades to come.
- Since the growth potential of both these markets is limited, new drivers are required to accelerate the economic growth, and so new low carbon products have to find market niches in the emerging markets.

For oil, the key findings are as follows:

- Foreign markets will be steadily shrinking at a pace determined by the low carbon transition progress and -- at least for a while -- by the political unwillingness to purchase the 'politically toxic' Russian oil;
- It is highly unlikely, that Russia will ever be close to 400 Mtoe in oil and petroleum exports registered back in 2018-2019;
- Oil prices growth in 2022-2024 will overcompensate (for a few years) the revenue loss associated with the sanctions on Russian oil;
- The effect of both decarbonization and sanctions will become severer after 2025;
- Extra revenues obtained in 2022-2024, if not fully used to support the Russian economy, may for some time mitigate the oil revenue collapse beyond 2025.

Figure 1.2 **Russian oil and petroleum exports with an account of embargo effects**

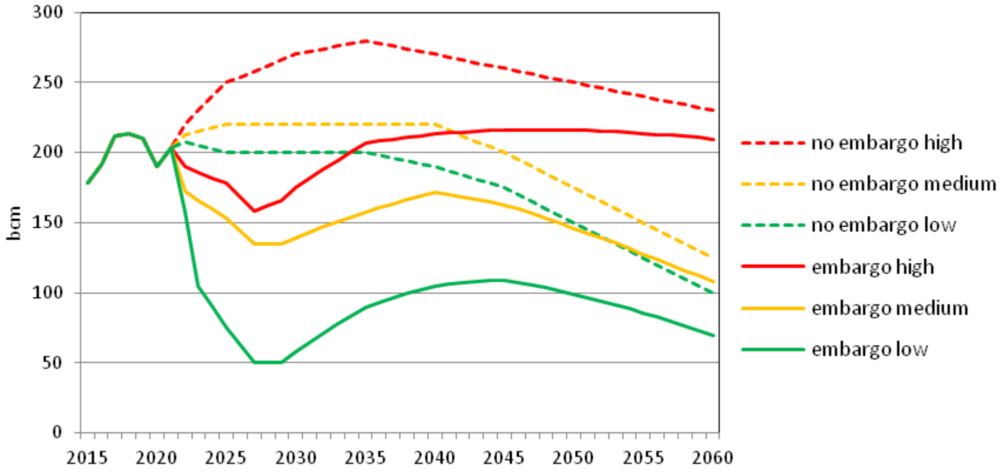


Source: CENEf-XXI.

The findings for natural gas are as follows:

- The EU market and some other markets will be shrinking for the Russian gas driven by decarbonization policies, high gas prices and the political unwillingness to purchase the 'toxic' Russian gas;
- Potential exports of Russian gas in BAU and announced policies-like scenarios may show a 70-100 bcm drop by 2027. It is very unlikely that gas exports and production in Russia will ever exceed the 2021 level;
- Russia has given a substantial push to the low carbon transition process in the OECD countries and worldwide;
- Global demand for Russian gas on the whole 2060 time span will be much lower, than what was expected before February 24;
- Domestic natural gas demand in Russia will be driven by two factors working in the opposite directions:
  - first, the demand will be declining due to the Russian economic recession with a subsequent slow revival; and
  - second, low carbon transformation of the Russian economy will slow down for the equipment import restrictions and declining incomes.

Figure 1.3 Russian pipeline gas exports with an account of embargo effects



Source: CENEf-XXI.

The conclusions for coal are as follows:

- Moderate progress towards global decarbonization and limited sanctions on coal may keep Russian coal production and exports close to the current levels with a very low potential to grow;
- A substantial progress in global decarbonization and taking action to cease coal imports from Russia by 2027 will halve Russian coal exports by 2035 and further reduce them beyond that point with a subsequent decline in coal production, as domestic coal use in Russia will be down as well.

Russia's non-fuel exports can be expected to go down in 2022 and in a few subsequent years.

- After (if) some of the sanctions are lifted, new markets are found for traditional exports, and logistics is developed to supply these new markets, some of the lost exports may be partly or fully regained with time.
- In the longer term, traditional markets for highly carbon intense basic materials will be steadily shrinking. Unless Russia manages to decarbonize its industrial production, these markets may be blocked for its exports.
- As to high-tech exports expansion, Russia starts from a very low base, and after February 24th it lost a lot of innovators who could give momentum to high-tech production.

The UN population projections show that:

Russia's population will be declining slowly until around 2070 and stabilize thereafter. The undulating dynamics of the working-age population will lead to its noticeable reduction before 2030 in all of the scenarios, with a subsequent stabilization to 2045, followed by another decline. Beyond 2060, the working age population will be varying between 60 and 70 million people.

Recent scenarios (developed before February 24, 2022) differ markedly regarding the "visions" of the Russian economic growth.

- The uncertainty zone includes three segments:
  - "slow growth" – AAGR up to 1% until 2050;
  - "moderate growth" – AAGR 1-2.5% in 2021-2030 and 1-2% in 2031-2050;
  - "dynamic growth" – AAGR to exceed the upper boundary of the "moderate growth".
- The most pessimistic estimates show AAGR close to, or below, 1%; these are provided by the IEA, US DOE and BP. Their projections account for the negative demographic trend as discussed above.

Sensitivity of Russia's GDP dynamics to fluctuations in the global oil and gas markets is gradually weakening.

- Growing oil and gas revenues give a limited and temporal impulse to the economic growth.
- Opportunities for hydrocarbon-led growth are nearly exhausted and undermined by the expected economic losses from declining hydrocarbon exports, which will be increasingly progressing, as the global low carbon transition gains momentum.
- Relying on the traditional resource-intensive model of the "red economy" can only ensure very low GDP growth rates.

After 2007, economic growth has been fully extensive, especially in the oil&gas sector

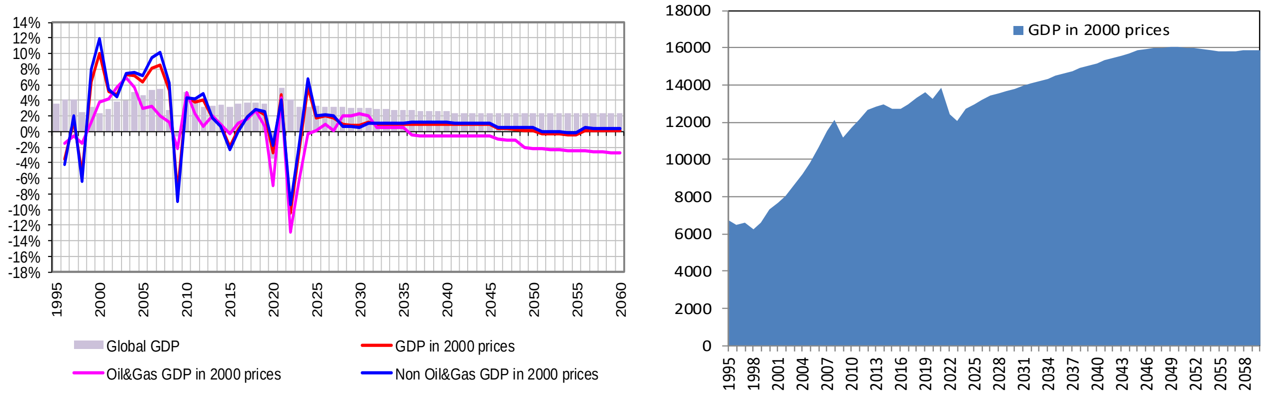
- The average 1995-2020 TFP for the NOG sector was assessed by CENEf-XXI at 0.7%, and for the whole GDP it was assessed by the KLEMS project also at 0.7%.
- For 2010-2020, it was -0.2% for NOG-GDP and, according to KLEMS, -1.6% in 2007-2016 for the whole economy.
- TFP went down to the negative zone, and only a coincidental growth in oil prices, which started in 2000, allowed it to maintain some very moderate, exclusively extensive, and very capital-intense economic growth.

Even some of the previous pessimistic expectations for the economic growth in Russia overnight became quite optimistic on February 24, 2022, as a result of the sanctions.

The resulting trajectories are shown in Figure 1.4-1.5 for two of the considered scenarios:

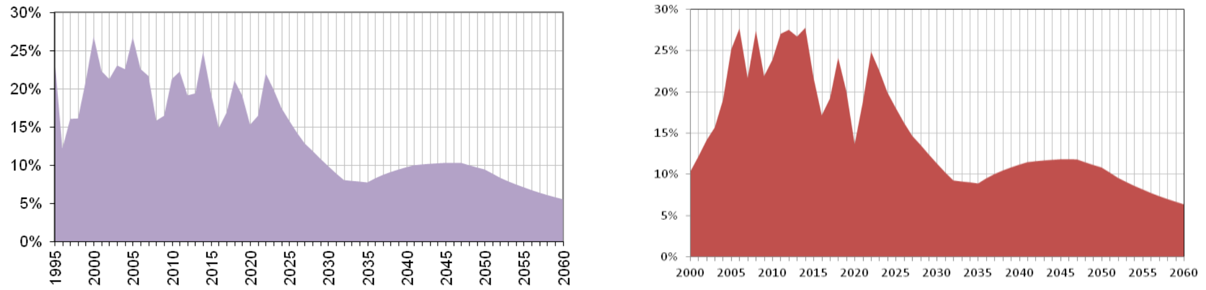
- Scenario 1: slight fuel export reductions and low TFP level;
- Scenario 2: medium fuel export reductions and medium TFP level;
- Scenario 3: high fuel export reductions and high TFP level.

Figure 1.4 Scenario 1. Parameters of Russian economic development: slight fuel export reductions and low TFP growth



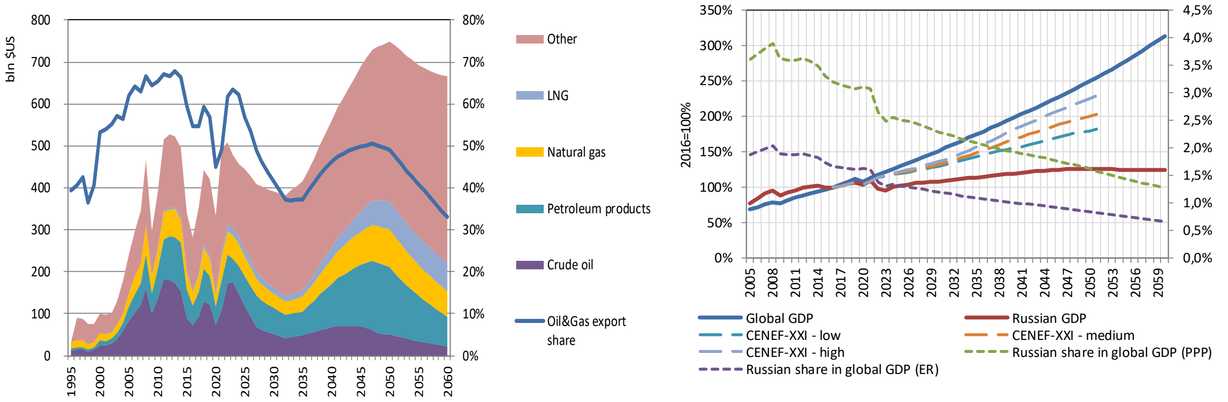
(a) Annual growth rates for GDP and its components

(b) GDP in 2000 prices



(c) Share of oil&gas GDP

(d) Share of oil and gas revenues in consolidated budget revenues

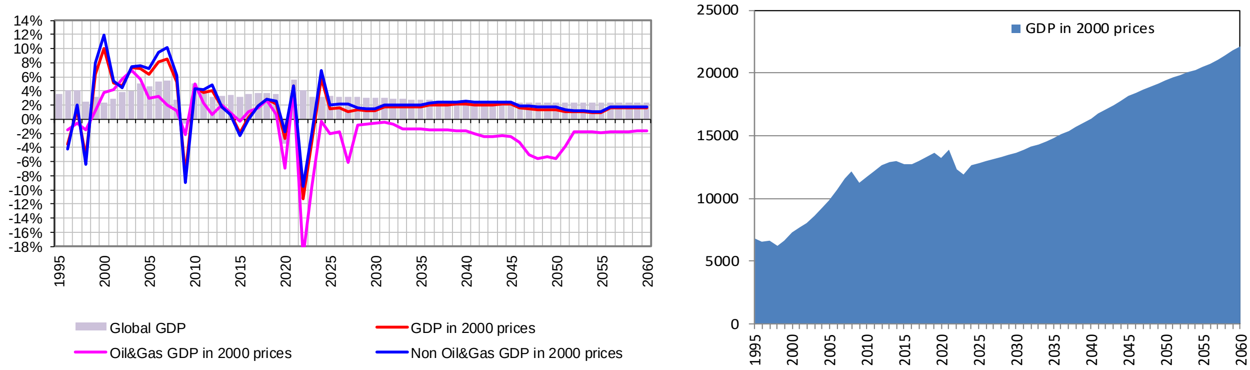


(e) Structure of goods export

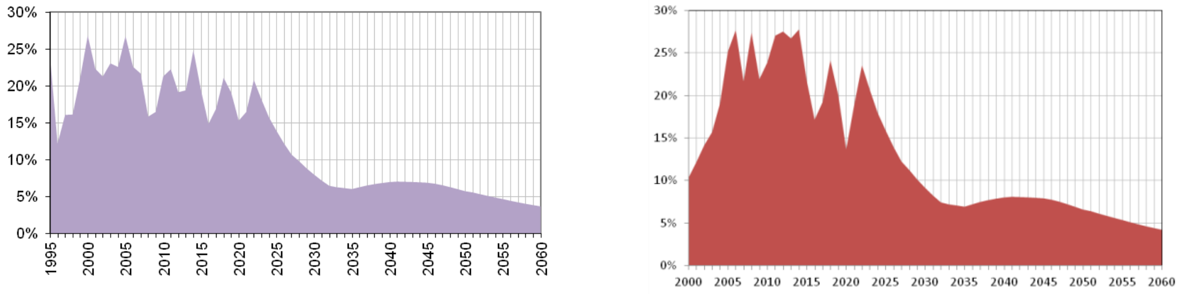
(f) Russian and global GDP growth (2016=100) and Russian share in global GDP

Source: CENEf-XXI.

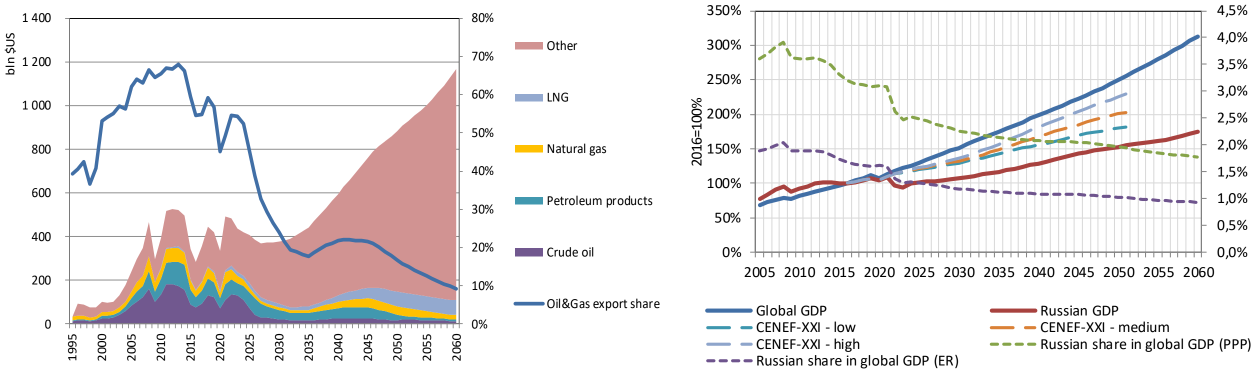
Figure 1.5 **Scenario 3. Parameters of Russian economic development: high fuel export reductions and high TFP growth scenario**



(g) Annual growth rates for GDP and its components (h) GDP in 2000 prices



(i) Share of oil&gas GDP (j) Share of oil&gas revenues in consolidated budget revenues



(k) Structure of goods export (l) Russian and global GDP growth (2016=100) and Russian share in global GDP

Source: CENEf-XXI.

As a result of such developments, Russia will lose 10-11 years of economic growth.

The 2021 GDP level will only be back in 2031-2032:

- By 2050, Russia will have lost 46-51% of the previously expected potential GDP;
- In 2060, Russian GDP will be 21-44% higher, than in 2021, reaching at the maximum 1.6% AAGR in 2040-2050 and 1.3% AAGR in 2050-2060. This is possible only with an assumption that the economic and institutional models in Russia will be altered to enable the TFP improvements. A failure to provide new institutional and socio-political frameworks for the economic growth will limit Russian GDP growth to just 6% in 2060 relative to the 2021 level. In other words, there will be four decades of economic stagnation ahead;
- The share of Russian GDP in the global GDP will still be shrinking from 1.6% in 2021 to 0.7-0.9% in 2060, when estimated in exchange rates, and from 3.1% to 1.3-1.7%, if estimated in PPP.

1.4 Scenario storylines. Three 4s

One lesson from the future is that there is no business-as-usual for the years to come; instead, business-as-unusual needs to be in the focus.

For Russia, there will be no business-as-usual even in the short- and medium-term.

- A few months ago, no one could foresee the Russian military operation in Ukraine and the subsequent strong and escalating sanctions.
- The sanctions will work to deepen the existing technology gap with the global leaders and cutting-edge technologies, leaving little chance to bridge it relying on imports substitution and self-sufficiency.
- It was equally difficult to anticipate that Russia will be cut off the global supply chains, and the world will progress to the future leaving Russia behind. But now such vision of the future is feasible and should be considered.
- Therefore, the task is to develop visions to embrace the range of uncertainty which greatly increased after February 24.
- Word selection in the title of Figure 1.6 is not unambiguous anymore. The future may look more like the right-hand part of this figure or more like the past shown on the left-hand side.

Figure 1.6 $\boldsymbol{Future\ is\ \frac{ahead}{behind}, Past\ is\ \frac{ahead}{behind}}$

Source: developed by I. Bashmakov.

Three sets of scenario storylines were developed to cover the abruptly widening uncertainty zone to draw the pathways which may get Russia to carbon neutrality by 2060:

- *4S – Stagnation, Sanctions, Self-Sufficiency,* which may be alternatively titled *Forward-to-the-Past* (as the opposite to the *Back-to-the-Future*);
- *4D – Development Driven by Decarbonization and Democratization,* which opens the door for Russia to return to the global economy;
- *4F – Fossil Fuels for Feedstock,* which builds upon *4D* and allows Russia to use its fossil fuel resources for non-energy use.

4S – Stagnation, Sanctions, Self-Sufficiency – Forward-to-the-Past.

This scenario is based on the following narratives and storylines:

- strong sanctions persist for Russia's dominating traditional exports, which are considered toxic in the global, and especially G7, markets; the ban on high-tech exports to Russia also persists;
- oil and gas exports quickly shrink, with just a limited potential to rebound later by turning to new regional markets, as the global economy is steadily switching to low carbon pathways;
- O&G sector declines, and so does its contribution to GDP, foreign trade, and consolidated budget (after 2025);
- Russia is cut off many global supply chains and forced to rely on self-sufficiency for domestic needs;
- strong government control over the economy with a subsequent decline in overall efficiency in the sectors under control;
- poor quality high-tech imports substitution with a low potential to improve total factor productivity in many sectors, which have already suffered from a deeper government control;
- slow economic growth in the NOG sector with low total factor productivity, declining labour force, intense brain drain, low investment, and limited inflow of foreign capital;
- inability of the NOG sector to fill shortfalls in GDP, foreign trade and consolidated budget revenues, which were historically yielded by fuels and raw materials exports;
- limited potential to expand non-fuel and non-basic materials exports to the global markets, which are dynamically switching to low carbon pathways;
- poor access to international financing for Russian companies and the public sector will restrict the ability of the consolidated budget to keep the expenditures growing, as beyond 2025 oil and gas revenues will drop driven by both low exports and low energy prices, and the NOG sector will be unable to fill the gap;
- aging production facilities, slow phasing out and low modernization rates;
- lower demand for additional production and low capacity additions, as demand for Russian products, both domestic and international, will be growing very slowly (if at all);
- only a small share of new capacity will meet the BAT (best available technologies) standards; the new capacities built to the BPT (best presently practical technologies) at the best will dominate, since poor competitiveness and lack of high-tech equipment will impede reaching the technology cutting edge.

4D – Development Driven by Decarbonization and Democratization is the Door Back to the Global Economy.

The story lines for this scenario are quite different:

- progress towards termination of Russia’s military operation in Ukraine will relax sanctions and enable Russia to regain some of its positions in the global value chains after 2030;
- proactive decarbonization policies in Russia will help the country to get a market niche in some global regions for a variety of products with low or no carbon footprint and get access to the hardware and software needed to produce low carbon products and services. Low carbon global markets are expected to reach $US 12 trillion by 2030 and $US 11-16 trillion in green investment by 2050. Getting just a 1% share in this pie could bring $US 110-160 billion;
- democratization will develop, as the role of the oil and gas sector will be shrinking, and reliance on a wider political and social spectrum will become key for sustaining social stability and inspire business activity. All this will bring more competition into the economy (while the role of the government will be declining), free up initiative, reduce migration intentions of qualified workforce, and attract skilled professionals from abroad to work in Russia. It will reduce corruption and provide incentives for investment and rewarding based on skills, rather than on loyalty;
- relaxed or removed high-tech import sanctions, competition-based incentives to invest in new technologies, and re-gained access to international financing will improve total factor productivity and therefore spur the NOG sector development with a growing potential to fill the income gap from the oil and gas revenues drop;
- growing potential to increase low carbon products/services production will accelerate phasing out obsolete capacities and boost modernization of the remaining capacities;
- higher demand for additional production in the domestic and international markets will significantly scale up capacity additions that perform to the BAT standards;
- low carbon footprint requirements for products and services will provide incentives to reduce scope 1 emissions via improved energy and material efficiency, circular economy, and electrification, CCUS and hydrogen application and scope 2 emissions via promoting low carbon energy penetration, including renewables, both in grid and off-grid systems; hydrogen-based technologies; CCUS; electric vehicles; and other low carbon technologies, as they reach the commercialization stage;
- the need to make low carbon technologies competitive at their initial deployment stages, along with a potentially wide geographical and products-wise spread of CBAM-like mechanisms supported by the Sakhalin experiment results (if positive), will inspire the launch of a CO_2 price mechanism at the national level.

4F – Fossil Fuels for Feedstock.

The storylines for this scenario mostly build upon the 4D scenario, but:

- they additionally assume more intensive fossil fuel use for chemical feedstock, along with "blue" hydrogen and ammonia production;
- a substantial external demand for Russian-produced chemicals and hydrogen is expected;
- a focus on the export of plastics and other chemicals will allow it to use more fossil fuels for feedstock with CCUS deployment;
- ambitious plans to export low carbon hydrogen or ammonia will be implemented on a large scale in Russia using large amounts of natural gas at facilities equipped with CCS.

1.5 4S – Stagnation, Sanctions, Self-Sufficiency – Forward-to-the-Past

This scenario is modeled in a framework, which is by no means BAU-like. Rather, it is a reference scenario.

4S captures the demand reduction option, but not because a reasonable sufficiency is achieved; rather, it is based on sufficiency willy-nilly (both on quantity and quality) driven by supply reduction.

- The sanctions force Russian companies to change their logistics for both raw materials and components supply.
- Broken export logistics result in physical restrictions on exports and higher product prices.
- Given the limited domestic market, which is shrinking during the crisis, the reorientation of production to the domestic needs can hardly offset export losses.
- Some optimists hope for a "powerful leap", which will take 2-4 years and will minimize the effect of the sanctions. However, it is more realistic to think that this process will take decades.
- Limited access to financing means that costly investment projects will be postponed indefinitely.
- Success criteria for revised government industrial strategies are different now. Success is no longer measured based on the integration in the global economy and expansion of exports; rather, it is based on the achieved degree of isolation, i.e. reduced share of imports in production.

Two decades – the 2020s and 2030s – which have the crucial role in accumulating the know-how and developing skills related to the uptake of technologies with high GHG mitigation potential may be wasted.

- The evolution of the capacity age structure in 4S is slow, however, many of the existing obsolete facilities will have to be replaced and/or deeply upgraded before 2060.
- The decades 'lost' in terms of technological development can make assets commissioned in the 2020s and 2030s stranded (suffering from unanticipated and premature right-offs) in the 2040s and 2050s.
- An assumption is made that new capacities will be built to meet at best the BPT (best presently practical technologies) or BART (Best Available in Russia Technologies) level.
- The evolution of the capacity age structure is slow, however, many of the existing obsolete facilities will have to be replaced and/or deeply upgraded before 2060.

Electricity generation will show practically no growth over two decades.

After a decline in 2022-2023, centralized electricity generation slowly recovers to reach the 2021 level only in 2042 and grows to 1,320 billion kWh in 2060

- Negative effects of the sanctions are observed in all segments of the electricity market.
- For fossil fuel-based generation, 4S scenario assumes moderate progress in improving the efficiency of both new and upgraded power plants to levels lower than global BAT.
- There is no simple or unambiguous solution to the problem of low-carbon generation development in Russia to 2060. However, despite the slow growth in electricity generation, the generation structure changes noticeably.
- Centralized generation based on variable RES (wind and solar) grows up to 279 billion kWh in 2060, or up to 21% of total generation.
- Due to the slow growth in electricity demand total capacity of power plants grows only slightly to 258 GW in 2060, including: nuclear – to 43 GW; wind – to 37 GW; solar – to 26 GW.

Russian industry has a long way to go to attain the net-zero GHG or net-zero carbon status by 2060.

- Slow decarbonization in the Russian industry impedes access to the international markets for traditional Russian basic materials, because global economy is becoming less carbon-intensive. This leaves no chance for a dynamic rebound of traditional markets.
- Russia’s isolation from the global supply chains and its self-reliance for the manufacture of new products will block the country’s penetration to the emerging trillions-of-dollars-worth markets.
- After a rebound to the 2021 level in 2031-2032, basic materials demand is expected either to stay nearly stable (steel and cement) or to slowly grow (pulp and paper, chemicals and aluminium).

Transport faces declining demand determined by both freight and passenger transportation drop coupled with reduced supply of cutting-edge transport equipment.

Transport activities decline, along with slowing down fleet modernization with a strong reliance on domestic cars production, will slow down fuel efficiency improvements and deployment of low carbon fuels by all transport modes.

- The most important effect for freight transport is the reduction of activity on the whole 2060 time horizon. In 2060, freight turnover per unit of GDP will be 45% below the 2021 level. This is not a new phenomenon: the 1991 level of freight turnover was back only in 2021. The 2021 level is not expected to be reached in 2060.
- Following personal incomes decline, personal mobility and passenger turnover will drop by 2025 and then grow very slowly to 2060 never reaching the pre-COVID 2019 level.
- Only 29% of LDVs were produced based on Russian automobile platform designs.
- Russian aircraft industry, highly relying on the imports, was also severely hit by the sanctions.
- Russians will have fewer cars, which, in addition, will be continuously aging to become less reliable and less fuel efficient. The share of imported second-hand cars is expected to grow.

GHG emissions from transport already peaked at 284 million tCO_2eq. in 2018 and will be steadily declining to 113 million tCO_2eq. in 2060.

- Total energy consumption by transport will be halved in 2021-2060 dropping from 148 to 73 Mtce.
- The share of fossil fuels in the transport energy balance will be moderately declining from 91% in 2021 to 80% in 2060.
- Fleet structure by power train will be slowly evolving towards less carbon intensive models, but in this race Russia will be lagging far behind the technological leaders.

Direct GHG emissions from residential buildings will slightly increase in the short term, and then will drop to 77 million tCO_2eq. in 2060.

- Energy efficiency of the apartment buildings in place will be declining. In the recent years, the share of capital retrofits associated with energy efficient projects did not exceed 0.15% of the total residential floor space.

After a stabilization in 2000-2020, residential energy consumption will be 24% up from the 2020 level by 2060 to reach 170 million tce.

- There are national plans to strengthen energy efficiency standards for new residential and public buildings on the 2028 time horizon to reduce specific energy heat consumption by 35%.
- It will not be possible to ‘import’ the energy efficiency of appliances on the previous scale, because the sales of appliances, especially of energy efficient models, will be decreasing in the coming years.
- Renewable energy use in buildings and transformation of Russian households into prosumers will be progressing, even if at a slower rate.

A limited set of measures in the waste sector allows it

- to freeze GHG emissions to 2030 at a level close to that in 2020 with a subsequent 9% decline. The waste sector will be suffering from the shortage of technologies.

Only one scenario for agriculture was considered, which assumes that the 2005-2020 GHG emissions growth trend will be reversed through a package of both demand- and supply-side measures.

- One key measure to reduce livestock enteric fermentation is to replace low-yielding breeds of dairy cows with high-yielding ones and to reduce the pig livestock.

GHG emissions from agriculture appear to have already peaked, and will be declining to reach 100 Mt CO_2eq.

- If agricultural emissions are to move down from the peak, it is important to implement demand-side measures, including food waste reduction and diet change.
- Bringing down the share of food products with a high carbon footprint (as carbon footprint estimation and reduction practices develop) and replacement of some products with their alternatives, for example, replacement of beef with poultry meat, could become important directions for GHG emission reduction.
- Diet control may be more effective, than GHG emissions mitigation in agriculture. However, because of a substantial diet patterns inertia, this option is less realistic.

In this paper, the evolution of net emissions in LULUCF was estimated as the additional net sink demand (LULUCF plus) to attain carbon neutrality in 2060

- A CO2 net sink baseline was set for 2021-2060, as extrapolated declining trend formed in 2010-2020. It scales net sinks down to 115 MtCO2 in 2060.
- These baseline values were deducted from emissions in other sectors.
- The result is an additional CO2-only net sink – LULUCF plus – needed to attain net-zero balance to ensure carbon neutrality in 2060.

Total primary energy consumption (TPES) peaked in 2021 at 1,121 Mtce, will fall down to 975 Mtce in 2024 to further rebound to 1,030 Mtce in 2031 with a subsequent decline thereafter down to 80% of the 2021 level.

- Energy efficiency does not contribute much to mitigation: in 2021-2060, GDP energy intensity (non-energy use excluded) will be declining only at 1% per year on average. With an account of non-energy use the decline will be 0.6% per year.
- As RENs, hydro, and nuclear power generation grows, fuel consumption will be 25% down in 2021-2060, and fuel combustion will be down by a third.
- In 2060, domestic natural gas consumption will be 15% down to 448 Mtce, and gas combustion will drop by 22% to 330 Mtce.
- Liquid fuel consumption will be 44% down, and liquid fuel combustion will be 74% down, mostly due to transport consumption decline.

Russia may attain carbon neutrality in 2060 only providing that strong and effective policies in LULUCF are implemented to block the net sequestration declining trend of the last decade and then to scale up LULUCF capacity substantially to capture additional $\mathrm{CO_2}$.

- Progress in energy decarbonization will give momentum to CO2 reduction in sectors other than LULUCF.
- Carbon price in 4S scenario will be 1 \$US/tCO2 in 2031, slowly growing to 30 \$US/tCO2 in 2060. It will bring 1.7 trillion rubles, or 0.6% of GDP.
- Investments in low carbon projects amount to 78 trillion rubles. This is twice below the investments in fuel supply (169 trillion rubles).
- The share of investments in low-carbon transformation (total investment less investment in fuel production and processing) of GDP will be gradually decreasing from 2.1-2.2% in 2021-2025 to 1.5-1.7% in 2050-2060.

Russian CO2 and GHG emissions peaked in 2021. Expected GHG emission reduction is 63% and that for CO2 is 67%.

- Russia is expected to be ahead of the EU in cutting GHG emissions by 2030.
- In the early 2020s, Russia is about to repeat the negative experience of the 1990s by reducing its GHG emissions through a deep activities (demand) reduction, which is the most expensive "mitigation" option costing 1,137 \$US/t$\mathrm{CO_2}$eq.

1.6 4D – Development Driven by Decarbonization and Democratization is the Door Back to the Global Economy

It is assumed that the Russian government will recognize the need for decarbonization in all of the sectors in addition to the importance of increasing sinks in LULUCF, in order to:

- Reduce the 2060 carbon neutrality non-compliance risks;
- Maintain fuels and basic materials exports to the global and regional decarbonizing markets, where low carbon footprint is becoming critical, while carbon price mechanisms undermine the competitiveness of carbon intensive products;
- Export high-tech products and services to emerging trillions-worth low carbon markets. These products and services, placed at the end of the value chains, will be less affected by carbon prices, but they will obtain financing and markets only if they can meet the requirements of the emerging regional taxonomies and end-users;
- End up the 2020s break in modernizing obsolete and degraded production facilities in all sectors. After it becomes clear that the self-sufficiency carriage has turned into a pumpkin, this will be a way to avoid being locked-in for decades in outdated carbon intensive technologies – less efficient and more expensive – that were developed during the decade of reliance on imports substitution;
- Rely on less costly technology solutions, as it is expected that in the 2020s and 2030s low carbon technologies will become less expensive compared to the traditional counterparts (RENs versus traditional power generation, EVs versus ICEVs, DRI-H2-EAF versus BF-BOF, etc.).

These considerations will encourage Russia to implement proactive decarbonization policies to combat climate change and at the same time get the Russian economy back on the development track.

- To make this happen, new institutions will be needed.
- Democratization will develop, as the role of the oil and gas sector will be shrinking, and reliance on a wider political and social spectrum will become key for sustaining social stability and inspiring business activity.
- All this will bring more competition into the economy and free up initiative, as unanimity and double-thinking will be replaced by dissent and sanity.

Electricity generation will be stable for 2 decades, and the 2021 generation level (1,159 billion kWh) will not be reached until 2041.

Beyond 2041, electricity generation will quickly scale up to 1,516 billion kWh in 2060, driven by the electrification of end-uses.

- This value breaks down into 1,471 billion kWh for centralized generation and 45 billion kWh generated by prosumers.
- Current business models in the power industry will be changing due to the growing role of system service providers associated with the need to integrate a high share of renewable energy and to the growing role of aggregators who manage distributed energy units.
- Low carbon power generation is based on carbon pricing for fossil fuels-based power, support for power storage and networks development to accommodate variable RENs, which are becoming cost-competitive, as economy of scale and learning rates bring the LCOEs down.
- When weighed by new capacity additions, average LCOE after a small growth in the 2020s will be steadily declining to 2060 to reach a level lower, than in 2021.

In 2060, the power system will not be zero carbon yet, but the share of low and no carbon power sources will scale up from the current 40% to 78%.

Carbon intensity of power generation will go down to nearly 50 gCO$_2$/kWh, but not yet to zero, in 2060.

- Low carbon power will be provided by nearly all new additional capacity in 2021-2060 compensating for phased-out fossil fuel capacities.
- By 2060, the share of low carbon sources in the installed capacity will scale up from the current 34% to 75%.
- Centralized variable RENs (wind and solar) power generation will approach 332 billion kWh, or up to 24% of total generation, in 2060.
- District heating will continue to decline (by 43% in 2021-2060) despite the fact that a lot of heated space will be added.
- Fossil fuel use for heat generation will be 60% down from the 2021 level.

Russian industrial companies will spend the 2020s to find new markets and to change the logistics for components supply, and after the decade-long crisis is over, Russian companies will benefit from lifted sanctions.

- Growing domestic and international competition will strongly encourage Russian companies to double the intensity of capacities modernization.
- Since the economic development is faster, than in 4S scenario, and will be going with a severer competition, none of the current capacities aged 25 or older will still be in operation in 2060 to produce basic materials, unless deeply upgraded and supplemented with new capacity additions after 2021 to dominate in the 2060 capacity balance.

The government will start implementing large and effective decarbonization policy packages in industry, such as:

- Carbon pricing to motivate businesses towards carbon footprint reduction and to reduce the risks of economic losses incurred by CBAM-like mechanisms. This would require effective carbon intensity benchmarking systems and tools to estimate and certify GHG footprint of products;
- Planning transition pathways and long-term strategies to coordinate mitigation activities in individual industries;
- Performance standards and codes, especially for cross-industrial technologies, such as electric motors or steam supply systems, to increase the durability of products and materials;
- Require extended producer responsibility for their products end of life service and to cover the recycling costs or otherwise responsibly manage problematic wastes.
- Subsidies will be provided to bridge the costs gap between traditional and low carbon products -- as long as this gap exists.

New low carbon technologies penetration will scale up substantially, when carbon price and subsidies for low carbon production are introduced.

- Improved materials efficiency across all sectors and promoting circular economy will keep virgin basic materials demand growth moderate, but will allow for an increasing contribution from secondary materials (metals, paper, and plastics).
- Carbon pricing will make technological options with improved energy efficiency, substitution (clinker), alternative low carbon fuels and CCS cost-effective, and new production facilities will be equipped with such technologies.

Russian industry will significantly progress towards carbon neutrality. In 2021-2060, combustion-related emissions will be down from 305 to 45 MtCO$_2$, and industrial processes emission from 194 to 62 MtCO$_2$.

- A low carbon strategy for iron and steel needs to be developed to identify low carbon transition pathways.
- The costs of DRI-gas with CCS-EAF and DRI-H$_2$-EAF routes will only get close to DRI-gas-EAF in 2060. Therefore, the uptake of these processes will be limited and mostly oriented to foreign markets with higher steel costs.
- CO$_2$ emissions in the cement industry will drop by two thirds in 2021-2060, and if the “sponge” effect is accounted for, the industry may become a net CO$_2$ sink in the 2040s.
- Carbon pricing, subsidies for CfD green ammonia supply contracts, and technological progress will cut net emissions from ammonia production by 3 times.
- Low carbon transformation of the Russian industry will improve the competitiveness and allow for stronger positions in the global markets.

Persisting low carbon transport transition policies, not very intense before 2031, but more intense thereafter, will allow it to come back on track.

- In the recent years, Russian transportation policies were focused on promoting less polluting and low carbon solutions.
- The sanctions make some of the previous plans unfeasible, and delay the implementation of others making some mitigation policy options impractical on the initially expected time horizon.

CO_2 emissions from transport will be more than 200 $MtCO_2$ down in 2021-2060, yet leaving 70 million tCO_2 unabated in 2060. Total GHG emissions from transport, including indirect emissions, will decline from 309 to 83 million tCO_2eq.

- Electrification of transport is the key GHG mitigation policy:
  - ✓ The share of electricity in the transport energy balance will be up from the current 7% to nearly 40% in 2060. For rail, it will reach 85%, for pipelines 44%, and for automobiles 32%.
  - ✓ The 2060 LDV fleet structure will evolve towards electric power train, and EVs share will reach 70% in new sales (12% PHEVs and 58% BEVs) followed by gas-powered vehicles (13%) with only 17% left for ICEVs. The share of EVs in the total vehicle fleet will approach two thirds.
- Total energy consumption by transport in 4D scenario will drop 3-fold in 2060: from 148 to 51 Mtce versus 73 Mtce in 4S scenario.

Direct GHG emissions from residential buildings will drop to 47 million tCO2eq. in 2060.

- In this scenario, housing construction will be larger, since a faster economic recovery is expected.
- From 2029 onwards, energy efficiency requirements for new buildings will be stricter to reach A+ class by 2060.
- Energy-efficient capital retrofits in buildings and their effects will increase significantly.
- More energy-efficient appliances will be available.
- Incentives will allow for a better uptake of on-site power and heat generation from renewables. Electricity generation by buildings-based prosumers will reach 45 billion kWh in 2060.
- Significant energy efficiency improvements will cut energy consumption in buildings by 20% to reach 108 million tce.
- An additional set of measures in the waste sector will allow it to reduce GHG emissions from 96 $MtCO_2eq$ in 2020 to 23 $MtCO_2eq$ in 2060.

Total primary energy consumption will be 27% down from 1,121 Mtce in 2021 to 818 Mtce in 2060.

- Energy intensity of GDP (non-energy use excluded) will be on the rise in 2022-2024 and then it will decline by about 60% in 2060 with 2.5% per year AAGR, which is twice the level in 4S scenario. With non-energy use energy intensity of GDP decline is limited to 1.6% per year.
- Energy efficiency improvements coupled with growing power generation by RENs, hydro, and nuclear will result in fossil fuel consumption drop by two thirds from 779 to 253 Mtce, or twice as much as in 4S scenario.
- In 2060, domestic coal consumption will decline 10-fold from the 2021 level, and a certain part of it will be with CCS.

Beyond 2030, Russia will never exceed 35% of 1990 CO_2 emissions and 36% of 1990 GHG emissions.

- Russia can attain carbon neutrality in 2060 without expanding LULUCF net sink, which can drop from 605 $MtCO_2$ in 2020 to 291 $MtCO_2$ in 2060.
- Like in 4S, Russia will be ahead of the EU in cutting CO_2 and GHG emissions by 2030. Expected GHG emission reduction is 64% and CO_2 emission reduction will be nearly 70%.

No additional investment demand is associated with 4D scenario.

- Total capital expenses in 2022-2060 will amount to 197 (versus 247 in 4S) trillion rubles in 2021 prices. Energy and GHG mitigation investments will be lower (50 trillion rubles), than in 4S scenario due to a much lower investment demand from the oil and gas sectors. Investments in low carbon projects will amount to 92 trillion rubles (versus 78 trillion in 4S). This is about as much as in fuel supply – 105 trillion rubles (versus 169 trillion in 4S).
- The share of investments in low carbon transformation (total investments less investments in fuel supply) in GDP will be gradually decreasing from 2.2-2.7% in 2021-2030 to 1.5-1.7% in 2050-2060.

1.7 4F – Fossil Fuels for Feedstock

4F builds upon 4D in all sectors and is developed to test another pathway and check to what degree Russian fossil fuel resources, including oil and gas, can be additionally used as feedstock for chemicals production, including plastics, ammonia, and hydrogen, and how then GHG emissions will be evolving.

- According to the available projections, global plastics production could more than double from almost 400 Mt in 2019 to 985 Mt in 2050.
- Global ammonia production is expected to grow 2.5-fold from 175-183 Mt in the recent years to 441 Mt or even more in 2050.
- Global hydrogen production is expected to grow from 87 Mt in 2020 to 528 Mt in 2050.
- In 4F scenario an assumption is made, that low carbon hydrogen exports will be up to 15 Mt in 2060 (versus 0.7 Mt in 4D), and low carbon ammonia exports will reach 15 Mt in 2060 (versus 6.5 Mt in 4D scenario). In addition, non-energy use for chemicals production will accelerate to maintain the industrial production growth rates to 2060.

4F scenario requires a green power revolution or green electrification. After a two decades-long stagnation electricity generation will skyrocket to 1,825 bln kWh in 2060 driven by low carbon hydrogen demand.

Even if 2060 Russian hydrogen production (15.8 Mt) is half “blue”, still additional electricity demand for hydrogen production will be 350 bln kWh in 2060, which is one third of today’s power generation in Russia.

- If carbon-free generation is limited, the high level of “green” hydrogen production may be responsible for significant additional GHG emissions.
- To meet the electricity demand in 4F scenario, total power capacity needs to grow up to 418 GW in 2060, including 102 GW wind, 86 GW solar, and 77 GW nuclear. It will be only one third of 2021 wind capacity installed in China (329 GW) and about one fourth of 2021 solar capacity in China (307 GW); so it seems feasible.
- Annual capacity additions will reach 18 GW in 2060 versus 7.7 GW commissioned in 2014 (maximum for the last 10 years).
- The share of non-fossil fuel-based power generation will reach 78% in 2060.
- Wind generation will reach 352 billion kWh (versus 118 billion kWh in Germany in 2021) and solar generation will reach 192 billion kWh (versus 49 billion kWh in 2021 in Germany).
- Taken together, these variable power sources contribute feasible 30% to total generation.

After a profound drop by 16% in 2027, total primary energy consumption will then be nearly stable at 932-944 Mtce until 2050 with a subsequent growth to 1,013 Mtce in 2060. For the whole time span, it will never exceed the 2021 level.

- Growing “blue” hydrogen and ammonia production, along with additional feedstock demand, will allow it to stabilize domestic natural gas consumption close to 470-480 bcm to 2045 with a subsequent decline to 400 bcm, as “blue” hydrogen is substituted with the “green” one.
- Additional liquid fuel demand for non-energy use doesn’t help avoid domestic liquid fuel demand reduction, but this decline is not as deep as in 4D. The remaining liquid fuel energy use will only be 21%, while the rest will be for feedstock.

CO_2 emissions trajectory in 4F scenario is quite close to the one in 4D, as additional ammonia and “blue” hydrogen production will use CCS and additional non-energy use for chemicals production will store carbon in plastics and resins until they are incinerated in the importing countries

- No additional investment demand compared to the 2021 level is anticipated.
- In 4F, total capital expenses in 2022-2060 will amount to 231 trillion rubles (versus 197 trillion in 4D and 247 trillion in 4S). They will be higher, than in 4D, for two reasons:
  - First, larger production of oil and gas due to additional fuel production for feedstock use;
  - Second, substantial additional investments are needed for hydrogen and ammonia production.

1.8 Fit for 55? - No. - Fit for 65? - Maybe. - Fit for 60? - Definitely yes!

The goal of the Russian Low Carbon Development Strategy is to more than double net sinks in 2050. It looks extremely ambitious.

2F pathway– *Forest First* – was chosen for the Russian LTS, which practically relies on one pillar, thus incurring high risks of non-compliance.

- 2F (Forest First) is the pathway to carbon neutrality favoured by the Russian Government. It implies a large additional sequestration in LULUCF (additional 665 Mt CO_2eq. of net sinks in 2019-2050), while emission reductions in other sectors will be moderate (-289 Mt CO_2eq. reduction in 2019-2050), but …
  - ✓ net sink from forests is going down driven by CO_2 losses. This decline equals 140 Mt CO_2 in 2010-2020;
  - ✓ net sinks reduction in LULUCF contributed 79% to the total net GHG emission increments in 2010-2020 and exceeded 100% (over-offsetting the reductions in other sectors) for total CO_2-only emissions increment.
- With the declining net sink trend, LTS will need additional LULUCF sink of 1,085 Mt CO_2.
- The government hopes, that LULUCF sink can be proven to be much larger with no declining trend.

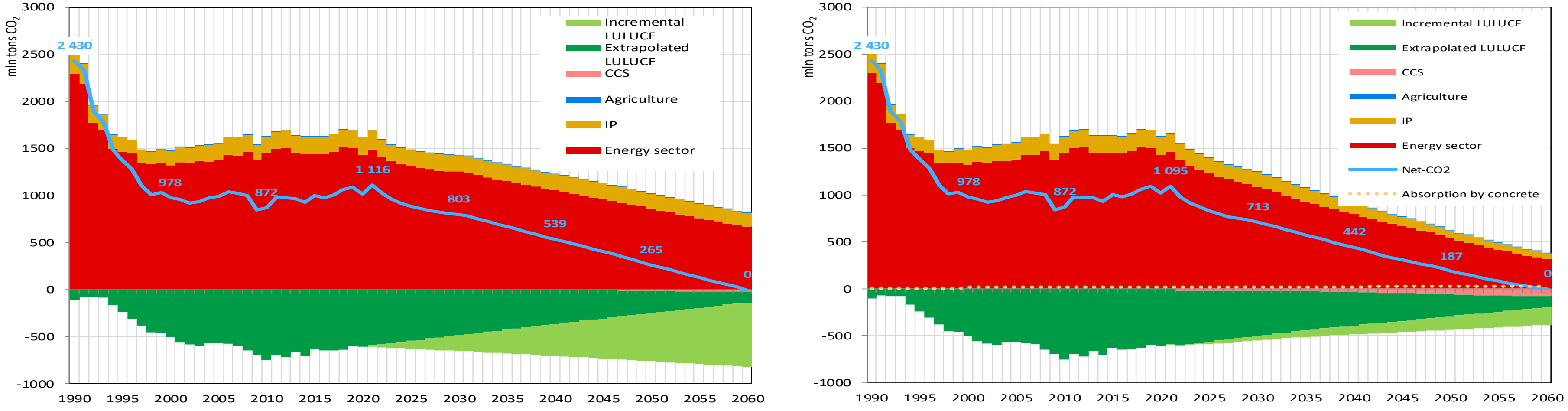
LTS needs more pillars to form a solid basis for the net zero carbon pledge.

- Even in 4S scenario, emissions reduction in all sectors (excl. LULUCF) amounts to 870 Mt CO_2 in 2021-2060. It is three times the reduction in non-LULUCF sectors specified in the LTS for 2050.
- In 4D and 4F scenarios, emissions reduction in all sectors (excl. LULUCF) is 1,250-1,300 Mt CO_2 in 2021-2060 (Figure 1.7).
- This overweighs what the LTS hopes to obtain as additional net sequestration in LULUCF.
- If only 2F (*Forest First*) is in the focus, and mitigation opportunities in other sectors are largely ignored, no compensation would be available, if the hopes for LULUCF sequestration are in vain.

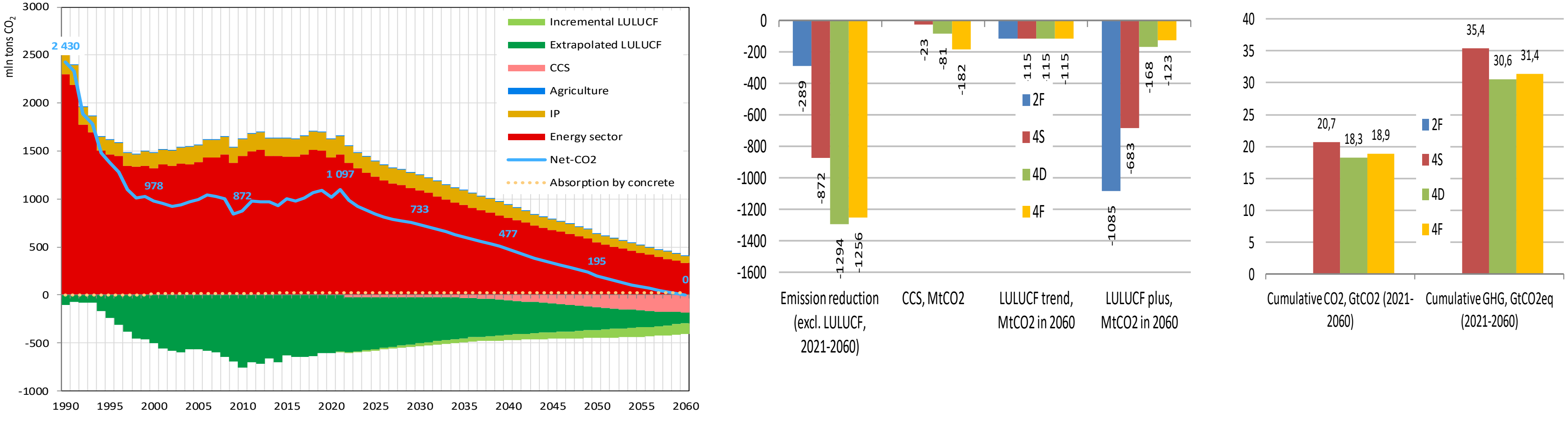
If in 2060 the carbon price doubles from 108 to 216 US/tCO_2$, carbon neutrality can be attained without any incremental LULUCF sink (Figure 1.8).

- The carbon price in 4D scenario is introduced in 2031 at 3 US/tCO_2$ and grows by 3 US/tCO_2$ annually to reach 108 US/tCO_2$ in 2060.
- Carbon price collections will reach 5.2 trillion rubles, or 1.3% of GDP.
- Energy affordability (the share of energy cost in GDP or personal incomes) will be staying close to, or below, the thresholds and ranges registered in 2000-2021.
- Driven by carbon prices, the uptake of low carbon processes in industry will smoothly increase the costs of basic materials to 50-60% with a subsequent reduction. In will not adversely affect the competitiveness in the markets with CBAM-like mechanisms, but will provide sufficient incentives and time for material efficiency improvements to offset the growing costs. As to the costs of the final products (for example, cars or houses), the rising costs of materials will only contribute 1 or 2%.

Figure 1.7 CO_2 emission structure by scenarios



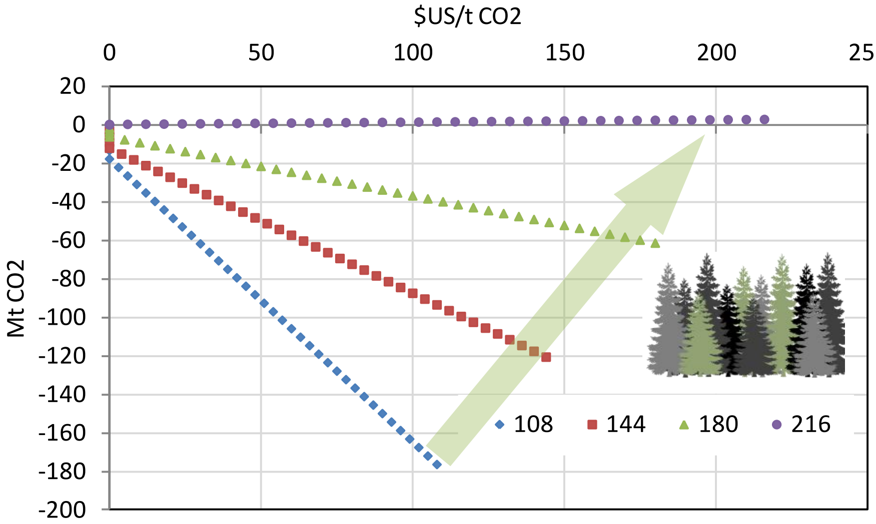
4S 4D



4F Sectors, CCS, and LULUCF cumulative 2021-2060

Source: CENEf-XXI.

Figure 1.8 Incremental LULUCF sink as a function of carbon price



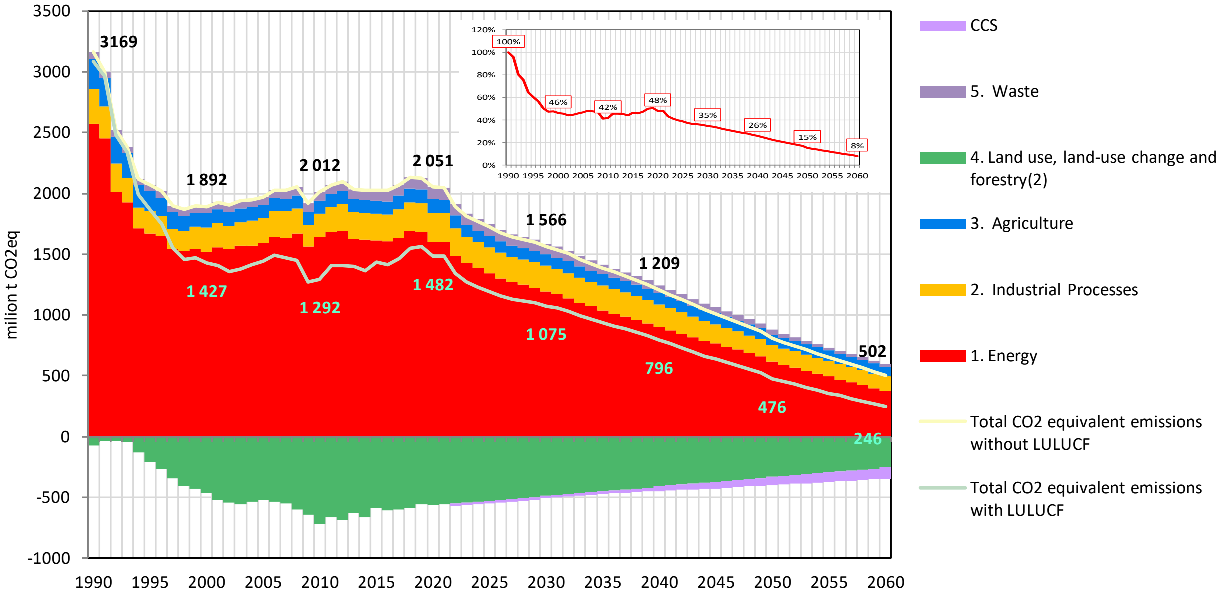
* The legend shows carbon prices in 2060.

Source: CENEf-XXI.

In all of the scenarios (4S, 4D, and 4F) Russia is ahead of the EU in cutting its CO2 and GHG emissions in 2030.

- Three sets of scenario storylines were developed to cover the abruptly widening uncertainty zone to draw the pathways which may get Russia to carbon neutrality in 2060.
- In all of the scenarios, in 2030 Russian CO_2 emissions will be 65% below the 1990 level, and GHG emissions will be 60% below the 1990 level.
- 4D and 4F scenarios are consistent with the global pathways to limit global warming by 1.5-2°C.
- In 2021-2060, cumulative net CO_2 emissions will be 21.7 $GtCO_2$, or:
- 4% of the current central estimate of the remaining carbon budget from 2020 onwards to limit the warming to 1.5°C with a 50% probability (500 Gt CO_2);
- 2% of estimated remaining 1,150 Gt CO_2 carbon budget with a 67% probability to limit the warming to 2°C.
- Cumulative reduction in Russia's GHG emission from the 1990 level will reach 140 GtCO2eq. in 2060. It is 2.4 times higher, than the global 2019 GHG emission.
- In none of the scenarios will Russia attain GHG neutrality in 2060, but it will come quite close with the remaining net GHG emission equal to 8% of the 1990 level (Figure 1.1).

Figure 1.9 GHG emission pathway in 4D scenario

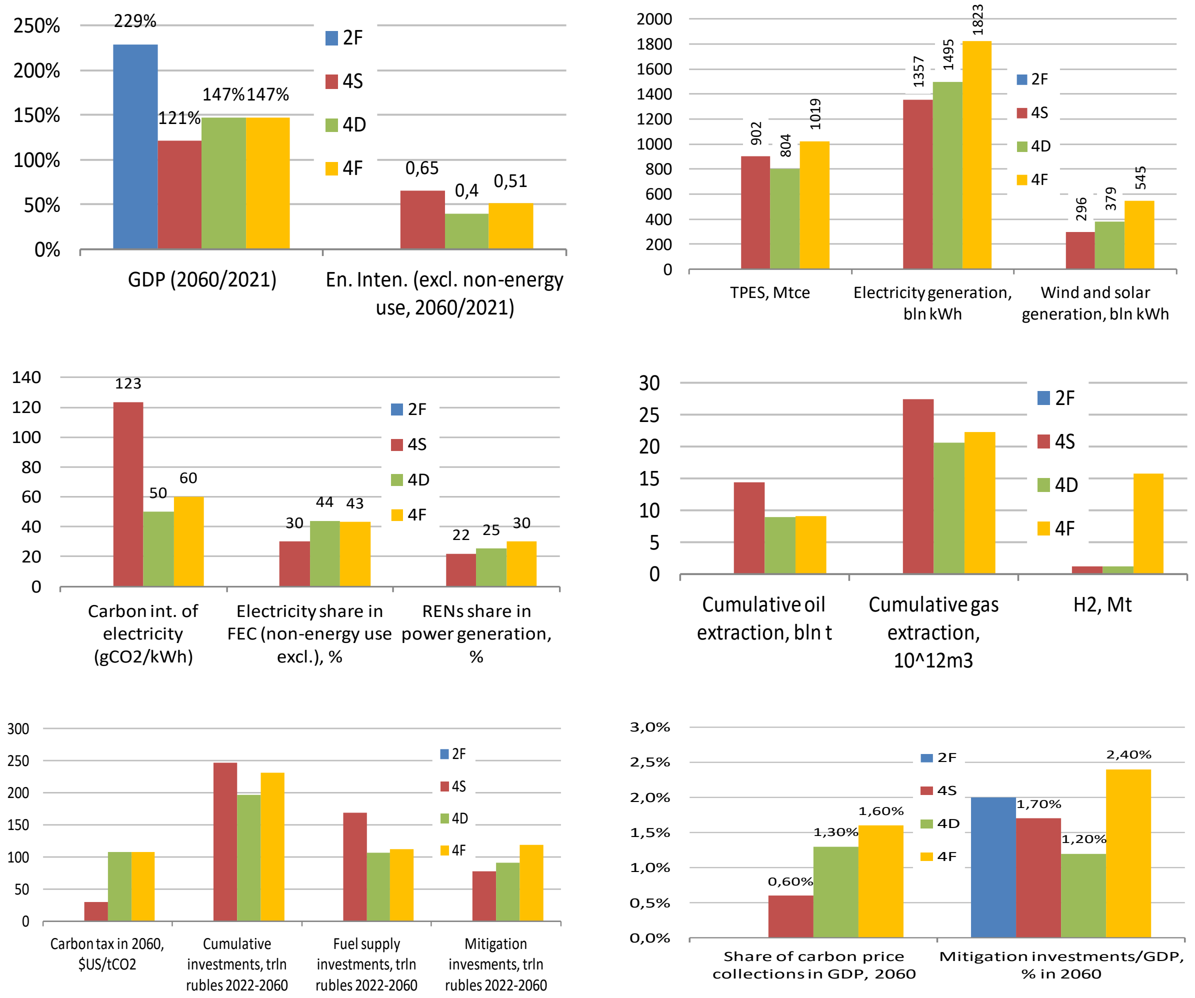


Source: CENEf-XXI

Limiting the global warming in 4F scenario requires a shift in energy investments away from fossil fuels towards low carbon technologies.

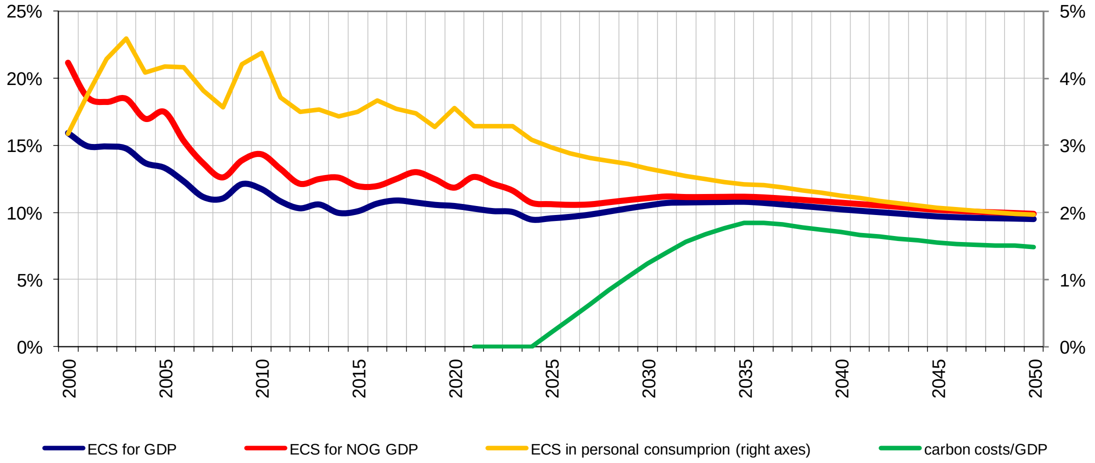
- Even in 4F scenario, there is no additional investment demand compared to the 2021 level.
- As investments in fuel supply are declining, growing investments in low carbon solutions with no additional investment demand is associated with 4D and 4F scenarios.
- The share of investments in low-carbon transformation may reach 3.2% of GDP in the 2040s and will then steadily decline to 2.4% or less in 2060.
- Energy affordability (the share of energy costs in incomes) will be staying close to, or below, the thresholds and ranges registered in 2000-2021, unless carbon price exceeds 100-150 \$US/tCO_2.

Figure 1.10 Energy transition effects and costs



Source: CENEf-XXI.

Figure 1.11 Energy costs shares (ECSs) in 4D scenario



Source: CENEf-XXI.

2 Projection tools

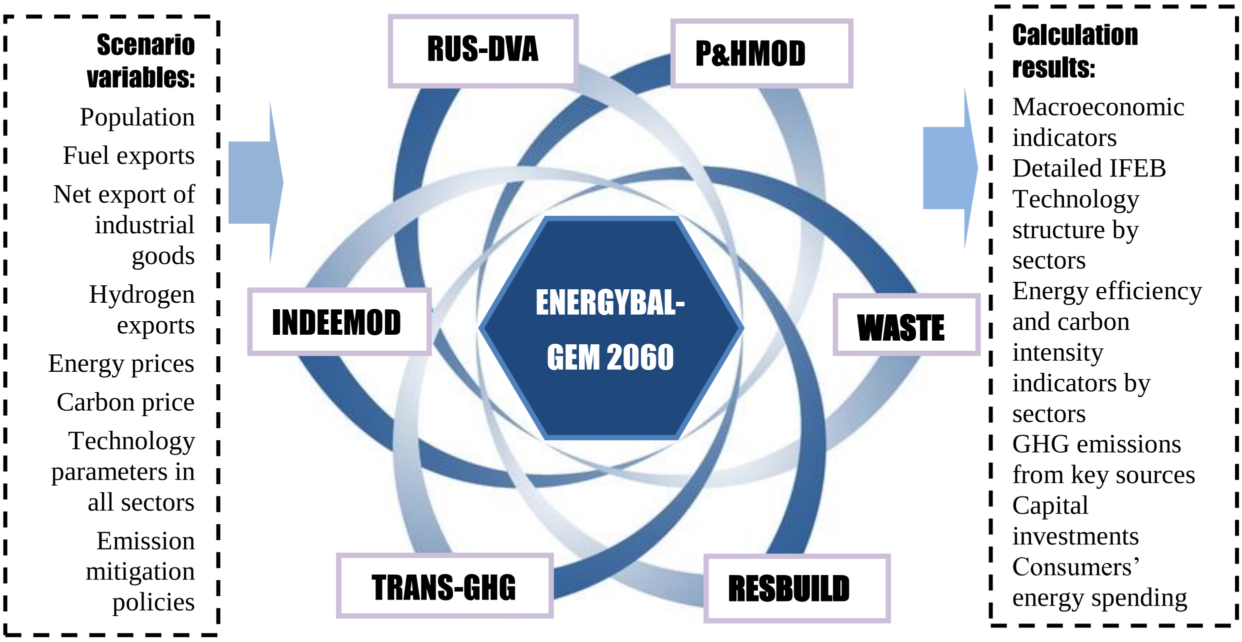
2.1 Set of computation models

Projections were developed using a set of interlinked models; their interplay is shown in Figure 2.1 and 2.2. The models are grouped around ENERGYBAL-GEM-2060, which is the core multisector model. Many of its parameters are identified using a ‘cloud’ of models developed by CENEf-XXI. The ‘cloud of models’ includes:

- macroeconomic model RUS-DVA;
- model for the power and heat sector P&HMOD;
- model for industry INDEE-MOD;
- model for transport TRANS-GHG;
- models for residential and public buildings RESBUILD and PUBBUILD. Some of the calculations for residential buildings were made using “EKR Assistant” model developed by CENEf-XXI for the Housing and Utility Reform Foundation;
- model for GHG emissions from the waste sector WASTE.

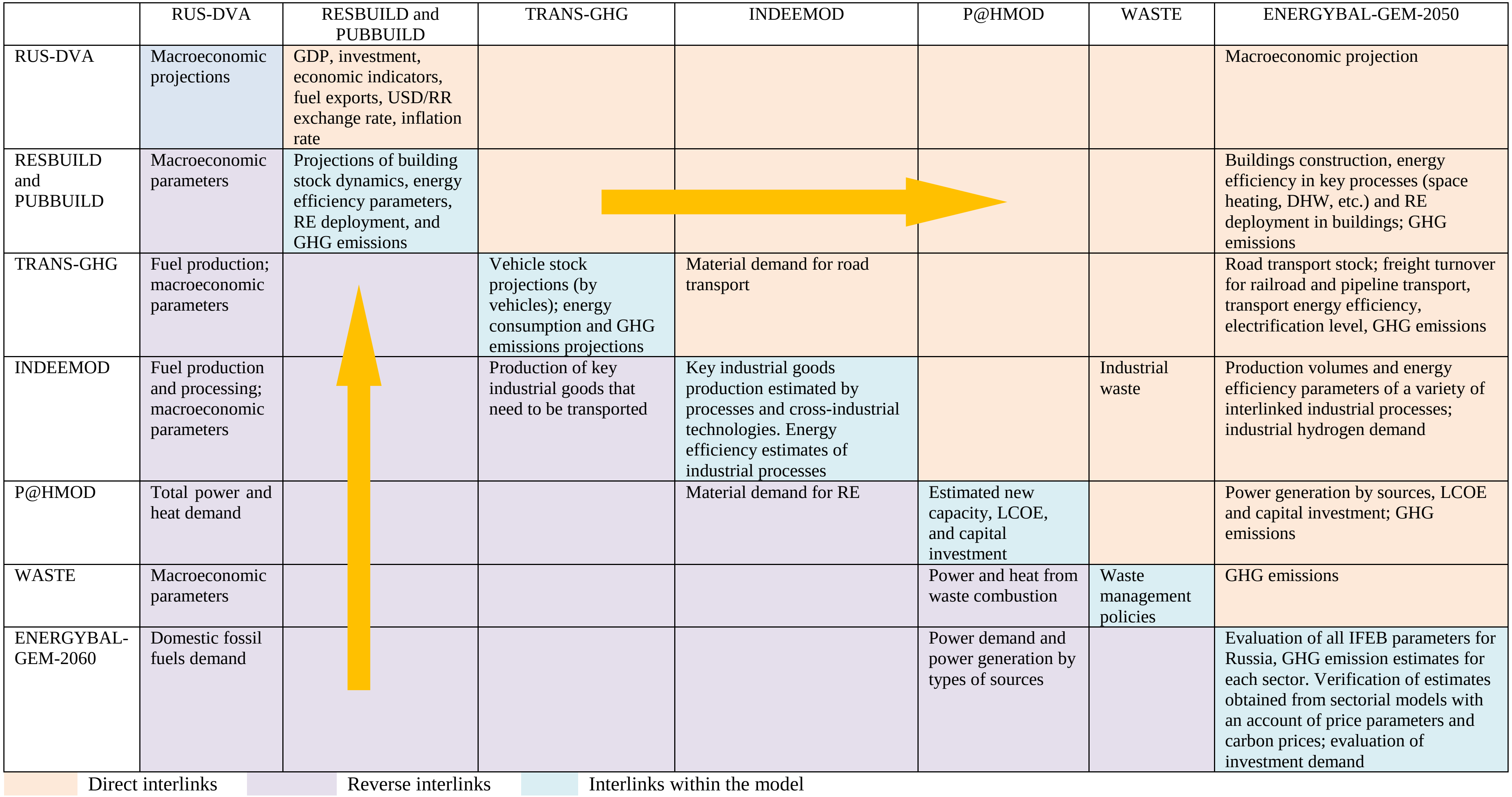
The results for all sectors are drawn up in ENERGYBAL-GEM-2060 model. It delivers GHG emission estimates for the energy sector (including fuel&energy, industry, transport and buildings), industrial processes, and agriculture. Emissions from the waste sector are estimated in the WASTE model. In the earlier versions, emissions from LULUCF were assessed using the ROBUL model; however, a strong debate was launched recently on how much this sector can additionally contribute towards the carbon neutrality target, and one vision is that the 2020 net sequestration level can be doubled. In the set of scenarios used in this paper total LULUCF emissions are estimated as the volume of carbon sequestration required to offset the CO2 emissions left in other sectors to attain the carbon neutrality goal by 2060.

Figure 2.1 The ‘cloud’ of models



Source: CENEf-XXI.

Figure 2.2 Direct and indirect interlinks in the ‘cloud’ of models



	RUS-DVA	RESBUILD and PUBBUILD	TRANS-GHG	INDEEMOD	P@HMOD	WASTE	ENERGYBAL-GEM-2050
RUS-DVA	Macroeconomic projections	GDP, investment, economic indicators, fuel exports, USD/RR exchange rate, inflation rate					Macroeconomic projection
RESBUILD and PUBBUILD	Macroeconomic parameters	Projections of building stock dynamics, energy efficiency parameters, RE deployment, and GHG emissions					Buildings construction, energy efficiency in key processes (space heating, DHW, etc.) and RE deployment in buildings; GHG emissions
TRANS-GHG	Fuel production; macroeconomic parameters		Vehicle stock projections (by vehicles); energy consumption and GHG emissions projections	Material demand for road transport			Road transport stock; freight turnover for railroad and pipeline transport, transport energy efficiency, electrification level, GHG emissions
INDEEMOD	Fuel production and processing; macroeconomic parameters		Production of key industrial goods that need to be transported	Key industrial goods production estimated by processes and cross-industrial technologies. Energy efficiency estimates of industrial processes		Industrial waste	Production volumes and energy efficiency parameters of a variety of interlinked industrial processes; industrial hydrogen demand
P@HMOD	Total power and heat demand			Material demand for RE	Estimated new capacity, LCOE, and capital investment		Power generation by sources, LCOE and capital investment; GHG emissions
WASTE	Macroeconomic parameters				Power and heat from waste combustion	Waste management policies	GHG emissions
ENERGYBAL-GEM-2060	Domestic fossil fuels demand				Power demand and power generation by types of sources		Evaluation of all IFEB parameters for Russia, GHG emission estimates for each sector. Verification of estimates obtained from sectorial models with an account of price parameters and carbon prices; evaluation of investment demand

🟧 Direct interlinks 🟪 Reverse interlinks 🟦 Interlinks within the model

Source: CENEf – XXI.

A detailed set of parameters for the power sector is modeled in P&HMOD; for industry – in INDEE-MOD; for all transport models – in TRANS-GHG; for buildings – in RESBUILD and PUBBUILD; and for waste – in WASTE. Generally, this set of models is very similar to the one used by IEA in its calculations for Russia, or to the approaches used in the POLES model for the EU.[3] For a number of sectors, CENEf uses simpler model versions, because more sophisticated approaches are not applicable for the data scarcity.

Model runs for each scenario start from the RUS-DVA and ENERGYBAL-GEM 2060 pair. Then each sectorial model is run coupled with ENERGYBAL-GEM 2060 clockwise in Figure 2.1 to finish by getting back to the RUS-DVA and ENERGYBAL-GEM 2060 pair. Several iterations are needed for each selected scenario.

2.2 Brief description of individual models

2.2.1 The core of the model system – ENERGYBAL-GEM 2060

ENERGYBAL-GEM-2060 is the core of the model system. This simulation model is based on the unified fuel and energy balance (IFEB) concept. ENERGYBAL-GEM-2060 is a dynamic accounting model combining economic and engineering data. It has an annual computation step and retrospectively covers 2000-2021, while the projection horizon is to 2060. It provides projections of single-product energy balances (split by supply, transformation, and final use) for coal, liquid fuels, natural gas, other solid fuels, electricity, heat, and hydrogen. The model forms detailed annual IFEBs for all energy carriers (coal, liquid fuel, natural gas, other solid fuels, nuclear power plants, hydro power plants, renewable energy sources, electricity, heat, and hydrogen) and for nine energy-use sectors (energy transformation, industry, construction, agriculture, transportation, communal services, commercial, residential and non-energy use. The activities in these sectors are split into 47 products, services and subsectors.

Energy demand in each sector is a function of the activity indicator and specific energy consumption (SECs). The latter is a function of technology improvements across the time period covered in sectoral models, HDD where applicable, capacity load (for industrial activities and pipeline transportation), and average energy prices. Therefore, no assumptions with regard to the autonomous technology progress are made in these functions. SECs progress is estimated in sectorial models and then verified for the evolution of energy prices. Energy prices include carbon price. So the model helps evaluate the effects of carbon pricing, as it reflects both the effects of consumer response to energy price change and the effects of interfuel competition. The latter are modeled based on:

$$d^*_{ijt} = d_{ij0} * \left\{ (y_t/y_0)^{aij} * \left[\left(\frac{p_{ijt}}{p_{it}}\right) / (p_{ij0}/p_{i0)} \right]^{bij} \right\} \tag{2.1}$$

$$d^{ij=} d^*_{ijt} / \sum_j d^t_{ij}$$

where:

d_{ijt} and d_{ij0} are shares of energy carrier *j* in sector *i* in years 0 and *t*;

y_0 and y_t are GDP per capita in years 0 and *t*;

p_{ijt} *and* p_{ij0} are real prices of energy carrier *j* in sector *i* in years 0 and *t*;

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[3] IEA. 2021. World Energy Model Documentation. October 2021. About the World Energy Model – World Energy Model – Analysis - IEA; Despres, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., *POLES-JRC model. documentation – 2018 update*, EUR 29454 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97300-0, doi:10.2760/814959, JRC113757.

a_{ij} is income elasticity in sector *i* for quality of energy carrier *j* (allowing to improve TFP and minimize negative environmental impacts);

b_{ij} is price elasticity in sector *i* for energy carrier *j*.

Annual IFEB matrix is used along with GHG emission factors to assess energy-related emissions (from fuels combustion, venting and flaring) in all activities for CO_2, CH_4 and N_2O. In addition, this model estimates GHG emissions and sinks (including CCUS) from industrial processes (in close interaction with INDEE-MOD) and from agriculture. The model has a block for integrating all GHG emissions from all sectors from more than 70 sources and sinks.

ENERGYBAL-GEM-2060 also estimates the emissions of pollutants, consumer energy costs, and capital investments.

Individual parameters of the ENERGYBAL-GEM-2050 model are determined using a cloud of simulation engineering (bottom-up) models for individual sectors (Figure 2.1 and 2.2). Those are models of a lower level of aggregation, which help present in detail (at the level of individual processes, products, subsectors) the decarbonization processes in these sectors and, based thereupon, determine the parameters of production volumes, SECs, CCS and hydrogen deployment, and GHG emissions to be transferred to the ENERGYBAL-GEM-2060. A set of sectorial models is used to assess the effectiveness of mitigation policies.

2.2.2 RUS-DVA-2060 macroeconomic model

Macroeconomic econometric dynamic model RUS-DVA-2060 is a two-sector (oil&gas and non-oil&gas sectors) simulation model for Russia's long-term economic development.[4] The oil&gas sector GDP (OG-GDP) component includes the value added in the extraction, processing, transportation, and sales of crude oil, petroleum products and natural gas.[5] The non-oil&gas GDP (NOG-GDP – other economy) includes one product. It is determined on the basis of the production function using accumulated non-oil&gas capital stock and labour factors. In 2021, Rosstat for the first time ever published data on the share of oil&gas GDP, which amounted to 21.1% of GDP in 2018, 19.1% in 2019, and scaled down to 15.3% in 2020.[6] Such GDP split and the use of non-oil&gas GDP as a key indicator for Russia's economic development was first recommended by Bashmakov fifteen years ago.[7] The RUS-DVA-2060 model parameters were calibrated to match the OG-GDP share as estimated by Rosstat for 2017-2020.

RUS-DVA-2060 model includes six blocks: GDP production; aggregate demand; investment in the oil&gas sector; balance of payments; consolidated budget; and prices. The econometric parameters of the equations were assessed based on the retrospective part of the model, which includes 1995 – 2021 data. The model time horizon is to 2060 with one year computation step.

Key model inputs include:

- external exogenous variables: labour force; global GDP growth rates; net exports of oil, gas, coal, and hydrogen; oil export price and domestic gas price; total factor productivity in the non-oil&gas sector;
- internal exogenous variables (estimated in other models): domestic oil and gas consumption, oil input to refineries.

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[4] Econometric macroeconomic model (as part of NEMS model set) is also used by the US DOE EIA. Macroeconomic Activity Module of the National Energy Modeling System: Model Documentation 2018 U.S. Energy Information Administration | NEMS Macroeconomic Activity Module Documentation Report. July 2018. Model Development - U.S. Energy Information Administration (EIA). It is much more sophisticated.

[5] Maksimov P. Methodology to identify the share of the oil&gas sector in the Russian GDP. Moscow, April 2021. Power Point Presentation (rosstat.gov.ru)- (In Russian).

[6] dolya_NGS_v_VVP_s2017.xlsx (live.com).

[7] Bashmakov I. Non-oil&gas GDP as an indicator of the evolution of Russia's economy. *Voprosy Ekonomiki [Issues of Economy]*. 2006;(5):78-86. https://doi.org/10.32609/0042-8736-2006-5-78-86.

Key model outputs include: GDP broken down by OG-GDP and NOG-GDP; final demand (gross fixed capital formation, private consumption, government consumption); consolidated budget revenues (oil&gas and others) and expenditures; balance of payments components (goods, services, investment and income transactions); inflation parameters (exchange rate, GDP deflator, consumer and investment price indexes). Cost outputs are provided both in current and in 2000 fixed prices.

RUS-DVA-2060 assumes an open domestic economy, in which energy exports and the balance of payments are important drivers of economic growth and provide direct contributions to GDP and to the evolution of the consolidated budget. Its dynamic structure (with time lag factors in many econometric functions) allows it to accommodate short-term shocks in the longer-term evolution of the economic system.

GDP production. The OG-GDP component is driven by external and domestic oil, petroleum products, and gas demand and by international and domestic fuel prices. OG-GDP production in current prices is assessed as the difference between gross output (domestic and international oil, petroleum products, and gas sales in physical units multiplied by corresponding domestic[8] or international[9] oil and gas price (including taxes and any other markups), and intermediate products in oil&gas-related economic activities. OG-GDP projection in constant prices for each year is a weighted function of oil&gas production and petroleum inputs to refineries. Projected non-oil&gas GDP evolution is estimated as a production function of working accumulated non-oil&gas capital stock, labour, and multifactor productivity. Hypotheses regarding petrocarbon exports build on the analyses of the latest literature on scenarios.

NOG-GDP evolution is driven by multifactor productivity, average annual number of employees and the working capital stock in this sector. Working capital is a function of the capacity utilization rate[10] and accumulated capital stock. The accumulated capital is driven by investment in the non-oil&gas sector and capital retirement. Capacity utilization rate depends on the investment evolution and sufficient supply of imported materials and parts expressed via the balance of current account to export revenues ratio.

One important parameter of the RUS-DVA-2060 model is the total factor productivity (TFP) for the non-oil&gas sector. Russia's KLEMS project[11] provides TFP for the whole economy and by subsectors. In recent publications,[12] TFP for expanded mining sector (EMS, which includes mining, processing and refining, transportation and trade of fuels and minerals) was also provided. EMS is responsible for 22.5% of GDP. However, in the KLEMS data set, this

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[8] Reported by Rosstat.

[9] Reported by the RF Central Bank.

[10] A simple indicator for capacity utilization in the non-oil&gas sector was developed, which is quite in line (accounting for activities coverage – in Russia, capacity load factor is higher in fuel production) with the results of the specific method for presenting the capacity utilization index aggregated for the whole economy as described in Marshova T.N. Government Stimulation of Technological Modernization of Production Capacity of the Russian Economy. Gosudarstvenoye Upravleniye [Public Administration. Electronic Bulletin] Issue 55. April 2016. Its evolution is also in line with the capacity utilization factor assessed via monthly market surveys of industrial managers from 1993 onwards. Tsukhlo S.V. Russian industry in 2021-2022. "Rapid recovery" after the 2020 viral crisis. Science-based workshop on energy and environmental economics at the Moscow School of Economics, 10.02.2022.

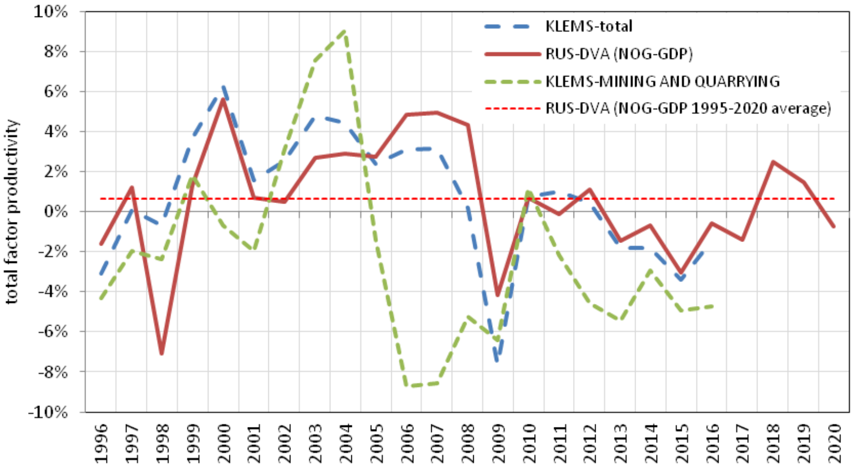
[11] Russia KLEMS. National Research University Higher School of Economics. December 2019. https://www.hse.ru/russiaklems/dataklems/; Voskoboynikov I.B. Recovery experiences of the Russian economy. Implications to the Indian Economy. State Bank Institute of Leadership, Kolkata, 18 September. 2020. 34 p. https://www.hse.ru/mirror/pubs/share/403285320.pdf.; Voskoboynikov I. Accounting for growth in the USSR and Russia, 1950–2012. J Econ Surv. 2021;35:870–894. DOI: 10.1111/joes.12426.

[12] Voskoboynikov I.B. Recovery experiences of the Russian economy. Implications to the Indian Economy. State Bank Institute of Leadership, Kolkata, 18 September. 2020. 34 p. https://www.hse.ru/mirror/pubs/share/403285320.pdf. Voskoboynikov I.B., Baranov E.F., Bobyleva K.V., Kapeliushnikov R.I., Piontkovski D.I., Roskin A.A., Tolokonnikov A.E. Recovery experiences of the Russian economy: The patterns of the post-shock growth after 1998 and 2008 and future prospects. Voprosy Ekonomiki [Issues of Economy]. 2021;(4):5-31. (In Russian) https://doi.org/10.32609/0042-8736-2021-4-5-31.

aggregate is not presented, so the mining and quarrying sector was shown in Figure 1.1 as a proxy to illustrate the contribution from TFP to the OG-GDP evolution. Calibrated TFP parameter for NOG-GDP in RUS-DVA-2060 perfectly fits the quite sophisticated assessments of TFP for the whole GDP and its oil&gas part provided by the Russian KLEMS project.

The average TFP for the NOG sector for 1995-2020 was assessed by CENEf-XXI at 0.7%, and for the whole GDP it was assessed by KLEMS project also at 0.7%. For 2010-2020, it was -0.2% for NOG-GDP and, according to KLEMS, -1.6% in 2007-2016 for the whole economy. Therefore, the economic growth after 2007 was extensive, especially in the OG sector (or EMS – in KLEMS aggregation). Analysis based on Russia's KLEMS shows, that in the fuel and energy sector capital intensity was growing noticeably faster, than in the other sectors: it doubled over the post-2006 decade, pulling up capital intensity of the entire economy. With the 21-22% accumulation rate, this slowed down GDP growth. Multifactor productivity in the fuel and energy sector decreased markedly after 2005-2007,[13] leading first to a halt, and then to a decline, in the economy-wide growth in multifactorial productivity. Therefore, with a persisting reliance on the fuel and energy sector it was impossible to accelerate GDP growth in the recent decade. One additional evidence of the low TFP impact on the economic growth is the result obtained from decade-long market surveys of industrial managers who keep ranking lack of labour high in the list of growth barriers against the background of low-ranking labour productivity.[14]

Figure 2.3 Evolution of TFP for non-oil&gas sector and for the whole economy



Sources: for Russia – CENEf-XXI for NOG-GDP and Russia KLEMS. National Research University Higher School of Economics. December 2019. https://www.hse.ru/russiaklems/dataklems/

Aggregate demand. All fixed capital investments break down into oil&gas and non-oil&gas sectors. Non-oil&gas investments are set as part of the non-oil&gas GDP. Personal consumption is a function of its one year lagged value and NOG-GDP. Government consumption is a function of its one year lagged value and consolidated budget expenditures. Consumption of non-commercial organizations is a function of its one year lagged value and NOG-GDP. Econometric equations parameters are updated regularly to better reflect recent trends. Total consumption is the sum of private, government, and non-commercial consumption. Savings are equal to GDP minus total consumption, and savings surplus equals the gap between savings and investments.

Investments in the oil&gas sector include investments in production, processing and refineries, transportation infrastructure and oil&gas trade facilities. Investments in production are driven by

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[13] In the mining and quarrying sector, TFP in 1995-2016 was 37% down, and in the coke and refinery sector 69% down. EMS contributed 76% to the TFP decline in 2011-2016.

[14] Tsukhlo S.V. Russian industry in 2021-2022. "Rapid recovery" after the 2020 viral crisis. Science-based workshop on energy and environmental economics at the Moscow School of Economics, 10.02.2022.

oil&gas production evolution accounting for the investment demand for the compensation of the scaling down production, as existing oil and gas fields are depleted.

Balance of payments block includes exports and imports of goods, net exports of services along with net earnings on cross-border investments, and net transfer payments. Exports of goods include oil, petroleum products, pipeline gas and NLG, hydrogen, and other goods. Fuel exports are assessed as exported volumes multiplied by export prices. Gas export prices are determined by oil export prices. Non-oil&gas exports are a function of NOG GDP in constant prices verified to increase the export share of NOG GDP and global GDP growth. Imports of goods are modeled as a function of aggregated demand and exchange rate. Net exports of services are a function of private consumption in constant prices (travel services) and net exports of goods (transport services). Net earnings on cross-border investments are a function of investment growth, and net transfer payments are a function of GDP.

In the **consolidated budget** block, budget revenues obtained for the whole budget system are a function of OG GDP and NOG GDP. They break down into oil&gas revenues (function OG GDP) and other forms of non-oil&gas revenues. Consolidated budget expenditures are a function of one year lagged value and revenues. The possible options are: to ensure zero budget deficit by keeping the expenditures equal to the revenues or to ensure fixed growth of real expenditures in constant prices.

The **Prices** block calculates ruble to dollar exchange rate as a function of ratio of consumer price indexes in Russia and US and the evolution of the import to export ratio of goods. GDP, OG GDP and NOG GDP deflators are ratios of their current and constant price values. Index of investment prices is a function of investment load of the economy, which for oil exporting countries is set as total investment (demand) divided by NOG GDP (investment realization capacity).[15] Consumer price index growth is set equal to NOG GDP deflator growth.

2.2.3 Power and heat model P&H MOD

The P&HMOD model for electric and thermal power engineering is a simulation model with a 1-year step. By concept it is close to the ones used by the IEA, EU and DOE,[16] but for the scarcity of data it is relatively simple. In the latest modification the time horizon was extended to 2060. The goal is to assess the development parameters in power and heat generation.

The model evaluates phasing out and new additions of capacity by technology (heat, nuclear, hydro, and renewables), the dynamics of LCOE and capital investment. The retrospective part of the model includes the 2000 – 2020 data and is the basis for some functions specification. The latest version of the model highlights coal and natural gas generation with CCS.

Power and heat demand are estimated in the ENERGYBAL-GEM-2060 model and are inputs to the P&HMOD model. Then, iteratively, using ENERGYBAL-GEM-2060 and P&HMOD models, generation is split by power sources. The model estimates LCOE and capital costs for separate generation technologies. The investments are inputs to ENERGYBAL-GEM-2060 model. Fuel prices and carbon tax rates are imported from ENERGYBAL-GEM-2060 model.

Power generation sources are split into: nuclear; hydro; pump storage; geothermal; gas; gas with CCS; coal; coal with CCS; wind and solar. Capacity developments for the 2030-2035 timeframe are based on the General Development Plan for the electricity sector. Up to 2035, the scale of RE investments corresponds to the already approved programme to support renewables via auctions for capacity supply contracts. Capacity evolution beyond 2035 is modeled based on the peak

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[15] Bashmakov I.A. Specificities of extended reproduction in oil extracting countries // Mirovaya ekonomika i mezhdunarodnye otnosheniya [Global economy and international relations]. 1983. No. 4. – Pp. 100-112.

[16] IEA. 2021. World Energy Model Documentation. October 2021; Despres, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., *POLES-JRC model documentation – 2018 update*, EUR 29454 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97300-0, doi:10.2760/814959, JRC113757; EIA DOE. 2020. The Electricity Market Module of the National Energy Modeling System: Model Documentation 2020. July 2020.

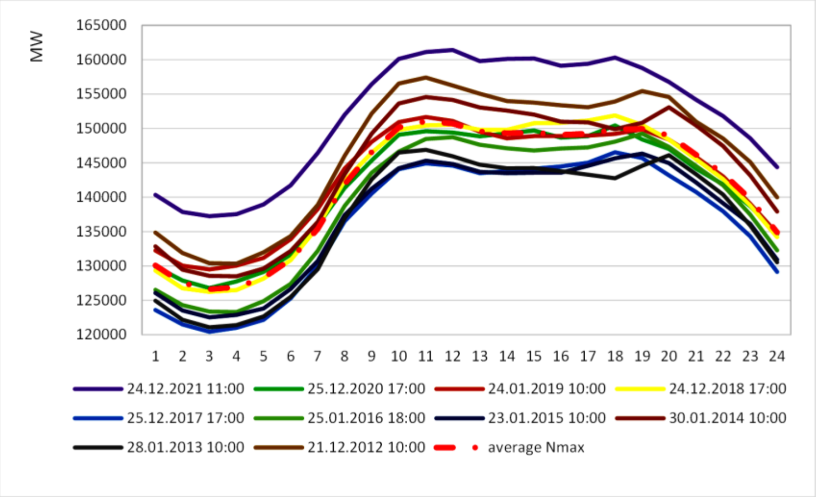
load dynamics accounting for required capacity reserve (security-of-supply margin); rate of phasing-out exiting thermal capacities, and distribution of new capacity additions by generation sources.

Basic winter and summer maximum peak loads are borrowed from the data reported by the System Operator of the Unified Power System.[17] Competition for shares in new capacity additions is modeled based on the levelized cost of electricity (LCOE) for each generation type. Subsidies for RE generation help promote their faster penetration.

Retrospective load factors for different types of generation for 2018-2020 are estimated based on Rosstat's statistical data. Prospective load factors for nuclear were taken from the General Development Plan for the electricity sector, and for wind and solar plants are assumed to become by 2050 equal to the present values for the US as estimated by LNBL (Lawrence Berkeley National Laboratory[18,19]). Retrospective generation efficiency parameters for gas and coal plants are taken from Rosstat's statistical data and assumed to reach the BATs levels.

Winter and summer maximum peak loads. Key input parameters for the assessment of winter and summer maximum peak loads include total electricity generation as taken from ENERGYBAL-GEM-2060 and outdoor air temperatures during winter and summer maximum peak loads as provided by the System Operator of the Unified Energy System. Regression parameters were estimated based on the 2012-2021 data (Figure 2.4). The average shape for the winter maximum load curve was constructed. Based on the 2021 load duration curve provided by the System Operator (Figure 2.5), annual electric load duration curves evolution was developed.

Figure 2.4 Winter peak load profiles for 2012-2021



Source: CENEf-XXI based on data from System operator of the Unified Power System.

Distribution of capacity additions by generation types. Key input parameter to calculate the generation capacity mix by technology are perspective values of levelized cost of electricity (LCOEs. For each technology, LCOE is calculated as follows (2.2):

$$LCOE = \frac{CRF*I+OM+FC*\frac{E}{\eta}}{E} \tag{2.2}$$

where:

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[17] https://www.so-ups.ru.

[18] Land-Based Wind Market Report. 2021 Edition. Ryan Wiser, Mark Bolinger, Ben Hoen, Dev Millstein, Joe Rand, Galen Barbose, Naïm Darghouth, Will Gorman, Seongeun Jeong, Andrew Mills, Ben Paulos. Lawrence Berkeley National Laboratory.

[19] Utility-Scale Solar Data Update: 2020 Edition. Mark Bolinger, Joachim Seel1, Dana Robson, Cody Warner. Lawrence Berkeley National Laboratory.

CRF is capital recovery factor;

I is investment costs, including construction costs at *i* interest rate;

OM is incremental operating and maintenance costs estimated by adding fixed operation and maintenance (*FOM*) to variable operation and maintenance (*VOM*);

E is electricity generation estimated by multiplying installed capacity by capacity load factor;

FC is fuel unit costs;

η is electricity generation efficiency.

Based on LCOE for each generation technology capacity additions are split using a logit function:

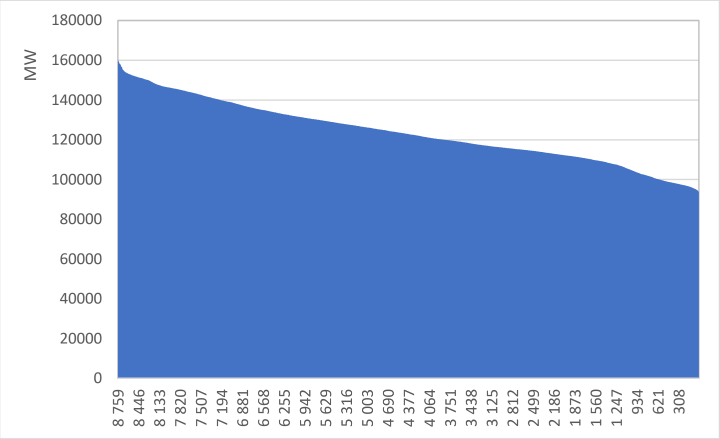
$$Shcap_i = a_i * LCOE_i^{-2} / (\sum a_i * LCOE_i^{-2}) \qquad (2.3)$$

where:

a_j is weight for a powerplant type;

$LCOE_i$ is levelized cost of electricity generation by technology i.

Figure 2.5 Electric load duration curve in 2021



Source: CENEf-XXI based on data provided by the System operator of the Unified Power System.

Before 2035, key parameters for new power capacity additions, modernization and phasing out were set equal to those specified in the General Development Plan for the electricity sector, data for RE projects selected at auctions for capacity supply contracts conducted by the System Operator of Unified Power System, and data for other RE projects selected for a variety of programmes and plans. Beyond 2035, prospective capacity additions were calculated based on projected maximum loads with an account of phased out capacity and capacity reserve requirements.

Prospective average load factors for power generation by technology were determined based on the winter and summer maximum peak loads. They were then used to model power generation by source. The RE contribution to peak loads was assessed based on the capacity credit factor (CC):[20]

$$CC = REN_{peak} / REN_{insllaed} \qquad (2.3)$$

where:

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[20] The capacity credit of variable renewables reflects the proportion of their installed capacity that can reliably be expected to be generating at the time of high demand in each segment. IEA. 2021. World Energy Model Documentation. October 2021; Investigating the Influence of Storage on Renewable Energy Capacity Credit. Pei Yong, Student Member, IEEE, Liang Cheng, Huan Zhu, Lei Tang, Ning Zhang, Senior Member, IEEE, and Chongqing Kang, Fellow, IEEE.

REN_{peak} is contribution of installed weather-dependent *RE* capacity to the peak load;

$REN_{insllaed}$ is installed capacity.

Proxies for CC were assessed based on the data for Germany provided by Fraunhofer Institute for Solar Energy Systems[21] (ISE). To improve CC, energy accumulation systems and storage demand are projected. Relationships between CC and storage capacity were assessed based on the data from a specific study[22] for both wind and solar power. Storage capacity demand is evaluated based on CC for winter and summer peak loads. CAPEXs for storage systems were borrowed from LNBL.[23]

Capital investment for all generation types is estimated based on capacity additions and CAPEXs. CAPEXs for wind and solar capacities were taken from Mercantile System Manager – wholesale electricity market – based on the lists of investment projects selected to launch RE generation capacity construction in 2021[24] (to be accomplished before 2028). CEPEXs for nuclear, hydro, and thermal capacity additions were borrowed from the System Operator of Unified Power System in 2021[25] (to be accomplished before 2035). CAPEXs for the construction of different types of generation beyond national programmes in place (2030-2035) are evolving over time based on the learning rates, driven by increasing construction additions by technologies.

2.2.4 Industrial model INDEE-MOD

INDEE-MOD is a simulation engineering (bottom-up) model for industry. Such models are also called dynamic accounting models and combine economic and engineering data.[26] INDEE-MOD has a 1-year step. The retrospective part of the model covers 2000-2021. In 2022, the projection time horizon was extended from 2050 to 2060. For energy and carbon intensive products (27 products considered) it combines process-flow (for industries) and energy end-use model (for separate products) approaches. INDEE-MOD describes in detail the effects of technology mix evolution in the iron and steel, chemical, cement, pulp and paper, aluminum industries, oil refining, coal, oil and gas production, as well as modernization in 5 cross-industry processes (electric motors, industrial lighting, steam, oxygen, and compressed air supply).

First, for each industry, the demand for key basic materials (rolled steel, cement, etc.) is assessed, and then, via upstream process supply chains, the demand for processes and energy inputs is estimated. This helps to factor in the richness and granularity of industrial low carbon technology options. Taking iron and steel for example, a change in domestic and international demand for rolled steel determines the need for crude steel production. Then, based on the process routes mix, capacity additions for incremental production are split (for steel: BF-BOF, DRI-gas-EAF, DRI-gas-EAF CCS, DRI-hydrogen-EAF, Scrap-EAF). This split is based on the production costs competition. Modeled capacity retirement, modernization and additions determine the evolution of the overarching technology mix across time. For each route, at every element of upstream supply chain, the model is used to estimate demand for energy and feedstock, such as pig iron, DRI, coke, hydrogen, sinter and agglomerate, iron ore and scrap, electricity, natural gas, etc. For each product, production capacity balance is modeled based on

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[21] https://energy-charts.info/charts/power/chart.htm?l=en&c=DE&stacking=stacked_absolute_area&year=2020&legendItems=10111111111111100&week=30&source=all&download-format=text%2Fcsv

[22] Investigating the Influence of Storage on Renewable Energy Capacity Credit Pei Yong, Student Member, IEEE, Liang Cheng, Huan Zhu, Lei Tang, Ning Zhang, Senior Member, IEEE, and Chongqing Kang, Fellow, IEEE.

[23] Cost Projections for Utility-Scale Battery Storage: 2021 Update. Wesley Cole, A. Will Frazier, and Chad Augustine. National Renewable Energy Laboratory.

[24] Mercantile system manager – wholesale electricity market.

[25] System Operator of the Unified Power System (competitive selection of capacity).

[26] EIA. 2020. Model Documentation Report: Industrial Demand Module of the National Energy Modeling System. December 2020. US DOE.

assumptions for phase out and modernization rates, with the balance to be met via new capacity. The process is set so as to keep capacity utilization rates below 100%.

For some basic materials (iron and steel, cement) the effects of accumulated material stock are assessed (Figure 2.6) to provide inputs to material demand functions and resource base for secondary materials supply. This allows it to address the issues of stock saturation and growing circularity via a larger supply of secondary materials beyond the stock elements' service life. The effects of material efficiency improvements are also factored in. Basic materials demand accounts for the developments in other sectors, such as accelerated renewables deployment leads to an increase in metals demand, while a reduction in the cars fleet brings it down.

Industry is disaggregated into 7 manufacturing and mining sectors: iron and steel; aluminium; cement; pulp and paper; chemicals; oil refining; oil, gas, and coal production; and cross-industrial processes. In each sector, technologies to produce upstream feedstock and energy are assessed. Technology parameters are set based on statistical data,[27] data from benchmarking systems, and data for new industrial technologies described in the literature.[28]

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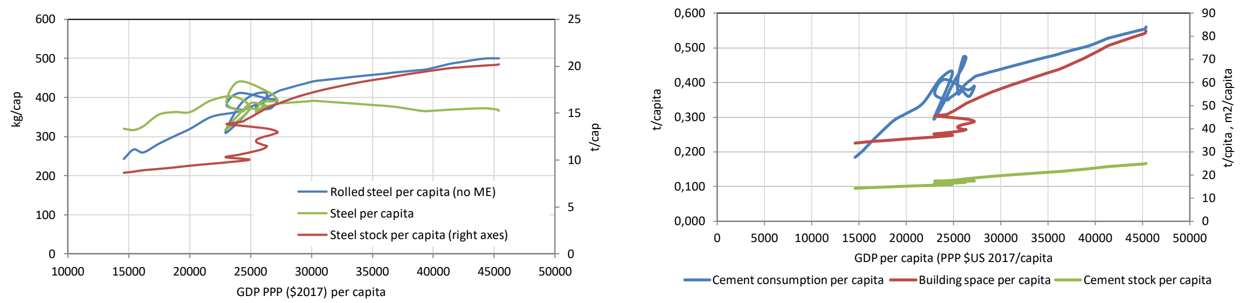
[27] EMISS – Rosstat database; Katunin V.V., Zinov'eva N.G., Ivanova I.M., Petrakova T.M. Basic indicators of steel industry of Russia operation in 2020. Ferrous Metallurgy. Bulletin of Scientific, Technical and Economic Information. 2021;77(4):367-392. (In Russ.) https://doi.org/10.32339/0135-5910-2021-4-367-392; Bashmakov I.A, D.O. Skobelev, K.B. Borisov, T.V. Guseva. 2021. GHG benchmarking system in the iron and steel industry // Chernaya Metallurgia. 2021. Vol.77, No. 9. (In Russian).

[28] For ferrous metallurgy based on: Bataille, C. et al., 2018a: A review of technology and policy deep decarbonization pathway options for making energy intensive industry production consistent with the Paris Agreement. *J. Clean. Prod.*, **187**, 960–973, doi:10.1016/j.jclepro.2018.03.107; Cao, Z., G. Liu, S. Zhong, H. Dai, and S. Pauliuk, 2019: Integrating Dynamic Material Flow Analysis and Computable General Equilibrium Models for Both Mass and Monetary Balances in Prospective Modeling: A Case for the Chinese Building Sector. *Environ. Sci. Technol.*, **53**(1), 224–233, doi:10.1021/acs.est.8b03633; CAT, 2020: *Paris Agreement Compatible Sectoral Benchmark*. 67 pp. https://climateactiontracker.org/documents/753/CAT_2020-07-10_ParisAgreementBenchmarks_FullReport.pdf; Energy Transitions Commission, 2018: *Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century*. 171 pp. http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf; EUROFER, 2019: *Low Carbon Roadmap. Pathways to a CO2-neutral European Steel Industry*, Brussels, Belgium, 18 pp. https://www.eurofer.eu/assets/Uploads/EUROFER-Low-Carbon-Roadmap-Pathways-to-a-CO2-neutral-European-Steel-Industry.pdf; GCCA, 2021a: *The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete*, London, UK, 46 pp. https://gccassociation.org/concretefuture/wp-content/uploads/2021/10/GCCA-Concrete-Future-Roadmap-Document-AW.pdf; Gielen, D., D. Saygin, E. Taibi, and J. Birat, 2020: Renewables-based decarbonization and relocation of iron and steel making: A case study. *J. Ind. Ecol.*, **24**(5), 1113–1125, doi:10.1111/jiec.12997; Gonzalez Hernandez, A., L. Paoli, and J. M. Cullen, 2018b: How resource-efficient is the global steel industry? *Resour. Conserv. Recycl.*, **133**, 132–145, doi:10.1016/j.resconrec.2018.02.008; GreenSteel for Europe Consortium, 2021. GreenSteel for Europe. Investment needs. March 2021; Hertwich, E., R. Lifset, S. Pauliuk, and N. Heeren, 2020: *Resource Efficiency and Climate Change: Material Efficiency Strategies for a low-carbon Future*. Paris, France, 155 pp.; IEA, 2019f: *The Future of Hydrogen*. Paris, France, 199 pp.; IEA, 2019g: *Transforming industry through CCUS*. Paris, France, https://www.iea.org/publications/reports/TransformingIndustrythroughCCUS/; IEA, 2019h: *Putting CO2 to use*. Paris, France, 83 pp.; IEA, 2020a: *Energy Technology Perspective 2020*. Paris, 397 pp.; IEA, 2020b: Tracking industry 2020. https://www.iea.org/reports/tracking-industry-2020 (Accessed December 20, 2020); IEA, 2020c: *Iron and Steel Technology Roadmap Towards More Sustainable Steelmaking, Part of the Energy Technology Perspectives series*. Paris, France, 187 pp. https://www.iea.org/reports/iron-and-steel-technology-roadmap; IEA, 2020: *Energy Efficiency 2020*. Paris, France, 102 pp.; IEA, 2020: *Energy technology perspective special report – clean energy innovation*, Paris, France, 182 pp.; ttps://webstore.iea.org/download/direct/4022?fileName=Energy_Technology_Perspectives_2020_-_Special_Report_on_Clean_Energy_Innovation. pdf; IEA, 2020: *World energy outlook 2020*. 461 pp. https://www.iea.org/events/world-energy-outlook-2020; IEA, 2021: *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Paris, 222 pp.; IEA, 2021: CO2 Emissions from Fuel Combustion online data service. data.iea.org/payment/products/115-co2-emissions-from-fuel-combustion-2021-edition.aspx. (Accessed August 27, 2020); IEA, 2021: *World energy outlook 2021*. Paris, France, 383 pp.; IEA, 2021: IEA, and WBCSD, 2018: *Technology roadmap – low-carbon transition in the cement industry*, Paris, France, 61 pp. https://webstore.iea.org/download/direct/1008?fileName=TechnologyRoadmapLowCarbonTransitionintheCementIndustry.pdf; International Aluminium Institute, 2021: *Aluminium Sector Greenhouse Gas Pathways to 2050*. London, UK, 20 pp.; Kirschen, M.; Hay, T.; Echterhof, T. Process Improvements for Direct Reduced Iron Melting in the

Figure 2.6 Steel and cement annual demand and stock per capita



Sources: CENEf-XXI.

Projected domestic consumption of basic materials (rolled steel, cement, chemicals, aluminium, paper, etc.) is a function of macroeconomic variables (such as GDP, indexes of industrial production and construction), assumptions on future products export potential, and modeled technology structure evolution. For example, domestic demand for rolled steel (RSD^t) is estimated via the following function:

$$RSD^t = RSD^{t-1} * \min(1 + kel_{rsd} * T^t_{gdp} \;\; ; \frac{RSD}{POP}^{sat} * POP^t) \qquad (2.4)$$

Rolled steel demand to GDP elasticity coefficient (kel_{rsd}) is set at 0.65, and per capita rolled steel saturation level was established at 0.5 t/cap.[29] The per capita consumption results were checked for consistency with the logic of material flow analysis, and steel stock embodied in accumulated physical capital per capita was traced. With no material efficiency (ME), both per capita consumption and stock will reach saturation levels closer to 2060. If ME options are exploited, per capita steel demand will not exceed 0.4 t/cap, which is slightly below the 2005-2021 average. Since the Russian economy is about twice less resource efficient, than advanced economies, per capita stock saturates at a quite high level (which is twice the UK level).[30] After February 24th, all macroeconomic assumptions, including for basic materials exports, factor in the effects of the sanctions as described in Chapter 3.

Steel, pig iron and DRI production are modeled to reflect six major process routs: BF-OH (totally phased out in 2027), BF-BOF, Scrap-EAF, DRI-gas-EAF, DRI-gas-EAF with CCS, and DRI-hydrogen-EAF. The BF-BOF-CCS route is also tested for sensitivity. There are more potential routes and emerging breakthrough technologies in steel making, many of which are still

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Electric Arc Furnace with Emphasis on Slag Operation. Processes 2021, 9, 402; Lovins, A. B., 2018: How big is the energy efficiency resource? *Environ. Res. Lett.*, **13**(9), 090401, doi:10.1088/1748-9326/aad965; Material Economics, 2019: *Industrial Transformation 2050: Pathways to net-zero emissions from EU Heavy Industry*. 207 pp. https://materialeconomics.com/publications/industrial-transformation-2050; Saygin, D., and D. Gielen, 2021: Zero-emission pathway for the global chemical and petrochemical sector. *Energies*, 14(13), 3772, doi:10.3390/en14133772; Saygin, D., E. Worrell, M. K. Patel, and D. J. Gielen, 2011: Benchmarking the energy use of energy-intensive industries in industrialized and in developing countries. *Energy*, 36(11), 6661–6673, doi:10.1016/j.energy.2011.08.025; UKCCC, 2019b: *Net Zero Technical Report*. London, UK, 302 pp. https://www.theccc.org.uk/publication/net-zero-technical-report/; Vogl, V., M. Åhman, and L. J. Nilsson, 2018: Assessment of hydrogen direct reduction for fossil-free steelmaking. *J. Clean. Prod.*, 203, 736–745, doi:10.1016/j.jclepro.2018.08.279; World Steel Association, 2020: *Steel's contribution to a low carbon future and climate resilient societies*. 6 pp. https://www.worldsteel.org/en/dam/jcr:7ec64bc1-c51c-439b-84b8-94496686b8c6/Position_paper_climate_2020_vfinal.pdf; Worrell, E., J. Allwood, and T. Gutowski, 2016: The Role of Material Efficiency in Environmental Stewardship. *Annu. Rev. Environ. Resour.*, 41(1), 575–598, doi:10.1146/annurev-environ-110615-085737; and many others.

[29] Bleischwitz, R., V. Nechifor, M. Winning, B. Huang, and Y. Geng, 2018: Extrapolation or saturation – Revisiting growth patterns, development stages and decoupling. *Glob. Environ. Chang.*, 48, 86–96, doi:10.1016/j.gloenvcha.2017.11.008; IEA, 2019. Material efficiency and clean energy transitions. 162 pp.

[30] Streeck, J., D. Wiedenhofer, F. Krausmann, H., Helmut (2020): Stock-flow relations in the socio-economic metabolism of the United Kingdom 1800-2017. Resources, Conservation & Recycling. https://doi.org/10.1016/j.resconrec.2020.104960.

at the pilot stage and are yet to reach maturity.[31] They were not considered in the model, as the potential deployment scale is expected to be small in 2060.

The split of required capacity additions of the listed technologies is based on LCOS (steel) competition via the following logit function:[32]

$$Share_i^t = \frac{a_i * LCOS_{it}^{-2}}{\sum_i a_i * LCOS_{it}^{-2}} \tag{2.5}$$

Weighting factors (a_i) capture the deviation from pure cost-based competition and reflect non-economic (strategic) preferences, or those economic factors which are not reflected in the INDEE-MOD. Since equation 2.2 reflects only the distribution of additional capacity shares, the whole capacity structure evolves smoothly accounting for inertia of long-term assets turnover in the steel industry.

LCOSs reflect CAPEXs, non-variable OPEXs, fuel and electricity costs, as well as carbon cost. There are options for LCOSs to account for only scope 1 or for both scope 1 and 2 CO_2 emission factors for each route. CO_2 emission factors were borrowed from several sources.[33] Data on CAPEXs and OPEXs were borrowed from a large variety of recent literature sources on steel industry decarbonization.[34] Via technology learning and subsidies provided to reduce CAPEXs, the model allows it to improve the competitiveness of low carbon technologies. A similar approach is applied to ammonia and cement production.

For individual products, the end-use approach is applied as the accounting framework to model SECs evolution. Based on production volumes and SECs, total final energy use is modeled, and the split by energy carriers is mostly reflected in ENERGYBAL-GEM-2060 based on interfuel

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[31] Hydrogen plasma smelting reduction; molten oxide electrolysis; iron bath reactor smelting reduction; alkaline iron ore electrolysis; gas injection into the blast furnace. IEA, 2020: *Energy technology perspective special report-clean energy innovation*, Paris, France, 182 pp.; ttps://webstore.iea.org/download/direct/4022?fileName=Energy_Technology_Perspectives_2020_-_Special_Report_on_Clean_Energy_Innovation. Pdf; GreenSteel for Europe. Investment needs. March 2021; EPRS. 2021. Carbon-free steel production: Cost reduction options and usage of existing gas infrastructure. Panel for the Future of Science and Technology. EPRS | European Parliamentary Research Service Scientific Foresight Unit (STOA) PE 690.008 – April 2021. IEA. 2020. Iron and Steel Technology Roadmap. Towards more sustainable steelmaking. 190 pp.

[32] This function is widely used in cost-based new technologies shares allocation. See Despres, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., *POLES-JRC model. documentation – 2018 update*, EUR 29454 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97300-0, doi:10.2760/814959, JRC113757; EIA. 2020. Model Documentation Report: Industrial Demand Module of the National Energy Modeling System. December 2020. US DOE. IEA uses a similar logic, but a more complex set of functions: IEA. 2021. World Energy Model Documentation. October 2021.

[33] Standard EN 19694-2 Stationary source emissions – Greenhouse Gas (GHG) emissions in energy-intensive industries – Part 2: Iron and steel industry. GreenSteel for Europe Consortium, 2021; GreenSteel for Europe. Investment needs. March 2021; IEA. 2020. Iron and Steel Technology Roadmap. Towards more sustainable steelmaking. 190 pp.; World Steel Association, 2020: *Steel's contribution to a low carbon future and climate resilient societies*. 6 pp. https://www.worldsteel.org/en/dam/jcr:7ec64bc1-c51c-439b-84b8-94496686b8c6/Position_paper_climate_2020_vfinal.pdf

[34] GreenSteel for Europe. Investment needs. March 2021; EPRS. 2021. Carbon-free steel production: Cost reduction options and usage of existing gas infrastructure. Panel for the Future of Science and Technology. EPRS | European Parliamentary Research Service Scientific Foresight Unit (STOA) PE 690.008 – April 2021. IEA. 2020. Iron and Steel Technology Roadmap. Towards more sustainable steelmaking. 190 pp.; Material Economics, 2019: *Industrial Transformation 2050: Pathways to net-zero emissions from EU Heavy Industry*. 207 pp. https://materialeconomics.com/publications/industrial-transformation-2050; Pissot, S., Thunman, H., Samuelsson, P. et al (2021). Production of negative-emissions steel using a reducing gas derived from DFB gasification. Energies, 14(16). http://dx.doi.org/10.3390/en14164835; Carbon-free steel production: Cost reduction options and usage of existing gas infrastructure. STUDY Panel for the Future of Science and Technology EPRS | European Parliamentary Research Service Scientific Foresight Unit (STOA) PE 690.008 – April 2021; Bataille C., S. Stiebert, F. G. N. Li CEng. GLOBAL FACILITY LEVEL NET-ZERO STEEL PATHWAYS. TECHNICAL REPORT ON THE FIRST SCENARIOS OF THE NET-ZERO STEEL PROJECT. OCTOBER 11TH, 2021.

costs competition with a few exceptions (for example, fuel split for DRI production is modeled in INDEE-MOD).

Current production capacity stock will be retiring based on retirement rate assumptions; this process will be going along with modernization and phase out of the existing capacities. Evolution of products demand determines the scale of new capacity additions. Energy efficiency parameters (SECs) of new facilities can be optionally taken equal either to BAT (state-of-the-art technologies), or to the best global practical technologies (BPT). It was assumed that modernization of facilities brings SECs down only to BPT levels. Therefore, capacity stock evolution (with other factors equal) brings SECs down. For sectors with a wide range of products, such as iron and steel, pulp and paper, or oil refining, INDEE-MOD not only evaluates SECs, but also integrated energy efficiency indices.

Cross-industrial technologies (motors, steam generation, compressed air systems, oxygen production, industrial lighting) are the largest energy consumers in non-energy intensive industries. They are modeled using the stock turnover approach with a split by energy efficiency classes. Modeling the stock change by efficiency vintage helps estimate the evolution of average efficiencies.

The following CO_2 stocks in industry (CCU) are addressed: captured CO_2 from ammonia production used to produce urea, and recarbonization, i.e. natural CO_2 uptake in concrete as a carbon sink.[35] In addition, CCS deployment is considered in detail for iron and steel, cement, and some chemical industries. CCS deployment scale depends on carbon price and basic materials costs competition.

As major decarbonization technologies are quite expensive, the effects on total basic materials costs are assessed. Logically, this cost escalation should encourage *ME* in industry and construction. But these effects are not yet reflected in the INDEE-MOD.

From RUS-DVA model, macroeconomic inputs are transferred through ENERGYBAL-GEM-2060 to INDEE-MOD, serving as factors in demand functions for various industrial products. INDEE-MOD outputs (production volumes of 27 energy intensive products and corresponding SECs annual decline rates) are then taken to ENERGYBAL-GEM-2060. Based on energy price variations, the evolution of these SECs values can be accelerated or slowed down. The approach used allows it to avoid the autonomous technological progress concept, which is largely used in energy modeling, and explains why and how the dynamics of technological structure results in SECs evolution in time.

Where key GHG emission reductions are yielded through energy efficiency improvements, only incremental capital costs per unit of energy savings are calculated and used in ENERGYBAL-GEM-2060. For other effects (when low carbon technologies are applied in iron and steel, cement industry, and some chemical processes), incremental capital costs as compared to the presently dominant technology per 1 t of product are used.

2.2.5 Residential buildings model – RESBUILD[36]

RESBUILD, a simulation (dynamic accounting) model for energy use in residential buildings, has a one-year calculation step. The retrospective part of the model covers 2000-2020, and the forecast horizon is to 2060. The model splits all residential buildings into multi-family and single-family houses. It simulates energy use for space heating, hot water supply, cooking, lighting, refrigerating and freezing, washing, air conditioning, TVs, computers, and other

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[35] Based on Cao, Z. et al., 2020: The sponge effect and carbon emission mitigation potentials of the global cement cycle. *Nat. Commun.*, 11(1), 3777, doi:10.1038/s41467-020-17583-w; Guo, R. et al., 2021: Global CO2 uptake by cement from 1930 to 2019. *Earth Syst. Sci. Data*, **13**(4), 1791–1805, doi:10.5194/essd-13-1791-2021.

[36] A detailed description of the model can be found in CENEf's report Analysis of the Real Estate Sector in Russia. Assessing the Need to Alter Energy Efficiency Regulations. The project was initiated by ROSIZOL association in 2014.

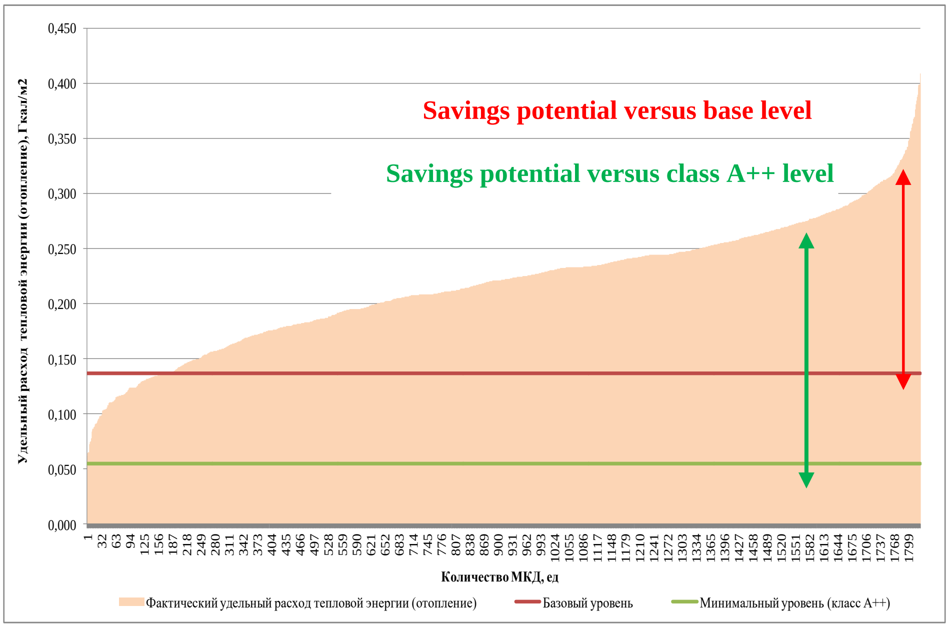
appliances. All of these processes rely on either fuels (including biomass) or centralized or onsite power and heat supply depending on the technologies used.

The model inputs are population, disposable incomes, HDD, housing construction, retrofits and demolition. Overall energy efficiency performance of space heating in new buildings depends on lifecycle costs comparison of packages to improve buildings envelopes and heating efficiency. However, for deep retrofits a different set of packages is used. Annual deployment rates for these packages are selected based on a logit function (similar to 2.2), where costs are expressed as lifecycle costs for 7 alternative energy efficiency renovation packages and 3 packages for new buildings.[37] The packages are modeled separately for multi-family and single-family houses. The evolution of lifecycle costs is assessed with an account of the learning rates, subsidies, and carbon tax. The costs and performance of new appliances and equipment for distributed power and heat generation are exogenous to the model and are verified for the dynamics of corresponding performance standards.

The model estimates the dynamics of specific energy use (SEC) based on buildings and equipment stock turnover. End-use energy demand is estimated by processes using activity data (demand for services), equipment performance, and SECs. It is then broken down based on energy prices competition into energy carriers in ENERGYBAL-GEM-2060. This provides a basis for the evaluation of corresponding direct and indirect GHG emissions.

To model average space heating efficiency for multi-family and single-family houses, the benchmarking functions are used for buildings age cohorts (see Figure 2.7[38]). Buildings age structure thus impacts overall energy efficiency, since demolished buildings have the poorest energy efficiency performance, and newly constructed houses rank the highest. For appliances, the evolution of stock by age cohorts is used to evaluate the average overall energy efficiency progress. Service life expectancies for equipment in place depend on disposal income level: the lower the income, the longer appliance service life.

Figure 2.7 **Benchmark curve for space heating energy use (Gcal/m2) in Kemerovo city multi-family buildings**



Source: CENEf-XXI.

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[37] The plan is to build three types of apartment buildings: some will be built in accordance with the regulations in force; others will have low energy consumption; the third group will be “passive” buildings. The first group has larger specific energy consumption, while “passive” buildings are the most efficient. Distribution of the commissioned living space by these three groups affects total residential fuel and energy consumption.

[38] In the model, this distribution is normalized to HDD and corrected to number of floors, which makes it universal across climate zones and across the number of floors in buildings.

The model accounts for the policy effects, such as EE building codes requirements for both new and retrofitted buildings; the share of retrofitted buildings covered by policies and programs, appliances standards, metering saturation requirements, the share of efficient lighting systems, renewables support, and other policies which allow for SECs reductions.

The model outputs are: energy use broken down by processes and energy carriers; specific energy consumption by all covered processes for both new and existing buildings, direct and indirect GHG emissions, investments in equipment and improvements to buildings envelopes.

The model simulates penetration of onsite microgeneration of power and heat from renewables, including photovoltaic panels, mini-wind installations, solar water heaters, and heat pumps. The market niches are assessed depending on the cost parameters (see Equation 2.5). Weighted factors in these functions reflect policies, which affect consumer preferences for particular technologies.

The RESBUILD model determines costs (lifecycle costs, LCOE, LCOH) for key decarbonization solutions. Besides, the model estimates household fuel and energy spending and its share in personal incomes along with budget spending to keep energy and housing services affordable for low-income families. PUBBUILD model for public and commercial buildings builds on a similar principle and accounts for education, healthcare, and 12 other types of public and commercial buildings.

From ENERGYBAL-GEM-2060 macroeconomic parameters are transferred to RESBUILD and PUBBUILD, which determine the dynamics of new buildings construction. In the opposite direction, the parameters of new buildings commissioning, energy efficiency of space heating, DHW, and energy use for other needs, as well as the initial structure of energy consumption for these needs are transmitted and further verified in ENERGYBAL-GEM-2050 by changing the price parameters.

2.2.6 Model for transport TRANS-GHG

TRANS-GHG is a simulation engineering (bottom-up) model for transport. It has a one-year step. The retrospective part of the model covers 2000-2021, and the projection horizon is extended to 2060. As in other sectorial models, TRANS-GHG is calibrated annually to fit historical energy use, fleet stock, and transport work to ensure it accounts for the recent developments. The model includes 12 main blocks (sub-modules). The transport sector in broken down into individual modules for different transport modes, including vehicles (cars, trucks, buses), rail transport, city electric transport, air transport, water transport, and pipeline transport. In passenger transport, personal and public vehicles are modeled.

The model projects transport activities (freight and passenger turnover), which are functions of macroeconomic parameters, such as population, GDP, industrial production, weight of basic materials produced, disposable personal incomes, etc. Passenger mobility is the function of population and personal income. Freight turnover is separately estimated for rail transport and pipeline transport. For the other transport it is a function of GDP. 13 modes for passenger transport (personal cars, taxi cars, company cars, carsharing, buses, air, sea, domestic water, rail, subway, tram, trolleybuses, two-wheeled transport, and bicycles) and 8 modes for freight transportation (trucks, rail, air, sea, domestic water, oil pipelines, oil products pipelines, gas pipelines) are included. Special modules are designed to assess vehicles cost of ownership. Each block for the transport sector includes energy consumption and GHG emissions (direct and indirect) – both historical and projected.

The LDV vehicle fleet module is broken down into personally owned cars, taxi cars and company cars, trucks, buses and two-wheeled vehicles. Each of these is further broken down into powertrains and fuel used, including gasoline, diesel, LPG and CNG, hybrids and electric. The rail transport module includes data on electric and diesel powertrains, operational length of railways, including the length of electrified sections, passenger and freight turnover, energy use, and GHG emissions. Urban electric transport module includes subways, trams, and trolleybuses. It models the length of traffic routes, fleet stock, passenger traffic, and electricity use. Air transport and water transport modules project passenger and cargo transport demand, fleet, fuel use, and GHG emissions. Pipeline transport module includes oil, oil products, and gas pipelines.

In the IEA model and POLES, vehicle ownership is a per capita income function with a specified saturation level.[39] This involves two problems: the saturation level is arbitrarily set and it is a continuously growing function of income. Therefore, no reduction in per capita vehicle ownership can be assumed when the income is growing. TRANS-GHG allows for the selection of the vehicle ownership function. One option is based on regression for new car sales as a positive function of disposable income and a negative function of lagged per capita vehicle ownership (reflecting saturation). Where the number of cars added to the stock is smaller, than stock retirement, per capita vehicle ownership may steadily decline. Another option involves modelling vehicle ownership as a function of passenger turnover attributed to LDVs. The latter breaks down into taxi cars and office cars, carsharing, and personal cars. Obviously, effective policies that encourage a switch from road to other transport modes and to taxi, carsharing and carpooling, can bring down vehicle ownership even when the income is growing. In reality, stock reduction may go not as fast as modeled one and some LDVs may be still listed in the stock, but their milage may shrink significantly,[40] thus barely affecting overall fuel use and GHG emissions.

The powertrain split for new car sales is based on the costs of ownership competition. There are two options: to use cost of driving LCOD[41] or lifetime cost of ownership. The second option was selected. Costs of new cars, fuel costs, other costs (taxes, insurance, technical service) were assessed based on the data available for Russia. Where only scarce data were available (on PHEV and EVs, the fleet of which is very small in Russia, and so the data are not representative), prices and maintenance costs data from other countries (mostly EU and USA) were borrowed.[42] A function similar to Equation 2.5 was used to estimate the shares of powertrai in new LDV sales. In this function, selection of weights can accelerate or impede the adoption of new powertrains, showing the impacts of policies and consumer preferences. There is an option to provide subsidies to reduce EV prices. TRANS-GHG also estimates infrastructure demand for road transport, namely, fueling and charging stations.

Road transport fuel efficiency is driven by three factors. First, it is fuel efficiency of new vehicles, which is exogenous. Fuel or emission standards for new vehicles can be introduced to improve this factor. Second, lifetime intensive service; in reality, it is a function of income per capita, but in the model it is exogenous. Third, the effects of fuel prices. Nominal energy prices include carbon price and are deflated to consumer price index.

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[39] IEA. 2021. World Energy Model Documentation. October 2021. Despres, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., *POLES-JRC model. documentation – 2018 update*, EUR 29454 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97300-0, doi:10.2760/814959, JRC113757.

[40] 3-5-fold, see CO2 EMISSIONS FROM CARS: the facts. A report by the Transport Environment. © 2018 European Federation for Transport and Environment AISBL. April 2018.

[41] Burnham A., D. Gohlke, L. Rush, T. Stephens, Y. Zhou, M.A. Delucchi, A. Birky, C. Hunter, Z. Lin, S. Ou, F. Xie, C. Proctor, S. Wiryadinata, N. Liu, and M. Boloor. Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains. Argonne National Laboratory. April 2021; IEA. 2021. World Energy Model Documentation. October 2021.

[42] Burnham A., D. Gohlke, L. Rush, T. Stephens, Y. Zhou, M.A. Delucchi, A. Birky, C. Hunter, Z. Lin, S. Ou, F. Xie, C. Proctor, S. Wiryadinata, N. Liu, and M. Boloor. Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains. Argonne National Laboratory. April 2021; Wappelhorst S., U. Tietge, G. Bieker, P. Mock. Europe’s CO2 emission performance standards for new passenger cars: Lessons from 2020 and future prospects. WORKING PAPER 2021-32. INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION. SEPTEMBER 2021; Bieker G. A GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF COMBUSTION ENGINE AND ELECTRIC PASSENGER CARS. 2021 International Council on Clean Transportation; CO2 EMISSIONS FROM CARS: the facts. A report by the Transport Environment. © 2018 European Federation for Transport and Environment AISBL. April 2018.

Activities in other transport modes are based on either activity demand functions, such as railroad freight transport or pipeline transport loads, depending on basic materials and fuels production, or on the breakdown of the remaining transport activities by modes, which are inspired by policies and corresponding infrastructure developments, such as the length of the subway system or of bicycle lanes. Like EU POLES,[43] TRANS-GHG allows for a comparison of energy consumption and emissions across all modes and regions for different scenarios.

2.2.7 Model for waste management – WASTE

This WASTE model is used mostly to assess CH_4 and N_2O emissions. It is a bottom-up model with a one-year step. The retrospective part of the model covers 1990-2020, and the projection horizon is to 2060. It is calibrated based on data from the 2020 national inventory. It is used to project emissions related to solid waste disposal, biological treatment of solid waste, and wastewater treatment and discharge. The main drivers include population, GDP, industrial outputs, personal income levels, which are borrowed from ENERGYBAL-GEM-2060.

All MSW are considered to be incinerable in special installations to produce heat and electricity. Where this is the case, GHG emissions from combustion are attributed to the energy sector. The main policy parameters are composition and the share of incinerated waste. The former is a function of MSW generated, the share of unsorted waste, and the commissioning rate of incinerator sorting facilities, as determines the volumes and composition of 'tails' to be burned.

Methane emission is a function of the amount of organic matter in wastewater; anaerobicity of wastewater treatment facilities; and the amount of methane burned. An assumption was made, that all emissions from sewage sludge occur inside the treatment plant (except when such sludge is incinerated). The amount of organic matter in wastewater is a function of both population and per capita waste generation. For N_2O emission, nitrogen-containing substances in wastewater are the key driver.

Methane emissions from industrial wastewater treatment and discharge is a function of organic matter in wastewater and anaerobic capacity of the treatment facilities.

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[43] Despres, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., *POLES-JRC model. documentation – 2018 update*, EUR 29454 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97300-0, doi:10.2760/814959, JRC113757.

3 The angle of incidence is not equal to the angle of reflection. Impacts of the global scale and of Russia's key trade partners' low carbon transition on Russia's economic development

3.1 Call for change

The purpose of this chapter is to assess the systemic impacts of the global scale and of Russia's key trade partners' low carbon transition on Russia's economic development depending on the selected decarbonization pathways. This assessment is broken down into exploring the effects on Russia's traditional exports (mostly fossil fuels and basic materials) and on the emerging low carbon markets. Russia's economy is raw materials-based. Fossil fuels and raw materials production contributes 28-30% to GDP, nearly two thirds to the industrial output, up to 40% to the federal budget, almost 25% to the consolidated budget, and nearly 75% to export revenues. Therefore, if the "old" model of economic growth persists, the economic progress will largely depend on the potential to supply fuels and basic materials to Russia's trade partners and to the domestic market in the decades to come. Since the expansion potential of both these markets is limited, new drivers are required to accelerate the economic growth, and so new low carbon products have to find market niches in the emerging markets. Global low carbon transition sets challenges, but also provides opportunities for Russia's economic future. The balance will largely depend on the ability of the Russian government to recognize the scale of the challenge and to address it via effective policy packages. Until very recently, all these three calls for significant transformation were poorly met.

The potential to reach such balance substantially shrank after the military operation of the Russian troops in Ukraine. Some countries announced their willingness to reduce imports from Russia as part of sanctions packages[44] and longer term energy security policy.[45] So short-term, as well as medium- and long-term export perspectives for the Russian fossil fuels and basic materials got much worse just overnight. Russian products are labeled as 'toxic', and many former trade partners have started to develop strategic goals to minimize their reliance on Russian products as their long-term policies. This may have severe effects for Russia's economic prospects.

3.2 Traditional markets

3.1.1 Crude oil and petroleum products

The future of markets for Russian crude oil and petroleum products depends on the evolution of the global oil market, the ability to maintain or expand Russia's market niches, and the evolution

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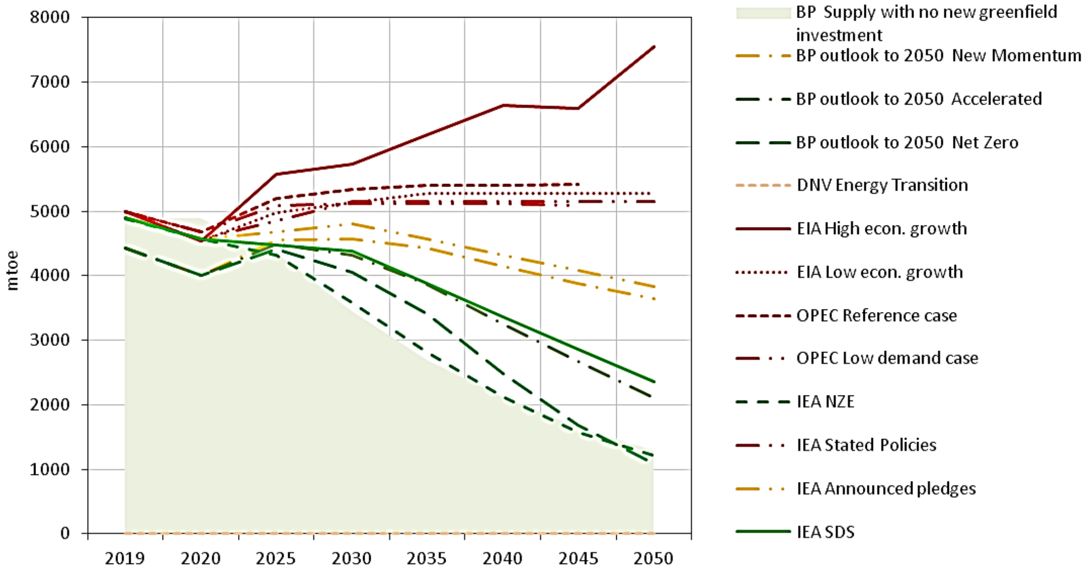
[44] Oil Market and Russian Supply – Russian supplies to global energy markets – Analysis - IEA; Background Press Call by a Senior Administration Official on Announcement of U.S. Ban on Imports of Russian Oil, Liquefied Natural Gas, and Coal | The White House; Oil rallies as US and UK announce bans on Russian oil imports – business live | Business | The Guardian

[45] Joint Statement between the European Commission and the United States on European Energy Security Brussels, 25 March 2022. Statement between the Commission and the US on energy (europa.eu)

of Russia's domestic oil demand. Most projections agree, that the global liquid fuel supply will peak before 2050 (Fig. 3.1). The only exception is the projection by EIA, which anticipates high economic and oil demand growth. In the IEA's scenario with stated policies, global oil market will saturate close to 5000 mtoe in 2030-2050; however, in the announced pledges and low carbon scenarios, after a peak in 2030, oil supply is expected to be steadily shrinking. In the IEA or BP NZE scenarios, there is no need for additional investments in oil production, as demand follows the natural production decline in currently operating oil fields. The gap between supply with no new greenfield investments and any other pathway plotted in Fig. 3.1 indirectly indicates the huge need for investments to bridge the corresponding gap in oil demand.

Figure 3.1 Projections of global oil and liquid fuels* production to 2050



* Some sources report crude oil, while others show liquid fuels.

Sources: IEA. 2021. World Energy Outlook 2021; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector; BP Energy Outlook. 2022 Edition; DOE. 2021. International Energy Outlook 2021with projections to 2050. October 2021; OPEC. 2021. World oil outlook. 2045; DNV. 2021. Pathway to net zero emissions. Energy transition outlook 2021; estimates by CENEf-XXI and The Energy Strategy of the Russian Federation to 2035. Decree by the Government of the Russian Federation No. 1523-r of June 9, 2020.

The analysis time span is to 2060. IAMs projections were explored to clarify, how oil supply may evolve beyond 2050 (Fig. 3.2). The evolution pattern beyond 2050 is similar. In low carbon scenarios, oil supply peaks before 2030 and then scales down with subsequent stabilization at a level below 2000 mtoe in most scenarios. For low carbon scenarios, declining trends plateau at a level nearly equal to the volumes of oil needed as chemicals feedstock. BP estimates feedstock oil demand by the chemical industry (plastics, fertilizers, fibers, etc.) at 360-765 mtoe.[46] IEA estimates it close to 750 mtoe in 2050.[47] Some of it can be substituted by liquid biofuels and synthetic oil. The current level is close to 500 mtoe. Therefore, only moderate growth is expected for non-energy use liquids. The rest are combustible liquids with a quite substantial future demand uncertainty range.

Maintaining the current level of oil supply by 2100 will require 400 thousand mtoe of proven resources. BP reports them at 244 thousand[48] mtoe in 2021. So about as much additional resource will be required in the decades to come to meet such demand.

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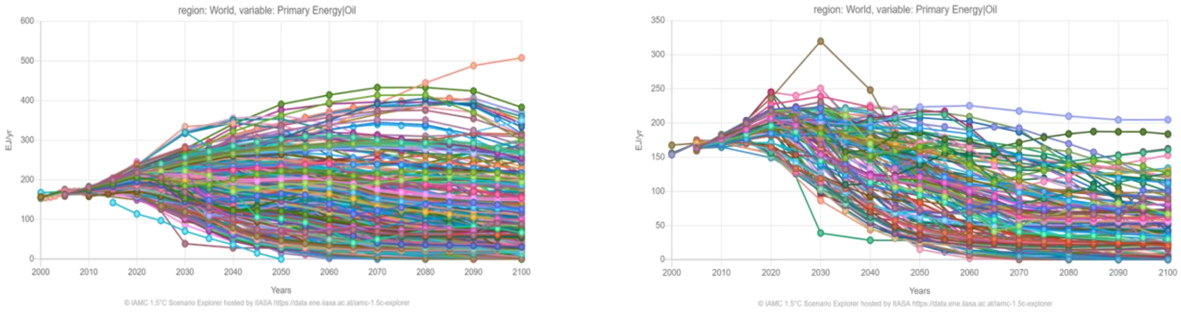
[46] BP Energy Outlook 1995-2050, 2020 Edition.

[47] IEA. 2021. World Energy Outlook. 2021.

[48] BP Statistical Review of World Energy, July 2021.

Figure 3.2 IAMs projections of global oil and liquid fuels supply to 2100

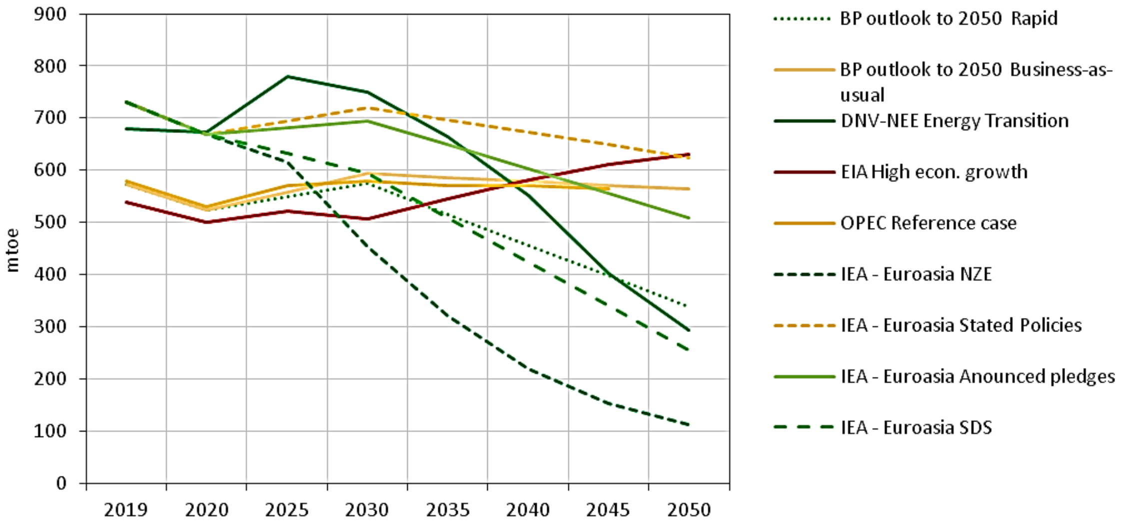


all scenarios scenarios of less than 2°C warming to 2100

Sources: IAMC 1.5°C Scenario Explorer hosted by IIASA

Russia contributes about 13% of global oil supply and is the world's third largest oil producer after the US and Saudi Arabia. Three quarters of produced oil and gas condensate are exported. The RF Customs Service reports 2021 crude oil and gas condensate exports from Russia at 230 mtoe and the exports of petroleum products at 144 mtoe[49]. Russia is (depending on the year) the largest or second largest oil and petroleum products exporter: 412, 381, and 383 mtoe in 2019, 2020, and 2021 respectively, which means Russia has a more than 10% share in the global liquid fuels international trade. This explains why oil and gas condensate production projections for Russia mirror the global market temporal patterns (Fig. 3.3). Until recently, only DOE had expected that Russian oil production could expand. All other projections either take production nearly constant or – for low carbon pathways – expect a deep decline by the mid-century. These pathways are based on the expected evolution of domestic demand and exports. The latter are projected by BP[50] for Russia to drop to 244 mtoe by 2050. OPEC[51] only expects a modest decline for Russia and Caspian: from 330 to 308 mtoe in 2020-2045.

Figure 3.3 Projections of Russia's* oil production to 2050 made before March 2022



* Projections by DNV and IEA are provided for global subregions, which include Russia.

Sources: IEA. 2021. World Energy Outlook 2021; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector; BP. 2021. Energy Outlook 2050; BP. 2022. Energy Outlook: 2022 Edition; DOE. 2021. International Energy Outlook 2021with projections to 2050. October 2021; OPEC. 2021. World oil outlook. 2045; DNV. 2021. Pathway to net zero emissions. Energy transition outlook 2021.

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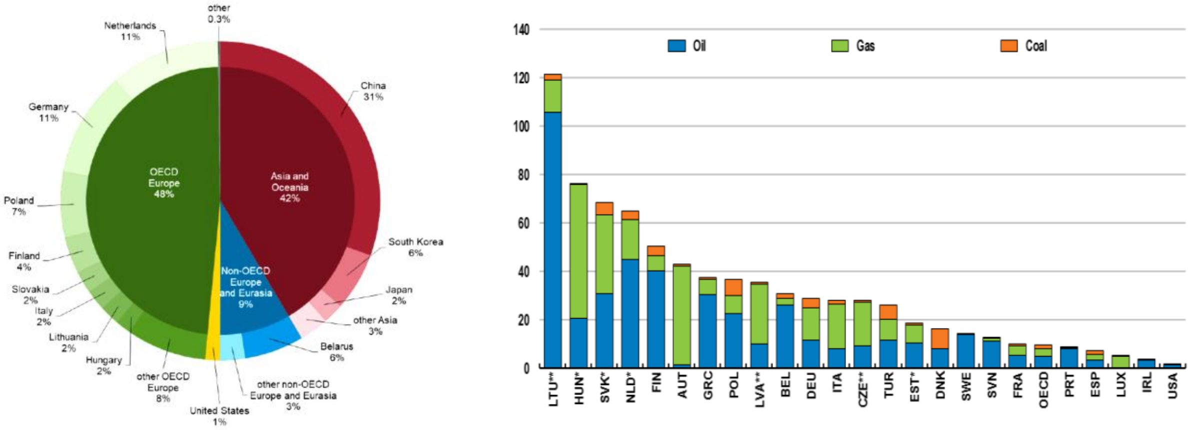
[49] RF customs service (customs.gov.ru)

[50] BP Energy Outlook 1995-2050, 2020 Edition.

[51] OPEC. 2021. World oil outlook. 2045.

All of the above projections had been developed before sanctions were announced. Some countries (USA, UK and Australia) have announced bans on the imports of Russian oil, liquefied natural gas, and coal by the end of 2022.[52] EU has proposed to phase out dependencies on Russian fossil fuels by 2027.[53] According to DOE, in November 2021 Russia was responsible for 26% of the OECD oil and petroleum imports: 17% of OECD-America; 34% of OECD-Europe; 3% of Japan and 9% of South Korea The share of external markets for the Russian oil, which may be affected by the sanctions, exceeds 55% (Fig. 3.4).

Figure 3.4 **Russia's crude oil and gas condensate exports by destination in 2020 (a) and Russian energy imports as a share in total energy supply, 2019 (b)**



a

b

Sources: US EIA. Country Analysis Executive Summary: Russia. 2021; OECD Economic Outlook, Interim Report Economic and Social Impacts and Policy Implications of the War in Ukraine, March 2022.

In 2019-2021, EU imported 117-138 mtoe of crude oil from Russia (Fig. 3.5), which is 26-29% of the EU import. Additionally, EU imported from Russia 71-79 mtoe of petroleum products per year (nearly half of the EU import) in 2019 – first half 2021.[54] EU's petroleum exports and imports are more or less balanced, therefore the crude oil import reliance doesn't deviate much from the total oil import dependence.[55] The cut of supply from Russia needs to be followed by the reorientation of some EU petroleum exports to domestic uses. This would reduce the EU export to other markets, where it potentially can be substituted by some Russian refinery products. Such profound dependence on the oil imports – more than a quarter of crude oil demand and slightly below 40% of liquid fuels supply – explains why EU cannot quickly refuse the Russian oil.

If the EU embargo schedule is adopted and fully implemented, Russia will lose 188-217 mtoe of the EU petroleum market by 2027. In the IEA NZE scenario, oil demand in Europe is expected to decrease by 160 mtoe in 2020-2030. The major part of this decrease is attributed to the EU. In the IEA's announced pledges scenario, the EU oil demand decline is limited to 95 mtoe. Therefore, if the entire EU is politically determined to implement the whole demand reduction potential and the expected consumption decline is attributed entirely to the Russian oil supply cuts, still some additional amount (60-100 mtoe) will be required and can be obtained either by

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[52] Background Press Call by a Senior Administration Official on Announcement of U.S. Ban on Imports of Russian Oil, Liquefied Natural Gas, and Coal | The White House; Oil rallies as US and UK announce bans on Russian oil imports – business live | Business | The Guardian

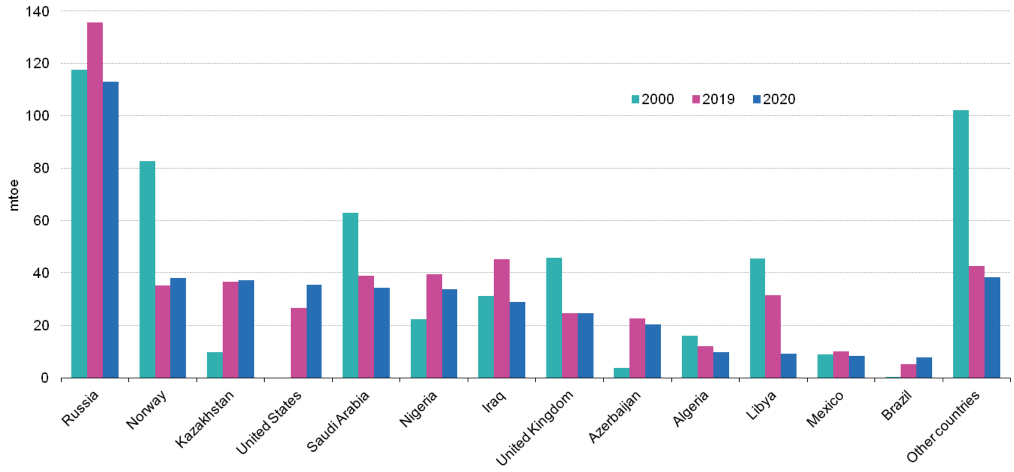
[53] War in Ukraine: Von Der Leyen Eyes Ending EU's Russian Energy Reliance by 2027 - Bloomberg

[54] BP Statistical Review of World Energy July 2021; BP Statistical Review of World Energy July 2020; EU imports of energy products - recent developments - Statistics Explained

[55] Table_and_figures_oil_and_petroleum_products_2020.xlsx (live.com)

redirecting the EU exports of petroleum products to domestic use[56] or by turning to other regions for supply to substitute Russian imports. In this case, average annual decline in Russian imports in 2021-2027 will be 31-36 mtoe, which may be larger (35-45 mtoe) in 2022, if all of the announced measures are effectively adopted. Part of the 2022 EU consumption decline will originate from the economic slowdown in response to the energy price shock and resulting low energy affordability.

Figure 3.5 EU crude oil imports by country of origin



Source: Eurostat (online data code: nrg ti oil)

Source: [Table_and_figures_oil_and_petroleum_products_2020.xlsx (live.com)]

Russian crude oil exports to the US were below 5 mtoe in 2019, below 3 mtoe in 2020, and below 1.5 mtoe in 2021. For petroleum products the corresponding numbers are 11.4, 17.4 and below 4 mtoe. President Biden's Executive Order blocks new purchases of Russian crude oil and some of the petroleum products, LNG, and coal. UK imported 2.4 mtoe of crude oil in 2019, 3.1 mtoe in 2020, and 2.7 mtoe over three quarters of 2021, along with 3.9, 2.1 and 1.7 mtoe of petroleum products. So an embargo on oil and petroleum products supply will squeeze the external market for Russian oil by additional 11-15 mtoe. This effect may be distributed over two years with a cut of some 8-11 mtoe in 2022. Australian imports of Russian oil and refinery products in 2021 was only 0.06 mtoe, so an Australian embargo will have little impact. After the active phase of the invasion is over, these sanctions may persist depending on the outcome.

IEA has estimated, that 10 immediate steps taken by advanced economies can cut oil demand by 2.7 mbd in the next 4 months.[57] But many of these 10 actions (car-free Sundays in cities, or work from home up to three days a week, where possible) require a significant and sustainable behavioural change, which is hard to attain to the required level and to back up with necessary regulation in limited time. Therefore, only a fraction of this potential is practically available.

The total market loss for the Russian oil is estimated close to 200-230 mtoe by 2027, or 52-60% of 2021 exports (383 mtoe), or 38-44% of Russia's total production (524 mtoe). If about 1 mbd in 2022 and 4-5 mbd by 2027 are removed from the global market (which is about 100 mbd) at the ascending stage of the cyclical energy price evolution, oil prices might grow up to US$/b 100-150 or even higher, while the average annual price may reach US$/b 100-120 in 2022, up by 50-80% from US$/b 67 in 2021. In this case, despite the embargo in 2022 and a few subsequent years, Russia's oil revenues may not drop, but increase compared to 2021. The embargo effects might become painful for Russia only after the oil prices fall down substantially

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[56] There are some problems related to the different structure of petroleum products imports and exports.

[57] IEA. 2022. A 10-Point Plan to Cut Oil Use, 18 March 2022. A 10-Point Plan to Cut Oil Use (windows.net)

along with a supply decline closer to 2027. An additional short-term reduction in Russia's oil production will result from a deep recession in the Russian economy.

In a longer term, the global switch from fossil fuels and oil will accelerate as a result of both political determination to reduce the energy dependence on Russia and a greater uptake of alternative technologies as these become more competitive. Russian oil will be viewed as 'toxic' for a long time, unless this label is removed after a change of the regime. Therefore, pathways that are based on the stabilization in Russia's oil production are becoming unfeasible. After a significant decline in 2022-2027, Russian oil exports may somewhat rebound in the mid-term, but in a longer term they will "highly likely" decline faster, than expected before February 24th (Fig. 3.6a). Reduction in foreign investment and limited access to new technologies and financing would additionally limit the ability of Russian oil companies to scale up production in a longer term. As to the alternative markets for Russian oil, there is some potential for additional supply by 2030 to China, India, Africa, and Southeast Asia to meet their respective demands projected by the IEA stated policies and announced pledges scenarios, but this potential will expire by 2050 (and it is non-existent in the NZE scenario).

Oil price predictions are risky both in the short and long-term. The logic of oil price projection shown in Fig. 3.6b is based on the observed cyclical evolution of energy prices (and energy costs shares in the income) with some 25-30-year cycles. The cyclical nature of energy price dynamics has manifested for five centuries and experienced multiple technological transitions and changes in the energy mix.[58] Energy costs constants, i.e. stable over long time energy costs to income ratios, are the center of 'economic gravitation'. Energy affordability thresholds are found in all major final energy use sectors manifesting the 'minus one' phenomenon, which shows that cycle-long real energy prices may only grow by as much as energy intensity declines.[59] Energy affordability thresholds and asymmetric price elasticities are important factors that determine the existence of the turning points towards the center of 'economic gravitation' in the cyclic evolution of the energy costs shares.

Despite a deep reduction in Russian oil and petroleum imports by 2025, Russia's oil export revenues will exceed the 2021 level for a while (Fig. 3.6c). A severe impact of sanctions will only be felt thereafter. In the strong decarbonization pathway, beyond 2027 oil revenues will stay below US$ 100 billion in current prices, which is just a half of the US$ 204 billion average in 2010-2021. Russian oil revenues in 2022 will exceed the 2021 level, unless the average annual oil price stays below 70US$/b.

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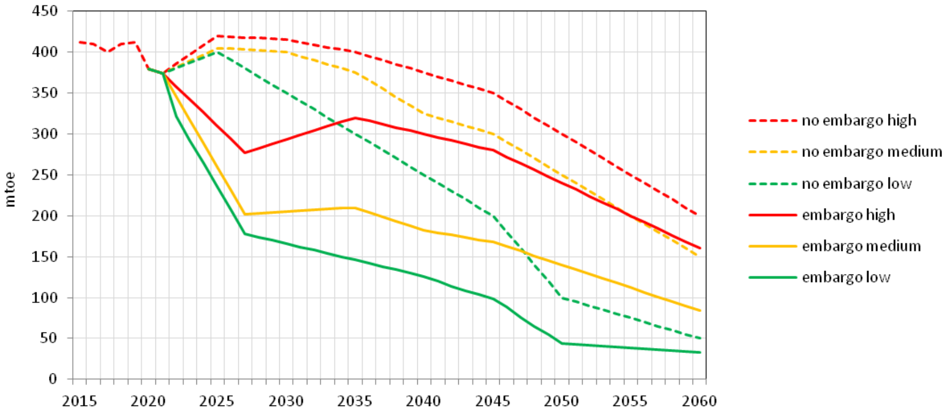
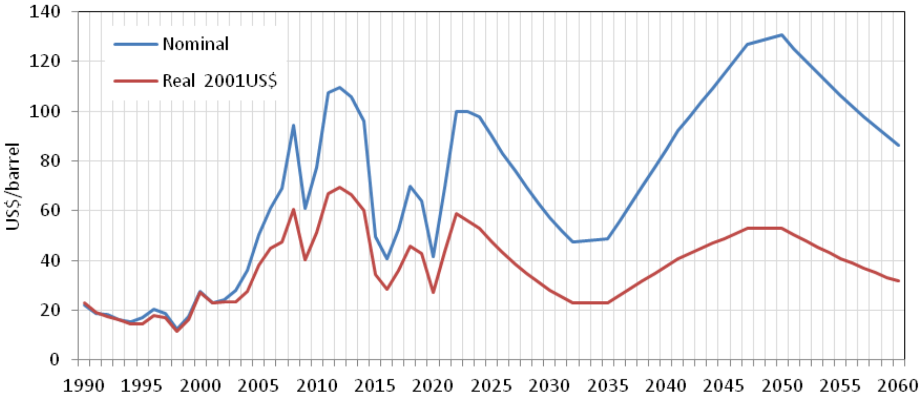
[58] Bashmakov I. "Economics of the constants" and long cycles of energy prices dynamics. *Voprosy Ekonomiki*. 2016;(7):36-63. (In Russ.) https://doi.org/10.32609/0042-8736-2016-7-36-63

[59] Bashmakov I. 2007. Three laws of energy transitions. *Energy Policy*, Vol. 35, No. 7, pp. 3583–3594; Bashmakov I. 2017. The first law of energy transitions and carbon pricing. *International Journal of Energy, Environment, and Economics*, Vol. 25, No. 1, pp. 1–42; Bashmakov I., Myshak A. 2018. 'Minus 1' and energy costs constants: Sectorial implications. Journal of Energy, Vol. 2018, Article ID 8962437. https://doi.org/10.1155/2018/8962437.

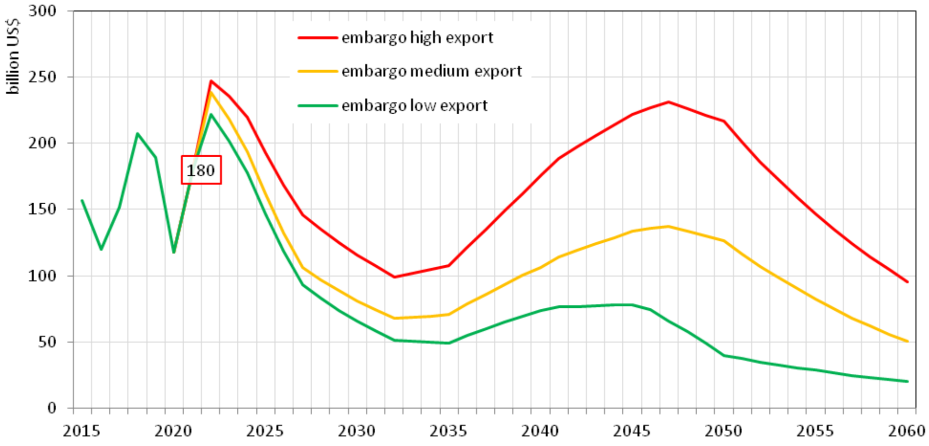
Figure 3.6 Russian oil and petroleum products exports, export prices and export revenues with an account of the embargo effects



(a) Russian oil and petroleum products exports



(b) oil export prices



(c) oil export revenues

Source: CENEf-XXI.

For oil, the key findings are as follows:

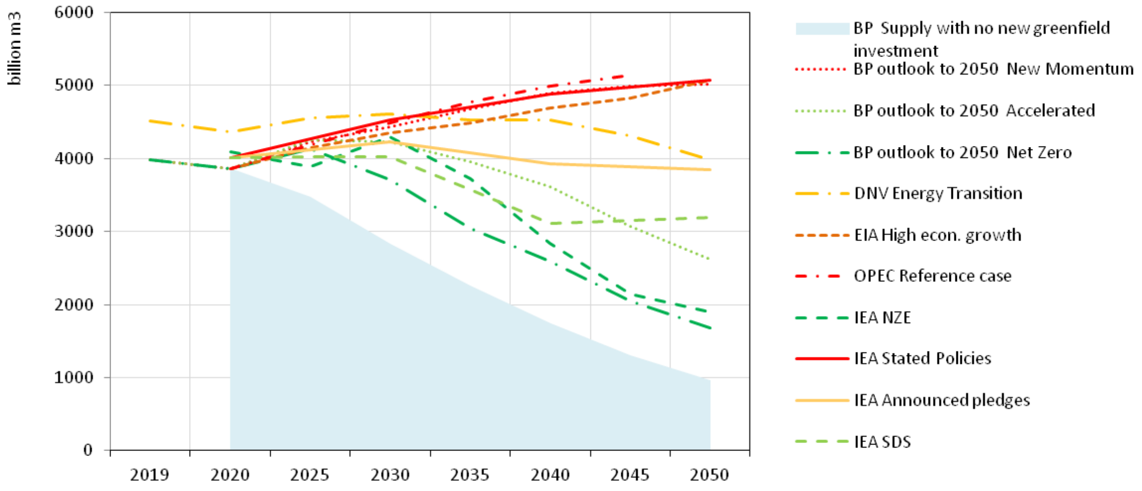
- Foreign markets will be steadily shrinking at a pace determined by the progress in low carbon transition and -- at least for some time -- by the political unwillingness to purchase the ‘politically toxic’ Russian oil;

- It is highly unlikely that Russia will ever be close to 400 mtoe in oil and petroleum exports registered back in 2018-2019;
- Oil prices growth in 2022-2024 will overcompensate (for a few years) the revenue loss associated with the sanctions announced for Russian oil. The effect of both decarbonization and sanctions will become severer after 2025. Extra revenues obtained in 2022-2024, if not fully spent to support the Russian economy, may for some time mitigate the oil revenue collapse beyond 2025.

3.1.2 Natural gas

The global prospects for natural gas, which was considered a fossil bridge to the non-fossil future, are much brighter for the decades to come (Fig. 3.7). In the BAU and stated policies-like scenarios, global gas demand doesn't peak until 2050. In the announced pledges scenarios, it peaks before 2030 and then declines quite modestly. In low carbon scenarios, it peaks before 2030 at about the current level or slightly above it, and then declines to 2000-3000 bcm by 2050.

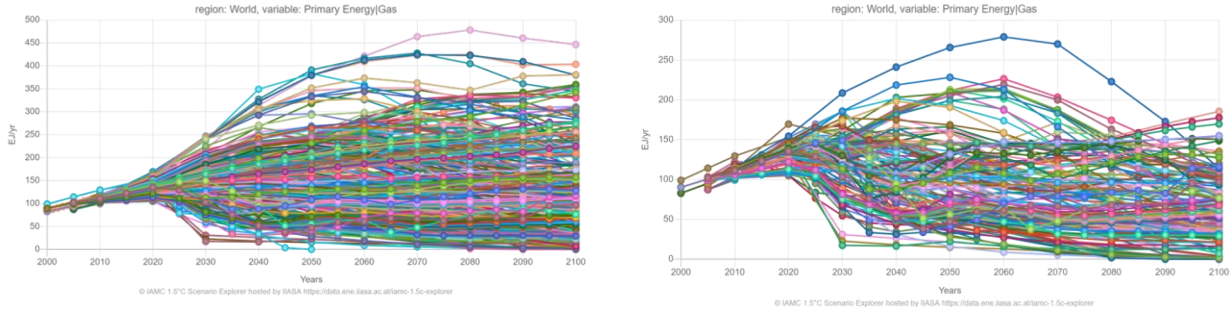
Figure 3.7 **Projections of global gas production to 2050**



Sources: IEA. 2021. World Energy Outlook. 2021; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector; BP. 2021. Energy Outlook 2050; BP. 2022. Energy Outlook: 2022 Edition; DOE. 2021. International Energy Outlook 2021 with projections to 2050. October 2021; OPEC. 2021. World oil outlook. 2045; DNV. 2021. Pathway to net zero emissions. Energy transition outlook 2021.

In IAMs projections, the uncertainty ranges are much greater, but generally, the 'spaghetti' of trajectories have a similar shape. In low carbon scenarios to 2050-2060, they are mostly traced below the current production level, while some trajectories depict the absolute end of the "gas era" by 2080-2100 (Fig. 3.8).

Figure 3.8 **IAMC projections of global gas production to 2100**



all scenarios

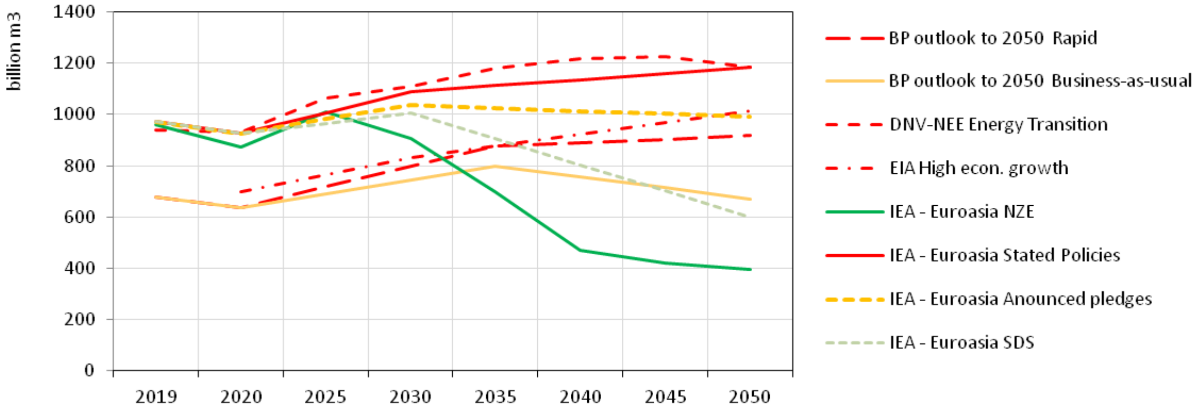
scenarios with less than 2°C warming to 2100

Sources: IAMC 1.5°C Scenario Explorer hosted by IIASA

Some 400 trillion cm are needed to maintain gas supply at the current level until 2100, while global proven resources were reported at 184 trillion cm at the end of 2020.[60] It is challenging to provide the growing supply with the required resources. If no additional greenfield investments are provided, gas supply from the currently operating fields will shrink 4-fold to 1000 bcm by 2050.

Until recently, Russia had been contributing 17-18% to the global natural gas supply. Just a little over 70% is consumed locally, the rest is exported (221 bcm in 2019, 203 and 204 bcm respectively in 2020-2021). As the local consumption slowly evolves, future production pathways will largely depend on the expected capacity of foreign markets and on their willingness to absorb Russian gas. The latter was undermined deeply after February 24th. Before this date, BAU projections expected some growth in Russian or Eurasian gas supply (Fig. 3.9). Announced pledges and low carbon scenarios assumed some growth in supply till 2030 and a plateau or a decline at a later stage. Only in the IEA NZE scenario a fast production decline for Eurasia was projected by 2040 with a subsequent stabilization in 2045-2050.

Figure 3.9 Projections of Russian* gas production to 2050 made before March 2022



* Projections by DNV and IEA are provided for global subregions, which include Russia.

Sources: IEA. 2021. World Energy Outlook 2021; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector; BP Energy Outlook 2050: September 2; DOE. 2021. International Energy Outlook 2021with projections to 2050. October 2021; DNV. 2021. Pathway to net zero emissions. Energy transition outlook 2021.

EU (68%) dominates in the geographical structure of Russia's natural gas exports. According to the RF Customs Service statistics, pipeline gas exports to EU was 151 bcm in 2019 and 142 bcm in 2020. In addition, 16 and 31 bcm LNG were imported by EU from Russia in 2019-2020. So the total is close to 170 bcm, or about 46% of the EU net gas imports, and about a third of total EU gas consumption. EU sources provide close estimates.[61]

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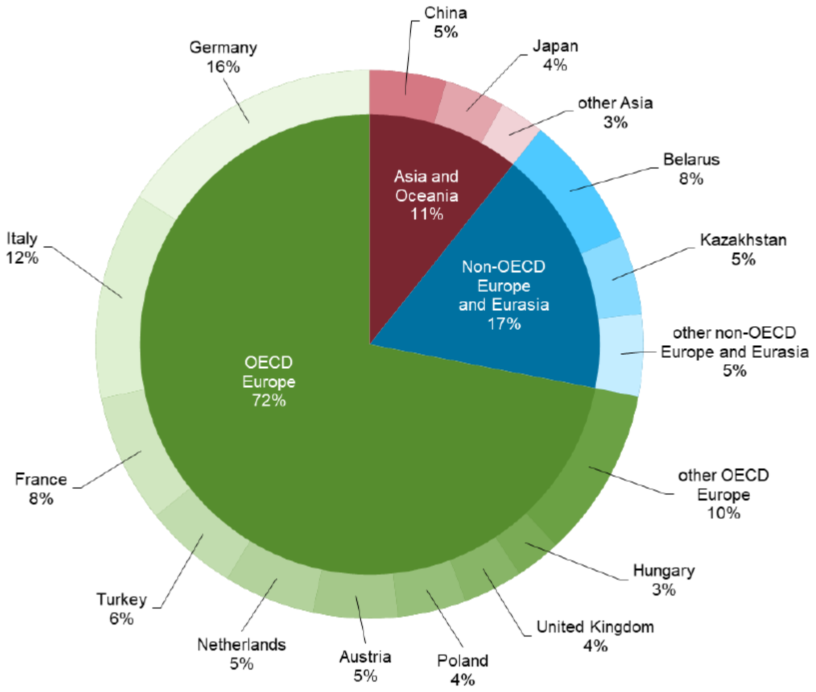
[60] BP Statistical Review of World Energy, July 2021.

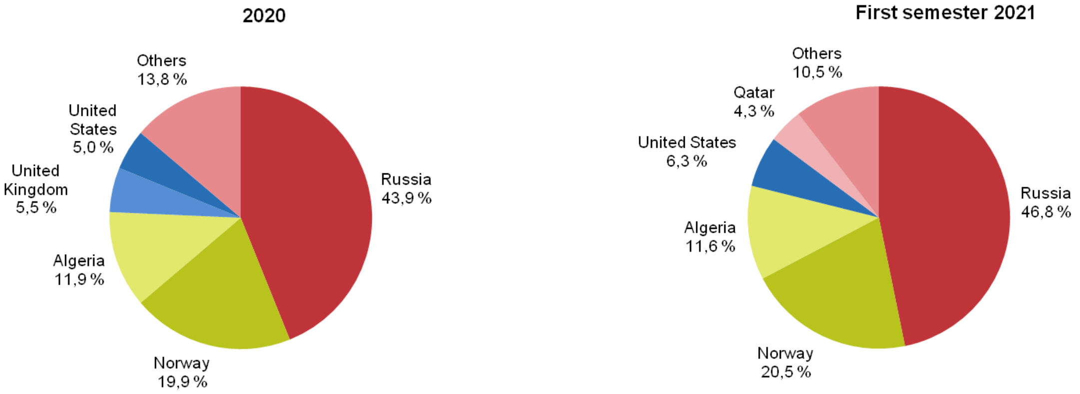
[61] European Union Imports of estimate of low valued import transactions from Russia - 2022 Data 2023 Forecast 2000-2020 Historical (tradingeconomics.com)

Figure 3.10 Russia’s natural gas exports by destination in 2020



Source: US EIA. Country Analysis Executive Summary: Russia. 2021.

Figure 3.11 Extra EU imports of natural gas from key trading partners, 2020 and first semester 2021



Source: Eurostat database (Comext) and Eurostat estimates European Union Imports of estimate of low valued import transactions from Russia - 2022 Data 2023 Forecast 2000-2020 Historical (tradingeconomics.com)

It is a challenge for EU to avoid the dependence on Russian gas. If EU is to phase out dependencies on Russian fossil fuels by 2027, it needs to reduce gas consumption and mobilize alternative sources to substitute 170 bcm supplied from Russia. There are even more ambitious plans to replace 100 bcm of Russian gas (two thirds) by the end of 2022.[62] To attain the latter goal gas exports from Norway, the second largest EU supplier, have to double, or supply from Algeria has to triple, or supply from the US has to more than quadruple over 9 months (Fig. 3.10). If LNG is to be used to replace Russian pipeline gas, then EU and LNG suppliers will probably need to sign long-term contracts for gas deliveries.

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[62] EU announces plan to slash Russian gas imports this year | Russia-Ukraine war News | Al Jazeera Joint European action for more affordable, secure energy (europa.eu)

In early March 2022, IEA published "*A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas*".[63] Potential gas demand reductions were assessed for many items. *Plan*. 1. *No new gas supply contracts with Russia* action can reduce the imports of Russian gas by 15 bcm in 2022 and by up to 40 in 2030. 2. *Replace Russian supplies with gas from alternative* sources can potentially bring 30 bcm in additional gas supply from non-Russian sources. 3. *Introduce minimum gas storage obligations to enhance market resilience* reduces the vulnerability of gas supply and improves the stability of gas process at the expense of the additional 18 bcm supply in 2022. That fully neutralizes the short-term effects of Item 1 above. 4. *Accelerate the deployment of new wind and solar projects* over and above the already anticipated growth in the short-term may reduce gas demand by 6 bcm. 5. Maximize generation by existing dispatchable low-emissions sources*: bioenergy and nuclear* would allow it to reduce gas use for electricity generation by 13 bcm. *6. Enact short-term measures to shelter vulnerable electricity consumers from high prices* will require introduction of a temporary tax on electricity companies' windfall profits. Gas-fired generation is the marginal source at the wholesale power markets, so higher gas prices lead to windfall profits for all suppliers along the power supply cost curve (up to EUR 200 billion) and part of this amount is going to be reallocated to support vulnerable consumers (around EUR 55 billion). This plan item enlarges gas demand by this group of consumers to enable them to maintain sanitary-required heating levels. 7. *Speed up the replacement of gas boilers with heat pumps* would save additional 2 bcm of gas use within the first year, but will require EUR 15 billion in additional investment. The slowdown of the EU economy may not allow it to mobilize that much within one year. *8. Accelerate energy efficiency improvements in buildings and industry* potentially allows it to reduce gas consumption by 2 bcm within a year. *9. Encourage a temporary thermostat adjustment by consumers:* turning down the thermostats by 1°C would reduce gas demand by 10 bcm a year. *10. Step up efforts to diversify and decarbonize sources of power system flexibility* option was not estimated in terms of demand reduction, but, along with peak power prices, it can push the flexible demand down through real-time electricity price signals.

All together, these items could reduce the EU demand by 3-40 bcm in the short-term and by 60-75 bcm by 2030. The goal of completely avoiding the EU's dependence on Russian gas supply by 2027 is highly challenging. It necessitates huge gas savings along with the pathway proposed in the IEA NZE scenario, which yields about 60 bcm in EU gas use savings in 2021-2027, to be supplemented with over 100-110 bcm in additional gas supply from alternative suppliers. The latter equals total current gas supply from alternative sources. If the EU plan is successful, Russia will have problems with finding new markets for 140-150 bcm of pipeline gas supply lost by or before 2027. It may eventually redirect some of the lost export amounts to other global markets, but this strategy takes time, meets with substantial infrastructure demand, and will face technology and financing restrictions.

Prior projections were substantially revised downwards to reflect the potential embargo effects on the Russian gas exports (Fig. 3.12). If EU manages to cut its gas imports from Russia by 100 bcm in 2022 and by 150 bcm by 2027,[64] then Russian total pipeline gas exports may shrink to 50 bcm by 2027. Russia might then rebound it, as some new markets with no sanctions expand, until the scaling effects of the decarbonization policies squeeze gas demand there as well. In 2021, average Russian export gas price (272 US$/1000 cm) was twice the 2020 level. In 2022-2025, it can reach and exceed 360 US$/1000 cm (keeping in mind that under long-term contracts gas prices are lower than in the spot markets). Demand for alternative supply (to substitute the Russian gas) will develop a market pressure to keep the gas prices high. In this case, Russia's gas export revenues in 2022 may exceed the 2021 level, despite a sharp decline in exported volumes. It is not until 2025-2035 that Russia will face a substantial decline in gas export

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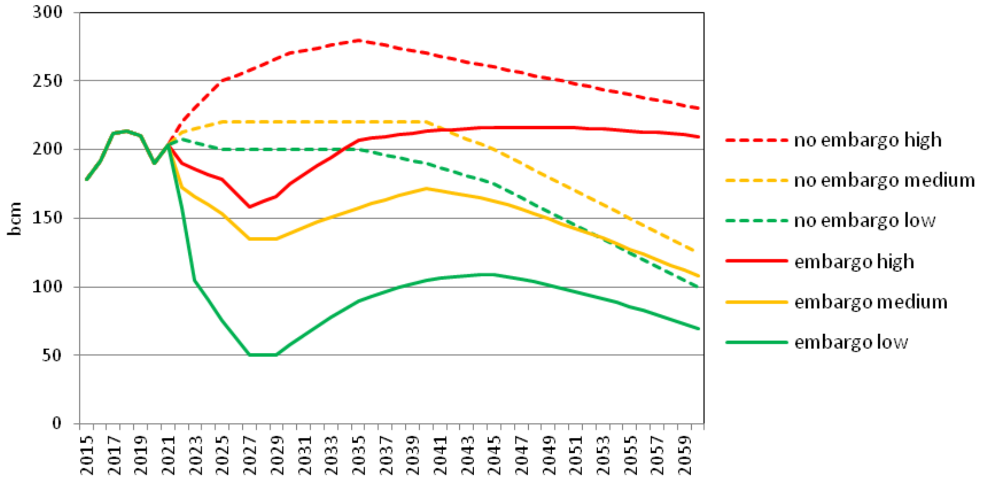
[63] A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas – Analysis - IEA

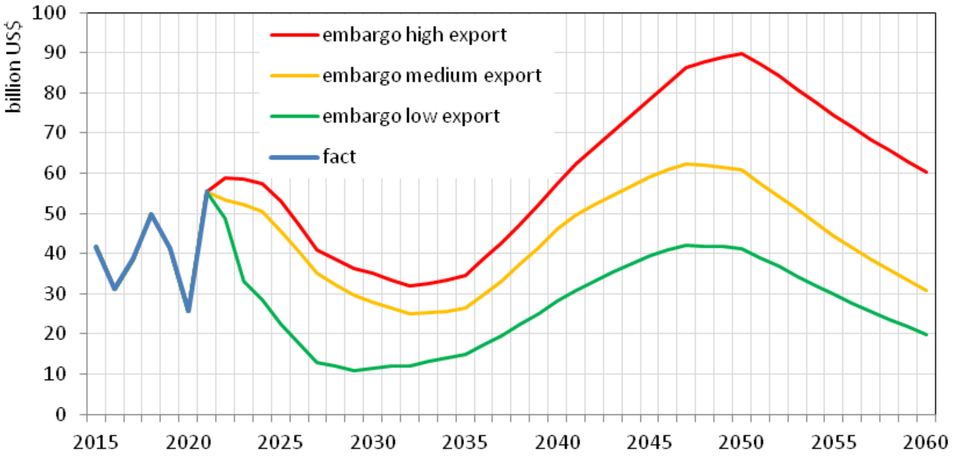
[64] Practical restrictions to attaining this goal are discussed in: Konoplyanik A. Europe's energy suicide. EXPERT, No. 11, March 14-20, 2022 (in Russian).

revenues to the level close or below the one registered in 2020 in nominal terms, but much lower if import prices growth is accounted for. So efforts to reduce the dependence on the Russian gas will bring visible export revenue impacts only beyond 2025.

Figure 3.12 Russian pipeline gas exports and export revenues accounting for embargo effects



(a) natural gas export



(b) gas export revenues

Source: CENEf-XXI.

According to the Russian Central Bank and RF Customs Service, in 2020-2021 Russia exported 66-68 bcm as LNG, which brought over US$ 7 billion in revenues in 2021.[65] In 2020, 17 bcm LNG were provided to EU. EU's decision to refuse Russian LNG may change the geography of the LNG trade. In this case, Russian former LNG exports to EU may be redirected to other destinations. Therefore, not many short-term impacts can be expected. In the long-term, lack of domestic technologies and financing will hamper projects aiming to expand LNG supply from Russia.

The conclusions for natural gas are as follows:

- The EU market and some other markets for the Russian gas will be shrinking driven by decarbonization policies, high gas prices and the political unwillingness to purchase the 'toxic' Russian gas;

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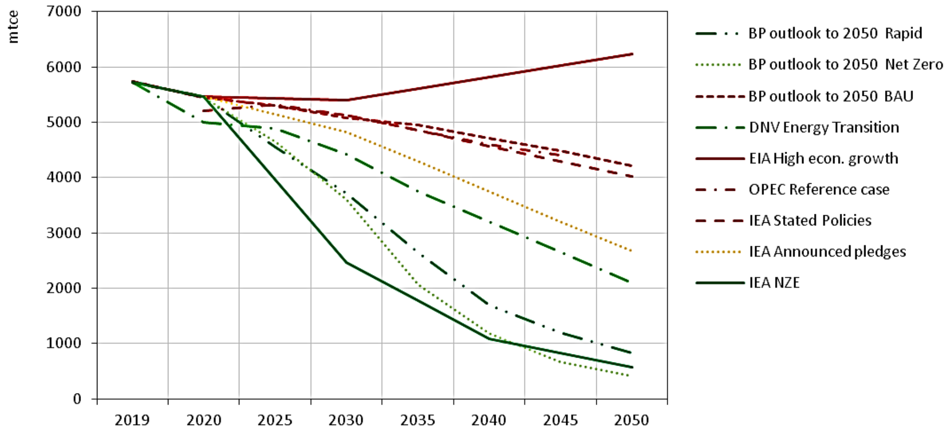
[65] The RF Customs Service (customs.gov.ru)

- Potential expected volumes of Russian gas exports in BAU and announced policies-like scenarios may show a 70-100 bcm drop by 2027. It is very unlikely that gas exports and production in Russia will ever exceed the 2021 level;
- Russia has given a substantial push to the low carbon transition process in the OECD countries and worldwide. Global demand for Russian gas on the whole 2060 time span will be much lower than that expected before February 24th;
- Domestic natural gas demand in Russia will be driven by two factors working in the opposite directions. First, the demand will be declining due to the Russian economic recession with a subsequent slow revival; and second, low carbon transformation of the Russian economy will be slowed down by the equipment import restrictions and declining incomes.

3.1.3 Coal

Recent developments have revived coal demand even despite higher coal prices, because gas prices have grown much faster making coal-based power generation more competitive even with high carbon prices (these dropped in March 2022 as a reaction to skyrocketing fuel prices). In the early 21st century, coal managed to win back some of the share it had lost in global energy demand. A larger coal use for power generation in China and India after 2000 gave rise to the "second coal wave." Some growth in coal consumption will unlikely last longer than until the mid-2020s. Coal consumption reached an absolute peak of 8 billion tons back in 2011. A return to this peak is possible by 2024[66] partially due to the recent surge in gas prices. Beyond that point, even before 2030, coal consumption will start declining steadily at a pace determined by the decarbonization progress. Only DOE expects some growth in coal use by 2050 (Fig. 3.13). All of the other recent projections show that coal will never come back, and there will be no "third coal wave". Even announced pledges-like scenarios expect a substantial (at least 25%) global coal demand reduction by 2050. Low carbon scenarios expect about 5-fold decline leaving coal use below 1000 mtce at facilities mostly using the CCS technology.

Figure 3.13 **Projections of global coal production to 2050**



Sources: IEA. 2021. World Energy Outlook. 2021; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector; BP Energy Outlook 2050: September 2; DOE. 2021. International Energy Outlook 2021with projections to 2050. October 2021; OPEC. 2021. World oil outlook. 2045; DNV. 2021. Pathway to net zero emissions. Energy transition outlook 2021.

According to the IIASA database, in all scenarios with global warming limited to 2°C coal production declines by a factor of four or more by 2050, and in the scenarios with the warming limited to 1.5°C it declines by almost an order of magnitude (Fig. 3.14). Many countries have already pledged to phase out coal-based power generation. The Powering Past Coal Alliance (PPCA) is a group of more than 137 countries, cities, regions and organizations that have

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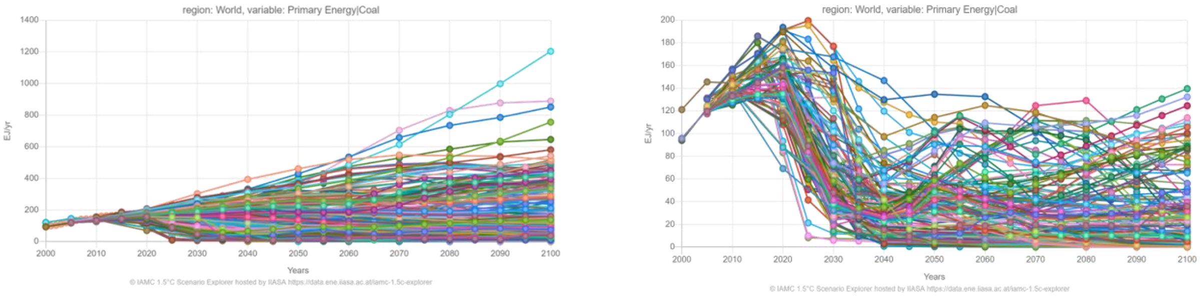
[66] IEA, 2021e. Coal 2021. Analysis and forecast to 2024.

announced the goal of “sending coal into the past” (by 2030 in OECD-countries and no later than 2050 in other countries) by phasing out coal-fired energy production that does not have carbon capture and storage systems in place. Larger-scale deployment of direct reduced iron production technology using hydrogen as a reducing agent will lead to a drop in metallurgical coal demand. Modern systems of taxonomy virtually block funding for new coal projects. The end of coal generation is close, but the exact date is still unclear.

Figure 3.14 IAMs projections of global coal production to 2100

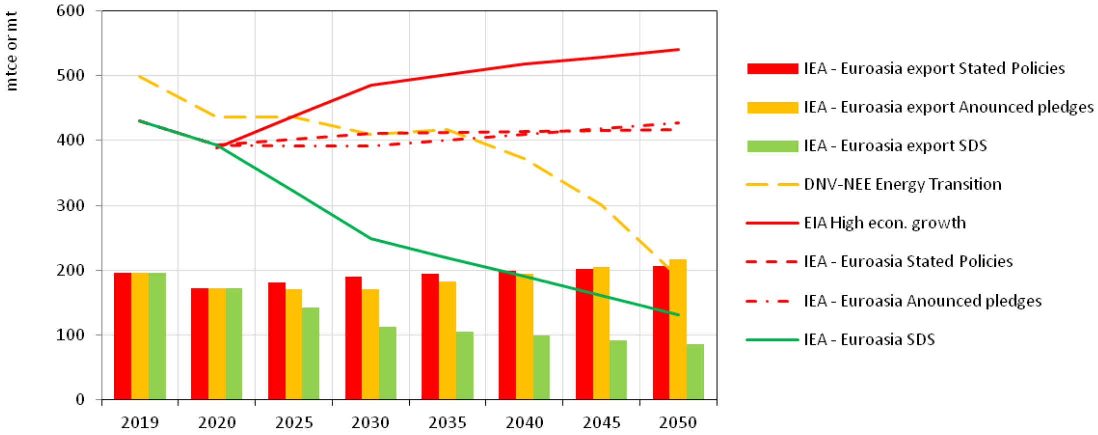


all scenarios   scenarios with warming below 2^{o}C to 2100

Sources: IAMC 1.5°C Scenario Explorer hosted by IIASA

Russia contributes 5% to the global coal supply. Nearly half of this amount is used domestically, the rest is exported. Domestic coal use has been shrinking since 2000, and the trend will persist for decades to come. In order to bring the growing coal production in line with the DOE’s expectations (Fig. 3.15) Russia would need to win new foreign coal markets. In the stated policies and announced pledges scenario, IEA projects Russian coal production nearly stable until 2050 and coal exports growing to about reach the 2019 level. So gaining new and losing current market niches is about balanced. But in the IEA SDS, the global export niche for Russian coal is halved by 2050 along with a reduction in domestic coal use leading to about 3-fold decline in coal production.

Figure 3.15 Projections of Russian* coal production and exports to 2050

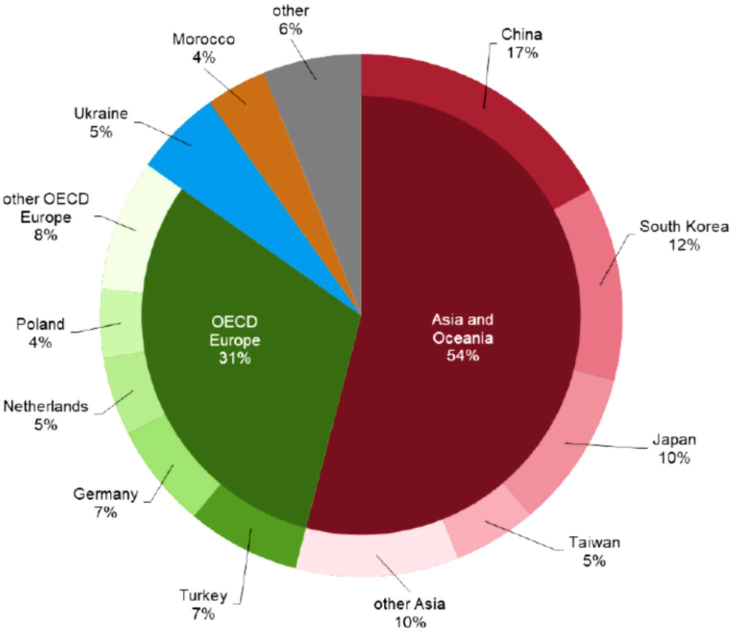


* Projections by DNV and IEA are provided for global subregions, which include Russia. IEA data are provided in mtce.

Sources: IEA. 2021. World Energy Outlook. 2021; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector; BP Energy Outlook 2050: September 2; DOE. 2021. International Energy Outlook 2021with projections to 2050. October 2021; DNV. 2021. Pathway to net zero emissions. Energy transition outlook 2021.

According to the RF Customs Service, in 2021 Russia exported 211 Mtons of coal worth \$US 17.6 billion (+41.7% to 2020) and imported 22 Mtons (worth \$US 0.4 billion). Coke and coal char exports in 2021 were 3.3 Mtons worth \$US 1.1 billion (2.2-fold growth from the 2020 level). In all, 2021 Russia’s net coal and coke exports were 192 Mtons worth \$US 18.3 billion. In 2020, over a third of Russian coal exports went to Europe (more than 20% to the EU) and about 23% to Japan and South Korea (Fig. 3.16). Altogether, nearly 60% of Russia's coal exports were to the OECD countries, which have strong low carbon reduction commitments and therefore not much potential to accommodate more of the Russian coal. In 2019-2021, EU imported 47-60 Mtons of coal and coke from Russia.[67]

Figure 3.16 Russia's coal exports by destination in 2020



Source: US EIA. Country Analysis Executive Summary: Russia. 2021.

Coal is not affected by the announced sanctions so far, but the EU's proposal to phase out the dependencies on Russian fossil fuels by 2027 covers coal as well. In 2021, EU imported over 55 Mt of Russian coal and coke, which was about 30% of Russian net coal exports and over 50% of the EU net coal imports. Back in 2019, the latter were responsible for 44% of total EU coal use. So Russia supplied nearly a quarter of the coal used in the EU. If sanctions are expanded to cover Russian coal exports, a large market niche in the global coal trade may be lost in the medium-term. There is a potential to offset some of the loss by redirecting coal flows eastbound, but logistical bottlenecks (substantially exacerbated by the overcrowded transport infrastructure where coal competes with other goods finding their way to the Asian markets) set limits, and a lot of time and investment will be needed to untap these options. This pushes Russian coal exports closer to the pathways described in the IEA SDS or NZE scenarios (Fig. 3.15) and away from those outlined in the stated policies and announced pledges scenarios. Some decline in coal exports from Russia will be more than outweighed with high coal prices which were ranging between 150 and 420 $US/t in July 2021-March 2022 versus 50-120 $US/t in 2016-2020.[68]

The conclusions for coal are as follows:

- Moderate progress towards global decarbonization and lack of sanctions on coal may keep Russian coal production and exports close to the current levels with a very low chance to grow;
- A substantial progress in global decarbonization and taking action to cease coal imports from Russia by 2027 will halve Russian coal exports by 2035 and further reduce them beyond that point with a subsequent decline in coal production, as domestic coal use in Russia will be down as well.

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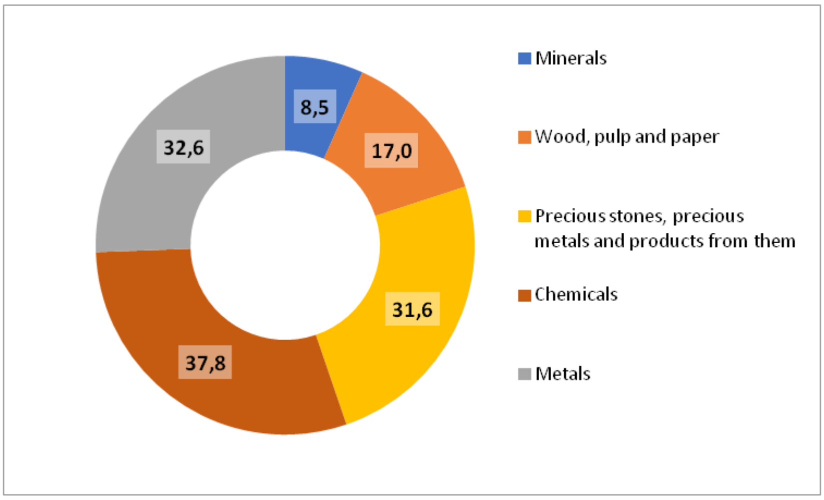
[67] European Union Imports of estimate of low valued import transactions from Russia - 2022 Data 2023 Forecast 2000-2020 Historical (tradingeconomics.com)

[68] Coal - 2022 Data - 2008-2021 Historical - 2023 Forecast - Price - Quote - Chart (tradingeconomics.com)

3.1.4 Basic materials and low carbon goods

Export of basic materials, precious stones, precious metals and relevant products provided 30% of Russian exports of goods, or $US 146 billion in 2021 (Fig. 3.17). With precious stones and metals excluded, the exports come down to $US 114 billion, or 23% of total export. The key items listed in Table 3.1 generated $US 63 billion in 2021, or 13% of total export. A substantial dependence on the exports of basic materials makes it essential to understand, how the global markets and also regional markets that are important for Russia may evolve in the near and distant future.

Figure 3.17 **Russia's exports of key basic materials, precious stones and metals in 2021**



Source: RF Customs Service (customs.gov.ru)

Service-accumulated stock-material flow-environment impacts chain models are increasingly being used to project basic materials demand.[69] Services (such as housing, mobility, healthcare, leisure) and economic activities require infrastructure, buildings, equipment, and durables, which are essentially accumulated as physical capital. The stock of materials is embodied in this capital. This in-use stock is annually replenished with new objects in which materials are embodied (materials for stock formation), and decreases by the amount of materials embodied in objects whose service life is expired. Some of the materials that have served their first term are recycled and reused, and some are landfilled. The concept of social metabolism and the analysis of material and energy flows (material flow analysis - MFA, material and energy flow analysis - MEFA, Material Inputs, Stocks and Outputs, MISO-model) allows it to see how demand for basic materials evolves as economy develops. The relationship between the dynamics of the accumulated stock of material and its annual consumption is anything but trivial. It depends on the stage of economic development and has certain turning points. In the first stage, both the stock of material and the current materials per capita consumption are growing dynamically, while in the fifth stage, both these indicators are declining. The transition from one stage to another depends on the achieved level of economic development. Therefore, it is erroneous to mechanically extrapolate the past trends.

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[69] Bashmakov I.A. GHG emissions from global iron and steel: past, present, and future // Iron and Steel. Scientific, technical, and economic bulletin. 2021. Vol. 77. No. 8. Pp. 882-901; Bleischwitz, R., V. Nechifor, M. Winning, B. Huang, and Y. Geng, 2018: Extrapolation or saturation – Revisiting growth patterns, development stages and decoupling. *Glob. Environ. Chang.*, 48, 86–96, https://doi.org/10.1016/J.GLOENVCHA.2017.11.008; Cao, Z., L. Shen, A. N. Løvik, D. B. Müller, and G. Liu, 2017: Elaborating the History of Our Cementing Societies: An in-Use Stock Perspective. *Environ. Sci. Technol.*, 51(19), 11468–11475, doi:10.1021/acs.est.7b03077.

Table 3.1 Key items of Russia’s basic materials exports in 2021

Products	Volume	USD 1000	USD/volume
NATURAL CALCIUM PHOSPHATES, NATURAL ALUMINIUM CALCIUM PHOSPHATES, AND NATURAL AND PHOSPHATIC CHALK	2 039	287 300	141
IRON ORES AND CONCENTRATES, INCLUDING ROASTED IRON PYRITES	25 296	3 796 000	150
Ores and minerals		4 083 300	
ANHYDROUS AMMONIA	4 418	1 668 300	378
METHANOL (METHYL ALCOHOL)	1 894	633 200	334
MINERAL OR CHEMICAL FERTILIZERS, CONTAINING NITROGEN	14 458	4 468 600	309
MINERAL OR CHEMICAL FERTILIZERS, CONTAINING POTASSIUM	11 904	3 321 100	279
MINERAL OR CHEMICAL FERTILIZERS, CONTAINING TWO OR THREE FERTILIZING ELEMENTS	11 201	4 708 600	420
SYNTHETIC RUBBER	1 094	1 897 000	1 734
Chemical products		16 696 800	
WOOD IN THE ROUGH	13 888	1 025 200	74
WOOD SAWN OR CHIPPED LENGTHWISE	17 310	6 143 700	355
PLYWOOD, VENEERED PANELS AND SIMILAR LAMINATED WOOD	3 043	1 937 900	637
PULP OF WOOD	2 042	1 312 300	643
NEWSPRINT IN ROLLS OR SHEETS	922	405 400	440
Wood, pulp and paper		10 824 500	
PIG IRON AND SPIEGELEISEN IN PIGS, BLOCKS OR OTHER PRIMARY FORMS	3 933	1 992 800	507
FERRO-ALLOYS	896	1 476 200	1 648
SEMI-FINISHED PRODUCTS OF IRON OR NON-ALLOY STEEL	14 979	9 176 400	613
FLAT-ROLLED PRODUCTS OF IRON OR NON-ALLOY STEEL	8 502	7 358 000	865
REFINED COPPER AND COPPER ALLOYS	463	3 848 200	8 311
NICKLE, UNWROUGHT	45	795 800	17 529
ALUMINIUM, UNWROUGHT	3 481	7 077 800	2 033
Metals		31 725 200	
Total basic materials		63 329 800	
Total		493 344 300	

Source: The RF Customs Service (customs.gov.ru)

Steel. Empirical data show that when GDP per capita reaches 10-12 thousand dollars, steel consumption per capita saturates at 300-700 kg/capita; however, the accumulated stock of ferrous metals continues to grow. It reaches the saturation level when GDP per capita is in the range of $US 16-20 thousand. The stock per capita reaches the saturation level 30 or 40 years after the peak in per capita consumption. In the developed countries, the accumulated stock of ferrous metals per capita is 10-16 t/person, while in sub-Saharan Africa it is only 0.5 t/person. The global indicator is not expected to reach a saturation level of about 10 t/person before 2100. This means that the world is on a trajectory close to the one travelled by the UK after 1800, but with an almost 100 years shift. Since the early 1980s, the accumulated stock of ferrous metals in the UK has saturated in absolute terms, and the gross additions in the accumulated stock have become equal to its physical retirement. On a per capita basis, it first stabilized and then dropped to a level slightly above 10 t/person. The UK has entered a decoupling stage: the economic growth continues, but no longer requires an increase in the consumption of ferrous metals.[70]

With a mechanical transfer of the UK trajectory, transition to the stage of decoupling and stock saturation for the world may be expected at a level of about 100 Gt of steel with a complete decoupling of economic growth and steel consumption around 2075. With a 2% annual stock replacement rate (by analogy with the UK in 2017), the annual consumption of ferrous metals may stabilize at around 2-2.2 Gt, and production at around 2.3-2.5 Gt. However, the deployment of material-saving technologies and the accelerated replacement of steel with other materials can reshape this trajectory and reduce both the level of saturation (by 2050 at 47–63 Gt) and the time required to achieve it. With the growth of the accumulated stock of ferrous metals, the volume of amortization scrap will increase (up to 950 million tons per year by 2050) and the share of steel produced from scrap may reach 40-45%. By 2075-2100, the volume of scrap will grow up to 2 Gt and the demand for primary metal will markedly shrink.

This logic fits very well with the recent long-term steel demand projections. Until 2050, steel production will be growing just slightly faster than the population. According to the logic of the historically observed cycles, in the next 30 years, a downward phase of steel consumption per unit of GDP should manifest, that is, the increase in the stock of steel and steel consumption should lag behind the GDP growth. According to the IEA's stated policy scenario, steel production will grow up from 1.9 Gt in 2019 to 2.5 Gt in 2050, or by 33%, and final consumption will increase from 1.5 to 2.1 Gt, or by 40%, which is noticeably slower than the global GDP, which is expected to grow 2.5-fold by 2050. It is assumed that GDP elasticity of steel demand will be as low as 0.36, and of steel production 0.33, versus almost 1 in 1900-2020. This is a reflection of both the downward phase in the long cycle of the dynamics of specific steel consumption per GDP, and of the transition to the stage of steel stock saturation in the increasing number of countries, as their level of economic development grows.

In its 2021 publication *Net Zero by 2050. A Roadmap for the Global Energy Sector*, the IEA reduces the 2050 forecasted steel demand for 2050 to 1987 Mt through measures to reduce material intensity.[71] In the developed countries, production will stabilize at the 2030 level until 2050, while in developing countries it will continue to grow, yet very slowly. As a result, in this projection global steel production in 2030-2050 is only 50 Mt up. In *Energy technology perspectives 2020*,[72] IEA shows that by reducing the material intensity steel demand may decline by 0.8 Gt, or by 29%, by 2070. In its 2019 publication *Material efficiency in clean energy transitions*, IEA also shows that by 2050 steel consumption (excluding waste from steel mills) even in the baseline scenario (*Reference Technology Scenario*) is only 2,170 Mt, or by 21%, up from 2019 (1790 Mt) via measures to reduce material intensity. In the other two scenarios (*Clean Technology* and *Material Efficiency*), steel consumption drops to 1,600 and 1,400 Mt, respectively.

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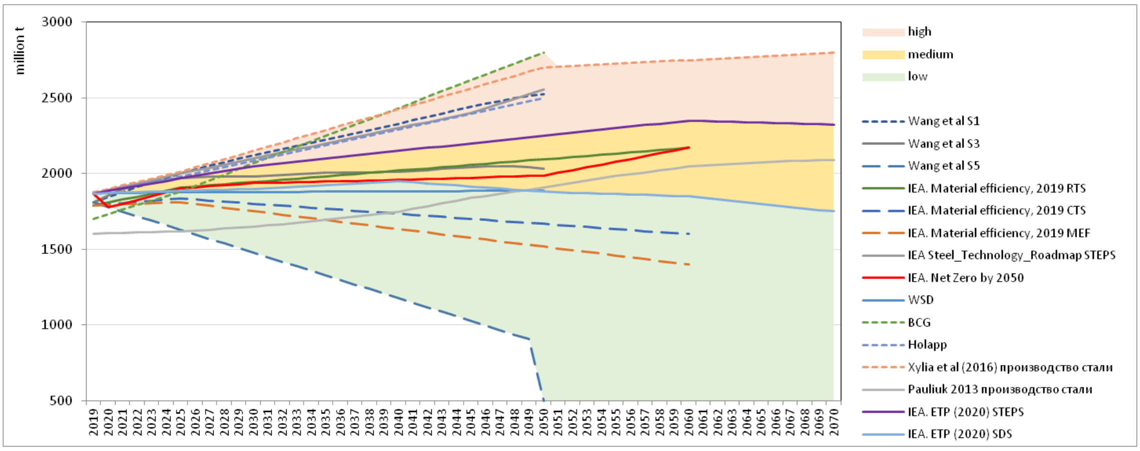
[70] Streeck, J., D. Wiedenhofer, F. Krausmann, H., Helmut (2020): Stock-flow relations in the socio-economic metabolism of the United Kingdom 1800-2017. Resources, Conservation & Recycling. https://doi.org/10.1016/j.resconrec.2020.104960.

[71] IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector.

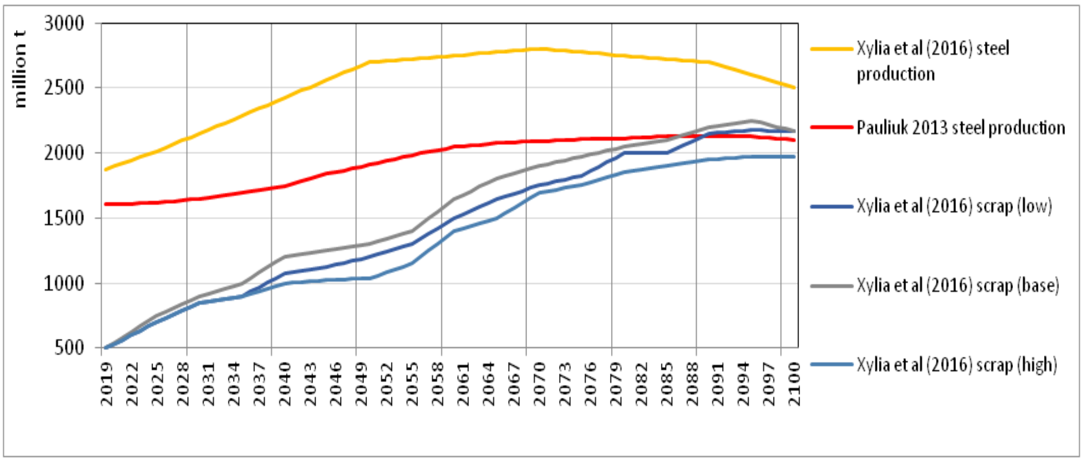
[72] IEA. Energy technology perspectives. 2020.

Gielen et al. (2020)[73] give the following estimates for 2050: crude steel production 2,400 Mt, finished steel 2,200 Mt, and steel products 2,064 Mt. Wang et al[74] considered 5 scenarios, of which only 3 differ in steel production volumes: inertial scenario S1 with a demand trend close to the IEA STEPS scenario; scenario S3 with improved material efficiency in line with the IEA's "*sustainable development*" scenario; and scenario S5, which estimates the effects of an additional 34% reduction in demand compared to the IEA's *"sustainable development"* scenario. This paper provides cumulative data for steel production. Based on these data, annual data were obtained. In terms of steel production, by 2050 three scenarios reach the levels of 2526 Mt, 2032 Mt and 500 Mt, respectively. The last estimate is the lowest of all.

Figure 3.18 Long-term forecasts of global steel production



(a) projections to 2050-2070



(b) projections to 2100

Source: Bashmakov I.A. GHG emissions from global iron and steel: past, present, and future // Iron and Steel. Scientific, technical, and economic bulletin. 2021. Vol. 77. No. 8. Pp. 882-901. DOI: 10.32339/0135-5910-2021-8-882-901.

OECD[75] indicates that by 2060 steel production may increase by 35-60% from the 2017 level to reach 2,344 – 2,878 Mt. In the BCG[76] forecast, steel production grows up to 2.8 Gt by 2050. At the same time, the amount of scrap metal grows to 1.4-1.6 Gt. Thus, the production of secondary

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[73] Gielen D., D. Saygin, E. Taibi, J-P. Birat. Renewables-based decarbonization and relocation of iron and steel making. A case study. March 2020. Journal of Industrial Ecology 24(5). DOI:10.1111/jiec.12997.

[74] Wang P., M. Ryberg, Y. Yang, K. Feng, S. Kara, M. Hauschild and W-Q. Chen. Efficiency stagnation in global steel production urges joint supply- and demand-side mitigation efforts. Nature Communications. (2021). https://doi.org/10.1038/s41467-021-22245-6 www.nature.com/naturecommunications.

[75] OECD, 2019: Global Material Resources Outlook to 2060. OECD, 210 pp.

[76] Haslehner R., Stelter B., and N. Osio. Steel as a Model for a Sustainable Metal Industry in 2050. Boston Consulting Group. October 07, 2015. Steel as a Model for a Sustainable Metal Industry in 2050 (bcg.com)

metal by or before the middle of the century can be equal to the production of primary metal or even exceed it. According to this forecast, pig iron and coking coal demand may stay at the 2015 level or increase by 650 and 350 Mt, respectively, by 2050. Based on the analysis of various publications, Holapp[77] considers three scenarios, and in the highest steel production reaches almost 3 Gt by 2050. Xilia et al.[78] expect steel production up to 2100. According to this forecast, production will peak at 2.8 Gt by 2070, and then will slowly decline by 2100, as the share of secondary metal increases markedly due to the availability of scrap (around 2 Gt) beyond 2075.

If we focus on the middle zone of the forecasts, we will see that there will be either a stagnation in demand for steel (4% growth by 2040 and getting back to 2019 level by 2060), or moderate growth by about 25%. If Russian ferrous metals suppliers succeed in maintaining their 2021 global market share, export volumes may evolve in the same way. About 25% of the Russian iron and steel exports go to the EU market. Steel consumption and production in the EU will be slowly growing or stay at the 2019 level until 2050, thus keeping the niche for exporters at about the current level with options for both a slight increase and a slight decrease. If CBAM helps increase the supply of European steel to the EU markets, the effect will be partially offset by the loss of foreign markets due to the fact that after CBAM is introduced, the EU steel will become more costly to produce bringing the exports down.[79]

The EU sanction package banned the imports of some ferrous products from Russia. According to some estimates,[80] it may apply to 40% of Russian steel exports to the EU (5-7 Mt in 2018-2021) with potential losses of $US 3.4 billion (40% of $US 8.6 billion earned in 2021). Total steel exports in 2021 were nearly 28 Mt. Therefore, the Russian exports may be expected to lose some 9%. It is less than 1% of globally traded steel and steel products (382-467 Mt in 2016-2020).[81] When the logistical problems are ultimately resolved, this loss may be partly compensated by redirecting Russian steel to other destinations with some discount. Such discounts are possible, since export prices for plate rolled steel were over 1,400 $US/t in March 2022 (average 2021 price for Russian steel exports was 865 $US/t). With a correction on the effects of partial embargo on Russian steel there is not much room to expand iron and steel exports above the 2021 level. The same goes for the exports of iron ores and concentrates which were 25.2 Mt in 2021 and yielded $US 3.8 billion in export revenues.

Aluminium. According to the IAI baseline forecast, the global production of primary aluminum will grow to 86.4 Mt, and of secondary aluminum up to 88 Mt by 2050 (Fig. 3.19). In other words, production of secondary aluminum will account for more than a half of total aluminum production by 2050. In the IAI high consumption scenario, production grows 2.6-fold to 167.4 Mt by 2050. This is the highest forecast. Secondary aluminum production in this scenario grows to 116 Mt. In the *1.5^{o}C* scenario, primary aluminum production grows only to 68 Mt, and secondary aluminum production to 78 Mt. The accumulated aluminum stock embodied in physical capital grows to 2.8 bln t by 2050, and in high scenario up to 3.7 bln t, which lays the basis for secondary aluminum production growth.

Russia’s 2020 aluminum exports were 3.6 Mt ($US 7.6 billion) and 2021 exports were 3.5 Mt ($US 7.1 billion), or about 5% of global supply. In 2019-2020, nearly 1 Mt, or about 25% of

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[77] Holapp L. A General Vision for Reduction of Energy Consumption and CO2 Emissions from the Steel Industry Metals 2020, 10, 1117; doi:10.3390/met10091117.

[78] Xylia M., S. Silveira, J. Duerinck and F. Meinke-Hubeny. 2016. Worldwide resource efficient steel production. In SUSTAINABLE PRODUCTION DESIGN AND SUPPLY CHAIN INITIATIVES. INDUSTRIAL EFFICIENCY 2016. Worldwide resource efficient steel production (eceee.org).

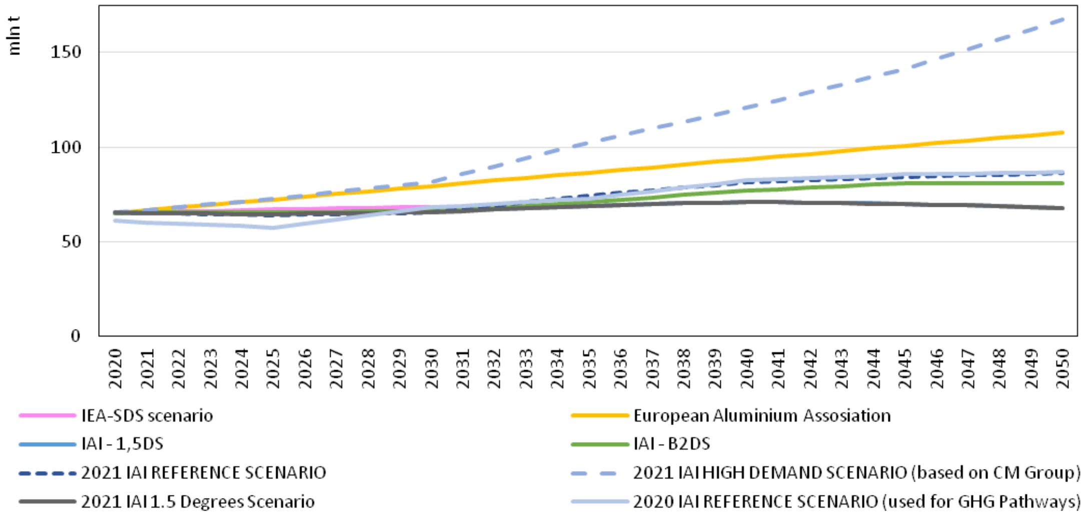
[79] CENEf-XXI (2021). CBAM. Implications for the Russian Economy. Moscow. Center for Energy Efficiency. (In Russian).]; Bashmakov I.A. CBAM and Russian export. Voprosy Ekonomiki. 2022;(1):90-109. (In Russ.) https://doi.org/10.32609/0042-8736-2022-1-90-109

[80] Russian steelmakers versus western sanctions – Post mortem - Finam (finam.ru)

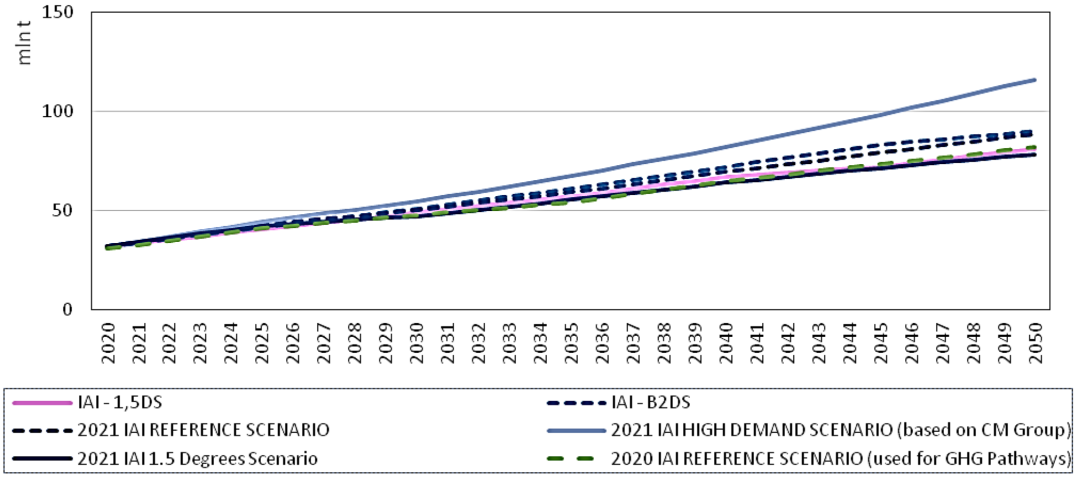
[81] World Steel Association, 2021: *World Steel in Figures 2021*. 32 pp. https://www.worldsteel.org/en/dam/jcr:976723ed-74b3-47b4-92f6-81b6a452b86e/World%2520Steel%2520in%2520Figures%25202021.pdf.

produced aluminum, was exported to EU. In 2021, it was reported to reach 1.6 Mt.[82] If these data are correct, EU is responsible for 46% of Russia's overall primary aluminum exports in 2021, being the dominant market one for the Russian aluminum.

Figure 3.19 Global aluminum production perspectives to 2050



(a) primary aluminum



(b) secondary aluminum

Sources: International Aluminium Institute, 2021: *Aluminium Sector Greenhouse Gas Pathways to 2050*, London, UK, 20 pp.; International Aluminum Institute, 2021: International aluminium institute statistics. https://alucycle.international-aluminium.org/public-access/ (Accessed: December 21, 2020).

The European Aluminum Association in its *Vision 2050* considered three possible scenarios for the development of the aluminium market in Europe. In the *Decreasing production case*, 35% of the demand will be met by imports. In the *Positive case scenario*, it is assumed that the indirect costs of rising electricity prices under the ETS will be fully compensated by 2030, and primary aluminium production in Europe may increase by 30%, which will limit the imports.

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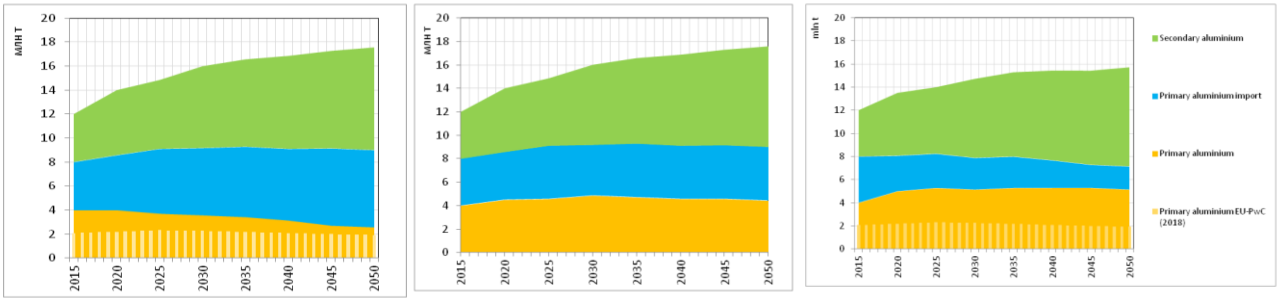
[82] Rolling stop – "Kommersant", No. 43 (7244), 15 March, 2022 (kommersant.ru)

Figure 3.20 **Projections of aluminum production and imports in EU and EAST to 2050**



Decreasing production case Base case Positive case

Source: The Vision 2050. EUROPEAN ALUMINIUM'S CONTRIBUTION TO THE EU'S MID-CENTURY LOW-CARBON ROADMAP. A vision for strategic, low carbon and competitive aluminium. EXECUTIVE SUMMARY. European Aluminium. March 2019.

Australia banned all alumina and bauxite exports to Russia (1.5 Mt, or 19% of UC Rusal's alumina consumption). In addition, production by Nikolaev Alumina Refinery (1.8 Mt of alumina per year, or another 20% of UC Rusal's alumina consumption) halted. In 2021, UC Rusal produced 3.8 Mt of aluminum and 8.3 Mt of alumina. It takes 4 t of alumina to produce 1 t of aluminum. So, the 3.3 alumina shortage brings aluminium production down by 22%, unless the supply shortage is compensated by export from China or other countries when the logistics are in place.

According to the above estimates, until 2050 aluminium consumption will continue to grow, both globally and in the EU. However, additional demand will be partly met by an increase in secondary aluminium production. EU imports in 2060 may stay in the range between 2 and 6 Mt, especially if power prices in the EU stay high for a long time. After the sanctions-based decline in 2022 and subsequent years (depending on how long the sanctions are in place) Russia may re-establish and even expand its aluminium exports by 2050.

Other metals. In 2018-2021, Russian exports of copper were down from 0.7 to 0.46 Mt, or from $US 4.1 to 3.9 billion. According to IEA, global copper demand may more than double in 2020-2060.[83] In 2018-2021, Russian exports of nickel was down from 134 to 46 thousand tons, or from $US 1.8 to 0.8 billion. According to OECD, global nickel demand may triple and reach 2 Mt by 2060.[84] The global decarbonisation process expands markets for both Russian copper and nickel exports.

Wood, wood products, pulp and paper. This group of Russian exports yielded $US 17 billion in revenues in 2021, including about $US 3 billion from pulp and paper. In 1970-2019, global timber production lagged behind GDP showing annual growth of less than 1% and reached 2,184 million m^3. This growth pattern (lagging behind GDP) is expected to persist in all FAO scenarios with projected 10-35% growth in global timber demand in 2019-2050.[85] The leading producers of roundwood are the USA (19%), Russia (10%), China (9%), Canada and Brazil (7% each).[86]

By 2030, global pulp production is expected to slowly decline, while paper production will be declining much faster driven by a deeper penetration of Internet. This may be partially compensated by the growing demand for paperboard for packaging uses, as plastics packaging will be scaling down.[87] According to another projection, global pulp, paper, and paperboard

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[83] IEA, 2020: Energy Technology Perspective 2020.

[84] OECD, 2019: Global Material Resources Outlook to 2060. OECD, 210 pp.

[85] Forestry-Food and Agriculture Organization of the United Nations. http://www.fao.org/3/X8423E/X8423E14.htm

[86] IRP, 2020: Global Material Flows Database. https://www.resourcepanel.org/global-material-flows-database (Accessed December 20, 2020).

[87] Craig M.T. Johnston (2016), Global paper market forecasts to 2030 under future internet demand scenarios, Journal of Forest Economics: Vol. 25: No. 1, pp 14-28. http://dx.doi.org/10.1016/j.jfe.2016.07.003

production will increase from 423 to 498 Mt in 2020-2050.[88] As a result, these articles of Russian traditional exports are not expected to significantly expand.

Chemicals. In 2021, Russia exported $US 38 billion worth of chemicals. Much of that – 42 Mt and $US 14 billion – are ammonia and fertilizers. 9 Mt of these were exported to EU in 2019. Consumption of nitrogen, phosphate and potassium fertilizers in EU is projected to remain close to the current level in 2050.[89] The general consensus is that global agricultural production will have to increase by about 60-70% from the current levels to meet the growing food demand by 2050.[90] This would drive the global demand for fertilizers up. For phosphate fertilizers, global demand is expected to be 43% up in 2020-2050.[91] For nitrogen fertilizers, the demand in medium scenarios may grow by a third.[92] The market for ammonia used as fuels and feedstock may expand rapidly from 172 to 440 Mt in 2017-2050 in BAU scenarios. In their *1.5°C scenario,* Saygin and Gielen (2021) expect ammonia production from fossil feedstock to drop to 106 Mt by 2050. But the demand for green ammonia may expand to 330 Mt and for ammonia from biomass to 162 Mt by 2050.[93] Russian ammonia exports may expand in the medium term, but then they will only be possible if green or biomass-based ammonia production is launched at scales.

Russia is responsible for 5% of the global methanol production (4.5 Mt, of which half was exported, including 1.9 Mt to EU). This global market (presently 86 Mt) is showing a fast growth, which is expected to continue to 2050 in BAU scenarios (174 Mt) to provide feedstock for fuels, ethylene (methanol-to-olefins), solvents and other products. However, in low carbon scenarios fossil fuels-based methanol production is down to 50 Mt by 2050, while green hydrogen-based methanol production skyrockets to 294 Mt.[94] Unless EU expands sanctions on methanol imports from Russia, fossil fuels-based methanol exports may somewhat grow, yet a substantial market expansion is only possible for bio-based and green methanol.

Plastics are another promising market to expand the non-oil&gas Russian exports. Plastics exports from Russia reached 2.4 Mt in 2020. According to the available projections, global plastics production is expected to more than double rising from about 400 Mt in 2019 to 985-1034 Mt in 2050.[95] Even in BAU scenarios, 106 Mt are expected to be produced from recycled plastics and 6 Mt from bio-plastics by 2050. In low-carbon scenarios, plastics production shows a more modest growth – to 450-659 Mt. Projected growth is 28-40% in 2019-2050 with a production peak in 2050 and subsequent 10% decline from that peak by 2060.[96] In *1.5°C scenario,* fuel-based plastics production will be down to 276 Mt by 2050, while hydrogen-based production will reach 154 Mt, and bio-based production – 18 Mt. The accumulated plastics stock

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[88] Dietz S., W. Irwin, B. Rauis, V. Jahn, J. Noels, V. Komar and R. Goo. Carbon Performance Assessment of Paper Producers: Note on Methodology Transition Pathway Initiative. February 2021 78.pdf (transitionpathwayinitiative.org)

[89] CENEf-XXI. 2021. CBAM: Implications for the Russian economy. Moscow: Center for Energy Efficiency CENEF-XXI.

[90] https://www.canr.msu.edu/news/feeding-the-world-in-2050-and-beyond-part-1

[91] Nedelciu C.E., K.V. Ragnarsdottir, P. Schlyter, I. Stjernquis. 2020. Global phosphorus supply chain dynamics: Assessing regional impact to 2050. Global Food Security 26 (2020). https://doi.org/10.1016/j.gfs.2020.100426

[92] Mogollón J.M. et al 2018 Environ. Res. Lett. 13 044008

[93] Saygin, D., and D. Gielen, 2021: Zero-emission pathway for the global chemical and petrochemical sector. *Energies*, 14(13), 3772, doi:10.3390/en14133772.

[94] Ibid.

[95] Ibid.

[96] Plastics future: How to reduce the increasing environmental footprint of plastic packaging. Article, January 2021; https://www.climateforesight.eu/global-policy/the-future-of-plastics-is-uncertain/; The Future of Petrochemicals, IEA, Technological report, 2018; Estimation of carbon dioxide reduction by utilization biomass bioplastic in Malaysia using carbon emission pinch analysis (CEPA), Research Paper, 2020; MDPI, Zero-Emissions Pathway for the Global Chemical and Petrochemical Sector, Deger Saygin and Dolf Gielen; https://www.iea.org/t_c/termsandconditions/.

has reached 2.5-3.2 Gt,[97] therefore, the recycling potential is substantial. Virgin plastics production by all routes will be 307 Mt, which is below the current level, while recycled plastics production will reach 279 Mt.[98] In other words, the market for traditional unabated fossil-based plastics will be declining, as low carbon transition gains momentum. In the IEA's *Sustainable Development Scenario*, as soon as in 2050 half of fossil fuel-based chemical production facilities will be equipped with CCUS systems.[99] Summing up, there is a potential for traditional chemicals export growth by 2030. Later, as the global economy turns towards low carbon pathways, markets for unabated fossil fuel-based chemicals will be shrinking, while those for low carbon chemicals will be markedly expanding.

Hydrogen. The *Concept of hydrogen energy development in the Russian Federation* was approved by the RF Government Decree No. 2162-r of August 5, 2021. Its key parameters are as follows:

- the use of low or no carbon hydrogen to support transition to low carbon economy;
- diverse sources for hydrogen production, including fossil fuels with CCS; steam reforming of natural gas; pyrolysis of hydrocarbon raw materials (hydrogen production technology with simultaneous production of elemental carbon); nuclear power and water electrolysis;
- reducing the costs of hydrogen production to less than 2 USD/kg;
- until 2035, priority for the production of hydrogen from fossil fuels, nuclear, hydro and renewables in regions with low hydrogen production costs;
- attaining hydrogen export volumes of up to 0.2 million tons in 2024, 2-12 million tons in 2035, and 15-50 million tons in 2050.[100]

It is not clear, whether such exports targets are supported by system-wide estimates. To conduct such preliminary analysis, pilot calculations based on the integration of hydrogen into the CENEf-XXI's ENERGYBAL-GEM-2050 model have been made relying on the following assumptions:

- Hydrogen exports will reach 15 Mt by 2050, and domestically, hydrogen will be used only for DRI production and by oil refineries, which in total will result in hydrogen production of 15,9 Mt in 2050;
- Four types of hydrogen will be produced: "green" (hydro and RE); "blue" (steam conversion of methane); "turquoise" (pyrolysis of hydrocarbon raw materials), and "yellow" using nuclear power;
- based on the literature sources, the initial and perspective technology parameters (specific energy consumption), CAPEXs and LCOHs for the above types of hydrogen were specified;
- It is assumed that different types of hydrogen will be competing based on LCOHs;
- It is further assumed that the share of installations for the production of "blue" hydrogen with CCS will grow up to 43% in 2035 and to 100% in 2050, and the efficiency of CO_2 capture and storage will be 95%.

Calculations were made for two options of the hydrogen production structure. With a limited availability of carbon-free power, substantial electrification of hydrogen production will lead to a

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[97] Geyer, R., J. R. Jambeck, and K. L. Law, 2017: Production, use, and fate of all plastics ever made. *Sci. Adv.*, **3**(7), doi:10.1126/sciadv.1700782; Saygin, D., and D. Gielen, 2021: Zero-emission pathway for the global chemical and petrochemical sector. *Energies*, 14(13), 3772, doi:10.3390/en14133772.

[98] Saygin, D., and D. Gielen, 2021: Zero-emission pathway for the global chemical and petrochemical sector. *Energies*, 14(13), 3772, doi:10.3390/en14133772.

[99] IEA, 2020a: Energy Technology Perspective 2020. Paris, 397 pp.

[100] In Operation plan for the implementation of the Low Carbon Development Strategy of the Russian Federation Russia sets the goal to contribute 20% to the global hydrogen trade by 2030.

significant increase in GHG emissions. If generation of carbon-free power is limited, more gas (55 bcm by 2050) will be required to fuel additional power production to meet the growing electricity demand, including that from installations that will not be equipped with CCS by 2050. The additional electricity demand in the “green” and “yellow” option will be 380 billion kWh by 2050, and additional heat demand will be 26 million Gcal. Additional electric capacity demand will exceed 75 GW (47% of the 2021 peak load), including 45 GW for renewable energy. Such manoeuvre makes sense only if large resources of cheap carbon-free power generation are available in addition to those already mobilized in the carbon neutrality scenario. If only “green” hydrogen is produced, the power demand will scale up to 608 billion kWh by 2050 and to 937 billion kWh by 2060. The latter value is only 18% below Russia’s 2021 total power generation. These effects multiply several times over, when trying to reach the upper levels of hydrogen exports required by the *Concept of hydrogen energy development in the Russian Federation* – 12 Mt in 2035 and 50 Mt in 2050.

With 3-4 $US/kg hydrogen price, the exports of 15 Mt of hydrogen will yield $US 45-60 billion in revenues by 2060, or as much as natural gas in 2021 ($US 55 billion), which is 5% of total export revenues in 2050. According to CENEf-XXI, the amount of CO_2 captured in the production of hydrogen from natural gas will reach 104 Mt.[101] With the costs of $40-60/t$CO_2$, annual costs of CCS will be $US 4-6 billion. Therefore, the hydrogen market is a promising option, but only for low or zero carbon hydrogen. Preliminary analysis shows, that scaling up hydrogen exports to 50 Mt may be quite challenging, as it would require a huge additional low carbon power capacity the additional networks development.

Other low carbon exports. Low carbon technologies will form new, trillions of dollars-worth markets by mid-century. Annual 2050 market for green buildings will be $US 10-17 trillion, for low GHG cars it will be $US 4-8 trillion, for hydrogen $US 2.5 trillion, for renewables and energy efficiency $US 1 trillion each.[102] This can be compared with $US 6.2 trillion 2019 global market for petroleum products. The technology race for dominance in these emerging markets is already at full swing. For Russia, integration into global technological supply chains is a potential new powerful driver for economic growth. Russia has experience in applying practically all of the low-carbon technologies, but at very modest scales.[103] It is one of the leading nations in the nuclear energy, the use of district heating, and the use of off-road transport in the structure of cargo transportation. However, the additional export potential of these groups of technologies is limited, and other markets need to be explored. Digitalization in all sectors requires a large number of IT experts. After February 24th, thousands of Russian IT experts left the country. Many supply chains were broken. This has undermined Russia’s ability to effectively bridge the already large gap with technology leaders and significantly scales down and delays its ability to penetrate these new markets. Machinery exports in 2021 yielded only 6.5% of the total export revenues.Only part of it was high-tech export. This high-tech export was 30-40 times below that of China and 20-25 times below that of the EU.[104]

Summing up, one can conclude that Russia’s non-fuel exports can be expected to go down in 2022 and in several subsequent years. After (if) some of the sanctions are lifted, new markets are found for traditional exports, and logistics is developed to supply these new markets, some of the lost exports may be partly or fully re-gained with time. In the longer term, traditional markets for highly carbon intense basic materials will be steadily shrinking.[105] Unless Russia manages to

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[101] Bashmakov I.A. Editor. Russia on the carbon neutrality pathway. 2021. CENEf-XXI.

[102] Bashmakov I.A., Bashmakov V.I., Borisov K.B., Dzedzichek M.G., Lunin A.A., Lebedev O.V., Drummond P., Carvalho P. (2020). Monitoring of low carbon technologies deployment in Russia. *Ekologicheskiy Vestnik Rossii*, No. 4, pp. 6–11. (In Russian).

[103] Ibid.

[104] Hi-tec products trade saw a substantial growth in the second half of 2020, which was to the benefit of the new Asian exporters (wipo.int).

[105] Russia’s losses on the 2050 timespan in the EU market from CBAM introduction were estimated to be in excess of 2 Mt for steel products and close to 1 Mt for fertilizers. CBAM. Implications for the Russian economy. https://cenef-xxi.ru/articles/issledovanie-cenef-xxi-%22cbam.-posledstviya-dlya-rossijskoj-ekonomiki%22

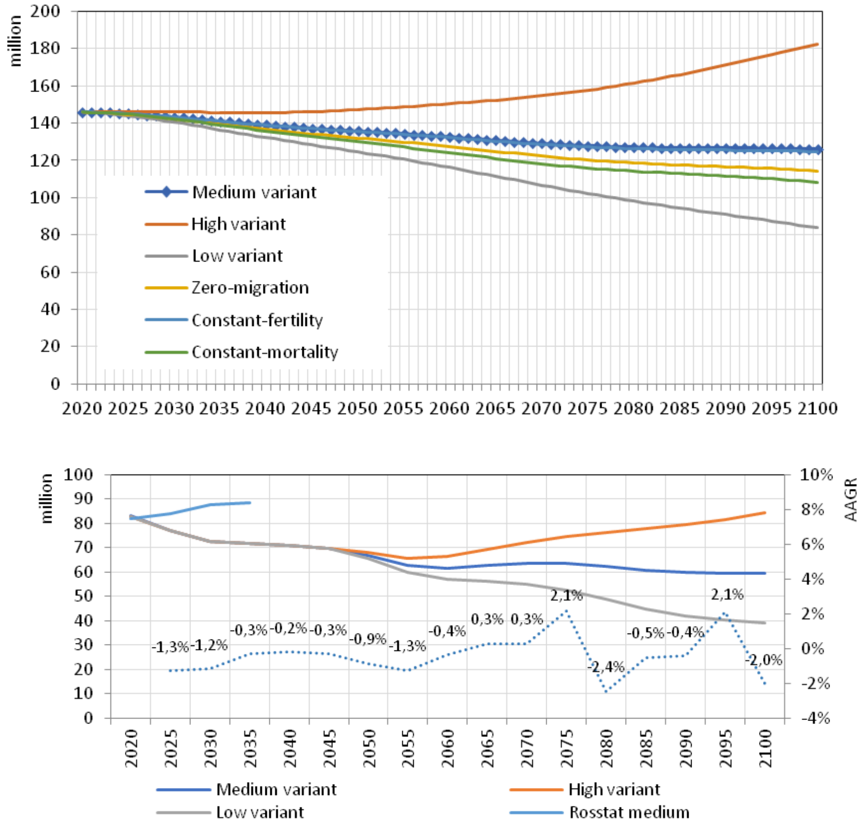
decarbonize its industrial production, these markets may be blocked for it. As to high-tech export expansion, Russia starts from a very low base, and after February 24th it lost a lot of innovators who could drive it up.

3.3 Economic growth

3.1.5 Demographic projections

The population and labour force projections are based on the medium option from the family of demographic projections developed by the UN (Figure 3.21). Those are pre-pandemic projections, which need to be revised downward by nearly a million to account for excessive COVID deaths (2020-March 2022). The medium projection trajectory practically coincides with the constant fertility scenario. The population is estimated at 141 million people in 2036 versus the 2020 medium projection by Rosstat of 143 million people.[106] Population aged between 25 and 65 was determined based on the UN dependence ratio forecast. For this characteristic, the medium option was also chosen. Rosstat reports working age population growth (working age is currently between 15 and the level expected to eventually shift to 65 by 2028) from 82 to 88 million people with subsequent stabilization in 2031-2036. This projection by Rosstat was not used, because participation rate at 60+ is relatively low, and the extension of working age will not add much to full-time employment, as even before the pension reform many people worked after they hit the retirement age.

Figure 3.21 UN demographic projections for Russia



Population of the Russian Federation (million)
2030
143
2060
133

Population aged between 25 and 64 (million)
2021
83
2030
71
2060
62

Source: United Nations. Population Division. Department of Economic and Social Affairs. World Population Prospects 2019. File POP/1-1: Total population (both sexes combined) by region, subregion and country, annually for 1950-2100 (thousands).

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[106] progn3a.xls (live.com)

The UN population projections show that:

- Russia's population will be declining slowly until around 2070 and stabilize thereafter;
- The undulating dynamics of the working-age population will lead to its noticeable reduction until 2030 in all scenarios, with a subsequent stabilization until 2045, followed by another wave of decline. Beyond 2060, the number will vary in the range between 60 and 70 million people.

Such dynamics of demographic indicators makes it much more difficult to sustain the economic growth, especially in 2022-2030 and 2045-2060. When the rates of working age population decline by 1% or more per year, even 2% per year improvement in labour productivity results in just 1% GDP growth. Therefore, demographic situation in the 2030s and 2050s will severely restrict potential growth rates.

3.1.6 Economic projections made before February 24th

Recent scenarios (developed before February 24th 2022) differ markedly regarding the "visions" of the Russian economic growth (Fig. 3.22). Estimates of GDP growth rates are down compared to a similar analysis conducted in 2014.[107] The uncertainty zone is split into three segments: "slow growth" – AAGR up to 1% until 2050; "moderate growth" – AAGR 1-2.5% in 2021-2030 and 1-2% in 2031-2050; "dynamic growth" – AAGR to exceed the upper boundary of the "moderate growth" range. CENEf-XXI estimated AAGR to be below or slightly above 2% in 2030 with some acceleration in the 2030s and a gradual decline in the 2040s. The most pessimistic estimates of AAGR – close to or below 1% – are provided by the IEA, US DOE and BP. These projections account for the negative demographic trend as discussed above.

The most optimistic GDP growth projections have been developed by the Institute of Economic Forecasting of the Russian Academy of Sciences (IEF). In their latest publication they estimate GDP AAGR in 2021-2050 at 1.9% for the 'inertial scenario', at about 3% per year for the 'modest decarbonization ambition' scenarios, at about 2.5% for two more "aggressive" ones, and at 1.8% for the most "aggressive" scenario.[108] So the overall logic is as follows: mitigation associated with some modernization accelerates growth, but higher ambition on the global scale slows it down as energy exports decline. Given the current demographic situation in Russia, slow labour productivity growth and multifactor productivity improvements, the assumption of AAGR acceleration to 3% can hardly be justified. Porfiriev et al.[109] argue, that Russia's fuel and energy sector (FES) has the potential to add up to 1 p.p. to the AAGR until 2035, and the loss of this contribution "will jeopardize the possibility of sustainable growth in the medium and long term". The last 15 years show that FES cannot spur the economic growth, whatever the oil price, and the dynamic global energy transition makes FEC totally unable to accelerate the economic growth in the future. The authors base their forecasts on the hypothesis that "with low economic growth… large-scale GHG reductions are unfeasible." In fact, there is inverse empirical evidence: the lower the economic growth rate, the more dynamic the GHG emission decline.[110]

The sensitivity of Russia's GDP dynamics to fluctuations in the global oil and gas markets is gradually decreasing. Oil and gas revenues growth gives a limited and temporal impulse for the economic growth. This growth pattern for Russia was reflected by the US DOE under the

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[107] Bashmakov I. Editor. Costs and benefits of low carbon transformation of economy and society in Russia. Perspectives to 2050 and beyond. CENEf. M. 2014.

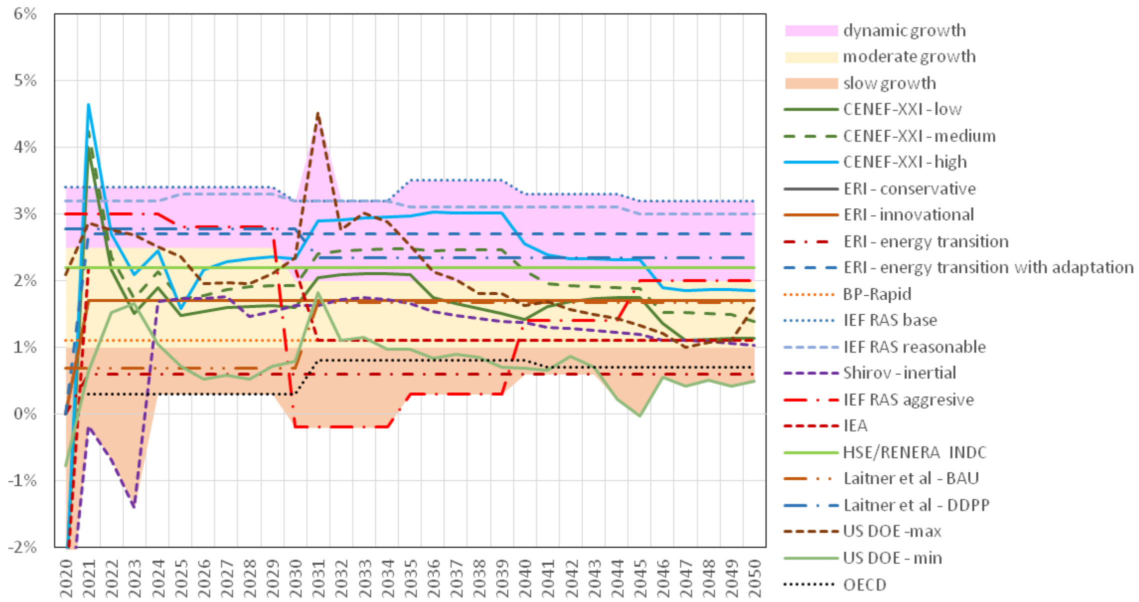
[108] Porfiriev B.N., Shirov A.A., Kolpakov A.Y., Edinak E.A. Opportunities and risks of the climate policy in Russia. Voprosy Ekonomiki. 2022;(1):72-89. (In Russ.) https://doi.org/10.32609/0042-8736-2022-1-72-89.

[109] Porfiriev B., Shirov A., Kolpakov A. Low carbon development strategy: perspectives for the Russian economy. Mirovaya energetika i mezhdunarodnye otnosheniya. 2020. Vol. 64, No. 9. Pp. 15-25, https://doi.org/10.20542/0131-2227-2020-64-9-15-25.

[110] For more detail see Bashmakov I. Low carbon development and economic growth. Neftegazovaya Vertikal. No. 19-20. 2021.

assumption of a significant surge in oil prices (up to 156 $US/bbl) in 2031 in the “high oil price” scenario.

Figure 3.22 Russia’s GDP projections to 2050



Sources: Bashmakov et al. (2021). Russia on the carbon neutrality pathway. CENEf-XXI; BP Energy Outlook. 2022 Edition; DOE. 2021; Energy Research Institute of the Russian Academy of Science and the Energy Center of Moscow management school SKOLKOVO. 2019. Global and Russian energy outlook 2019. Moscow; International Energy Outlook 2021with projections to 2050. October 2021; IEA, 2021. World Energy Outlook 2021; Laitner J., Lugovoy O., Potashnikov V. Costs and Benefits of Deep Decarbonization in Russia. Ekonomicheskaya Politika, 2020. No. 2, pp. 86-105. https://doi.org/10.18288/1994-5124-2020-2-86-105; Porfiriev B., Shirov A., Kolpakov A. Low carbon development strategy: perspectives for the Russian economy. Mirovaya energetika i mezhdunarodnye otnosheniya. 2020. Vol. 64, No. 9. Pp. 15-25, https://doi.org/10.20542/0131-2227-2020-64-9-15-25; Safonov G., V. Potashnikov, O. Lugovoy, M. Safonov, A. Dorina, A. Bolotov. 2020. The low carbon development options for Russia. Climatic Change. https://doi.org/10.1007/s10584-020-02780-9 Springer Nature B.V. 2020; Shirov A.A. Ustojchivoe razvitie, klimat i ehkonomicheskij rost: strategicheskie vyzovy i resheniya dlya Rossii. Prezentaciya na seminare “Strategiya dolgosrochnogo razvitiya Rossijskoj Federacii s nizkim urovnem vybrosov”. 23 marta 2021 g. [Shirov A.A. Sustainable development, climate, and economic growth: strategic challenges and solutions for Russia] https://cenef-xxi.ru; Shirov A. 2021. Presentation “The risks of the low carbon development policies for the Russian economy. The Institute of Economic Forecasting of the Russian Academy of Science. 2021.

Opportunities for hydrocarbon-led growth are nearly exhausted and undermined by the expected economic losses from declining hydrocarbon exports, which will be increasingly progressing, as the global low carbon transition gains momentum. Relying on the traditional resource-intensive model of the “red economy”[111] can only ensure very low GDP growth rates. Therefore, it is impractical to assume that GDP growth rates will accelerate in the Inertial or BAU-like scenarios. GDP growth can only accelerate through advancing to the fast-growing global markets for low-carbon goods and services that will dominate the global economy in the mid-21st century, and by significantly increasing the productivity of all resources (labour, capital, energy and materials), which is now on average twice lower in Russia, than in the developed countries. Therefore, in low-carbon scenarios, GDP growth rates cannot be lower than in the BAU or Reference scenarios.[112]

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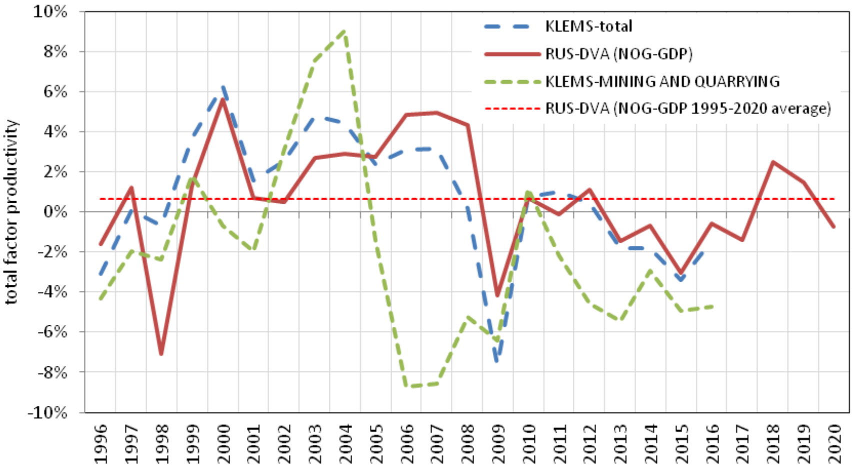
[111] Pollution and resources intensive economy.
[112] Ibid.

Russia's KLEMS project[113] provides TFP for the whole economy and by subsectors. In recent publications,[114] the TFP for the expanded mining sector (EMS, which includes mining, processing and refining, transportation and trade of fuels and minerals) was also provided. EMS is responsible for 22.5% of GDP. But in the KLEMS dataset, this aggregate is not shown, so the mining and quarrying sector is shown in Fig. 3.23 as a proxy to illustrate the contribution from TFP to the OG-GDP evolution. Calibrated TFP parameter for NOG-GDP in CENEf's RUS-DVA-2060 model perfectly fits the quite sophisticated assessments of TFP for the whole GDP and its oil&gas part provided in the Russian KLEMS project.

The average TFP for the NOG sector for 1995-2020 was assessed by CENEf-XXI at 0.7%, and for the whole GDP it was assessed by the KLEMS project also at 0.7%. For 2010-2020, it was -0.2% for NOG-GDP and, according to KLEMS, -1.6% in 2007-2016 for the whole economy. Therefore, after 2007 the economic growth was fully extensive, especially in the OG sector (or EMS in KLEMS aggregation). An analysis based on Russia's KLEMS shows, that capital intensity was growing noticeably faster in FES, than in the other sectors: it doubled over the post-2006 decade, pushing capital intensity of the entire economy up and thus slowing down the GDP growth.

Figure 3.23. Evolution of TFP for the whole economy and subsectors



Sources: for Russia – CENEf-XXI for NOG-GDP and Russia KLEMS. National Research University Higher School of Economics. December 2019. https://www.hse.ru/russiaklems/dataklems/

TFP in the fuel and energy sector decreased markedly after 2005-2007[115] leading first to a halt, and then to a decline in the economy-wide TFP. Therefore, with a persisting reliance on FES it was impossible to accelerate GDP growth in the recent decade. One additional evidence of the low TFP impact on the economic growth is the result from decade-long market surveys of industrial managers who kept ranking lack of labour high in the list of growth barriers against

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[113] Russia KLEMS. National Research University Higher School of Economics. December 2019. https://www.hse.ru/russiaklems/dataklems/; Voskoboynikov I.B. Recovery experiences of the Russian economy. Implications to the Indian Economy. State Bank Institute of Leadership, Kolkata, 18 September. 2020. 34 p. https://www.hse.ru/mirror/pubs/share/403285320.pdf.; Voskoboynikov I. Accounting for growth in the USSR and Russia, 1950–2012. J Econ Surv. 2021;35:870–894. DOI: 10.1111/joes.12426.

[114] Voskoboynikov I.B. Recovery experiences of the Russian economy. Implications to the Indian Economy. State Bank Institute of Leadership, Kolkata, 18 September. 2020. 34 p. https://www.hse.ru/mirror/pubs/share/403285320.pdf. Voskoboynikov I.B., Baranov E.F., Bobyleva K.V., Kapeliushnikov R.I., Piontkovski D.I., Roskin A.A., Tolokonnikov A.E. Recovery experiences of the Russian economy: The patterns of the post-shock growth after 1998 and 2008 and future prospects. Voprosy Ekonomiki [Issues of Economy]. 2021;(4):5-31. (In Russian) https://doi.org/10.32609/0042-8736-2021-4-5-31.

[115] In 1995-2016, TFP was 37% down in the mining and quarrying sector, and 69% down in the coke and refinery sector. EMS contributed 76% to the TFP decline in 2011-2016.

the background of low-ranking labour productivity.[116] Some experts argue that lower productivity of the Russian economy is the ‘price of cold’, but it was shown that it is the ‘cost of bondage’ in all dictatorship countries.[117] The growth in the TFP observed in 1999-2007 was a delayed result of the 1990s market reforms. After the architecture of those reforms had been stone by stone dismantled by 2007, TFP went to the negative zone and only a coincidental growth in oil prices, which started in 2000, allowed it to maintain some very moderate, exclusively extensive, and very capital-intense economic growth.

3.1.7 Economic projections made after February 24th

Even some of the previous pessimistic expectations for the economic growth in Russia overnight became quite optimistic on February 24, 2022, as a result of the sanctions. Three effects of the sanctions on the Russian economic growth are discussed below: from the sanctions on exports; on imports; and the implications for the incomes associated with the first two. The calculations rely on Rosstat’s 2019 Supply and Use Tables for goods and services for the Russian Federation as a statistical basis, and use Leontiev’s inverse matrix $(I-A)^{-1}$ assessed for 2016 (the latest available 98x98 matrix). In addition, data from the RF Customs Service on external trade flows for 2019-2021 were used. The exports data were split by products and destinations. Three Russia’s major trade counterparts, which already have imposed sanctions or may do so, were selected (EU-27, USA and Japan). The export sanctions depth parameters show how much export to a certain destination is expected to drop as a result of sanctions.

The effects of export-related sanctions on the Russian economy were explored using input-output tables: $\Delta X^{ex} = (I-A)^{-1} * (\Delta EX)$, where ΔEX is sanctions-related export decline. The sanctions package is a moving target along time: some sanctions may be added, while others may be laxed or eliminated in certain contexts. Changes in the exports were calculated based on the data from the RF Customs Service, which include a limited list of products. Then, based on the 2019 Supply and Use Tables for goods and services, they were translated into export revenue reductions. Reductions in the export of services were also estimated. In all, 61 economic activities were covered. All that was translated into a 98 dimensions export cuts vector by splitting some of the activities proportionally to their shares in gross outputs subtotals. Finally, export cuts were assessed as $\Delta EX = r * d_{exs} * EX$. The vector r reflects regional coverage of the sanctions. The depth of export cut to the regions is reflected as d_{exs}. For the services sectors, export reduction was evaluated as effects of some announced sanctions on the air travel, banking services, etc. The impact on gross value added (*GVA*) was estimated as $\Delta GVA_i^{ex} = \Delta X_i^{ex} * GVA_i/X_i$, or proportionally to GVA_i/X_i ratios, so $\Delta GVA_{ex} = gva * (I-A)^{-1} * (\Delta E)$.

The effects of import sanctions were assessed as: $\Delta X^{im} = d_{ims} * IMP_{int} * (I-A)^{-1} * (GVA - GVA_{ex})$, where d_{ims} is the depth of import sanctions; IMP_{int} is the vector of imported intermediate goods ratios to gross output. Then gross value added losses from the import sanctions are: $\Delta GVA_i^{im} = \Delta X_i^{im} * GVA_i/X_i$.

The loss in GVA resulting from reduced incomes and profits are reflected via depressed final demand (only private consumption and investments were included in the calculations): $\Delta GVA^d = (PC + INV) * (sh^{ex} + sh^{im})$, where sh^{ex} is $\Delta GVA_i^{ex}/GVA$ and sh^{im} is $\Delta GVA_i^{im}/GVA$. The total loss of GVA is: $\Delta GVA^{sanctions} = \Delta GVA_i^{ex} + \Delta GVA_i^{im} +.\Delta GVA^d$. Then GVA loss was broken down into the loss in the oil and gas sector and the loss in the rest of the economy. Some simplifications were used in the analysis: assumptions about linear effects; assumption that the effects of imported goods shortage is proportional to the total imports needed to satisfy the additional unit of final demand; assumptions that the depth of export- and import-related

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[116] Tsukhlo S.V. Russian industry in 2021-2022. “Rapid recovery” after the 2020 viral crisis. Science-based workshop on energy and environmental economics in the Moscow School of Economics, 10.02.2022.

[117] Bashmakov I. A. (2007) The Cost of Bondage, Rather Than of the Cold; Problems of Economic Transition, 49:9, 16-20, DOI: 10.2753/PET1061-1991490903.

sanctions is equal across activities and varies only due to the regional coverage. The possibility for exports of goods and services to other destinations in time is not reflected either. Growing government consumption expenditures may mitigate some of the loss in private consumption and investments.

The results are shown below (Table 3.2) for a variety of combinations of assumptions. The data present a static picture of GDP decline at the point of time the with greatest sanctions coverage and depth. The depth of GDP decline varies between 12 and 20%, and for NOG GDP between 11 and 19%. In reality, the sad road towards these deep bottoms will take some time. In contrast to the consensus forecasts, by the end of 2022 we may be only half way to the bottom, while the remaining part might be travelled over 2023 or later, as the sanctions reach the levels shown in Table 3.2 and are supplemented with higher customs duties for the imports from Russia. If any new markets for the Russian exports or new import suppliers are found, the GDP loss may be partially mitigated. Also, the impacts may be smaller, if the announced import restrictions are not fully implemented.

Table 3.2 Implications of sanctions for Russian GDP in constant prices

Assumptions	Parameter	Export sanctions	Import sanctions	Demand reduction effect	Total
Export sanctions (EU-27, USA, Japan), 20% coverage for major export items to these countries; 40% for air transport; 20% for other items and services; 30% cut in intermediate imports	GDP	-5.4%	-1.8%	-4.5%	-11.7%
	NOG GDP	-3.6%	-2.0%	-5.1%	-10.7%
Export sanctions (EU-27, USA, Japan), 50% coverage for major export items to these countries; 40% for air transport; 20% for other items and services; 30% cut in intermediate imports	GDP	-8.3%	-1.8%	-6.2%	-16.2%
	NOG GDP	-5.4%	-2.0%	-7.0%	-14.3%
Export sanctions (EU-27, USA, Japan), 50% coverage for major export items to these countries; 40% for air transport; 20% for other items and services; 50% cut in intermediate imports	GDP	-8.3%	-4.5%	-7.6%	-20.3%
	NOG GDP	-5.4%	-5.0%	-8.5%	-18.9%
OECD*					-10%-15%
Consensus projection by Russian experts (Kommersant 11.03.2022; Kommersant 17.03.2022)	GDP		-2.3-2.8%		-8%
		2022	2023	2024	2022-2024
		-8%	1.5%	2%	-5%
Consensus projection by foreign experts (Focus economics; Kommersant 18.03.2022)	GDP	-5.7%	-1%		-6.2

* OECD Economic Outlook, Interim Report Economic and Social Impacts and Policy Implications of the War in Ukraine, MARCH 2022.

Source: CENEf-XXI.

The ranges assessed for NOG GDP in Table 3.2 were used to set TFP evolution for this sector in the RUS-DVA model. OG-GDP is more accurately assessed in this model based on the physical fossil fuels export pathways as discussed above.

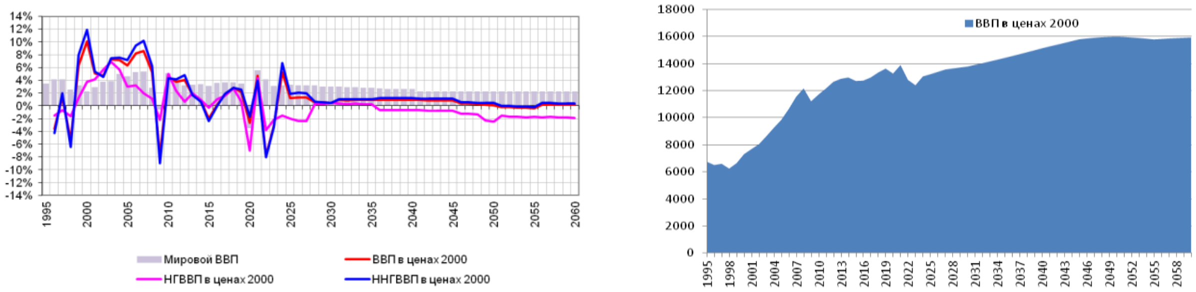
Based on the assessment presented in Table 3.2, the TFP for NOG GDP was taken to be -10% in 2022 and -4% in 2023, thus reflecting the expected medium estimate of potential output decline at 14%. It is assumed that the effect will slowly weaken over time as the sanctions relax through the progress in the peace process or (and) adaptation of the Russian economy and re-orientation of export and import flows. As a result, TFP for 2024 is assumed at +6%; and for 2025-2027 at +2% per year.

For the subsequent years, an assumption is made that the lower the income from the oil and gas sector and the higher the potential effects of the sanctions and mechanisms such as CBAM, the greater the effort Russia will make to technologically modernize the non-oil&gas sector. The share of the oil and gas sector in the economy will eventually decline. Therefore, it is assumed that the contribution from TFP will be positive staying at 0.5% per year in option 1, at 1% in option 2, and at 1.5% in option 3 (double of the 1996-2020 average). The two latter values will be difficult to attain as restrictions in terms of access to the foreign capital, cuts in investment goods imports (in the long run), and the accelerated after February 24th brain drain will negatively affect the TFP evolution in the years to come. The availability of the needed sophisticated equipment and qualified labour force will be limited, while the overdependence on Chinese machinery supply will be dangerously growing.

The resulting trajectories are shown in Fig. 3.24-3.25. Three scenarios were considered:

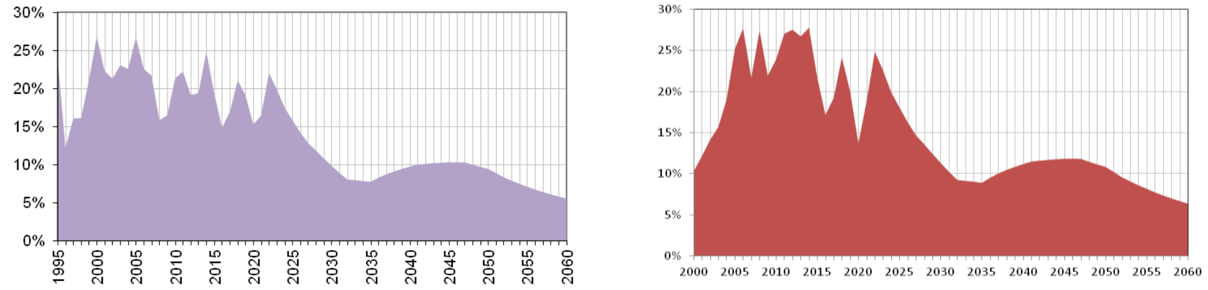
- Scenario 1: low fuel export reductions and low TFP level;
- Scenario 2: medium fuel export reductions and medium TFP level;
- Scenario 3: high fuel export reductions and high TFP level.

Figure 3.24 Scenario 1. Parameters of Russian economic development: low fuels export reduction and low TFP growth scenario



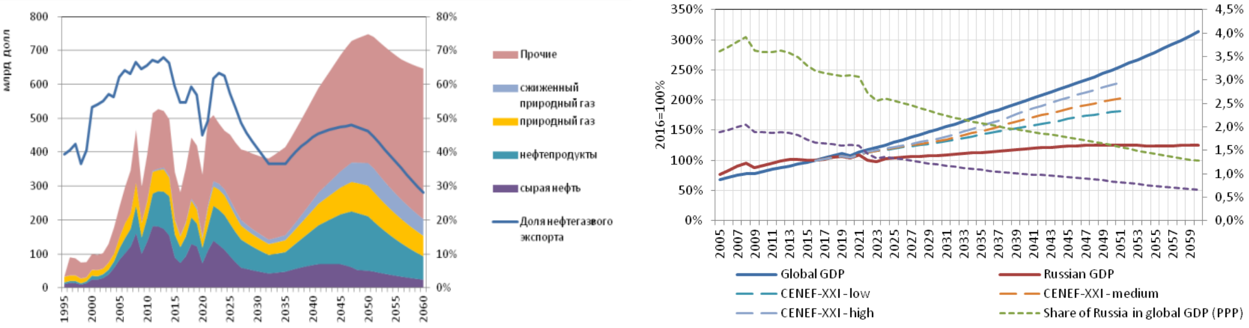
(m) GDP and its components annual growth rates

(n) GDP in 2000 prices



(o) Share of oil and gas GDP

(p) Share of oil and gas revenues in consolidated budget revenues



(q) Structure of goods exports

(r) Russian and global GDP growth (2016=100) and Russian share in global GDP

Source: CENEf-XXI.

Only scenarios 1 and 3 are discussed below, as scenario 2 provides results within the uncertainty range bordered by the former two.

Scenario 1. In 2021-2023, Russian GDP will be down by 10.7% (-7,9% in 2022 and -3% in 2023); OG GDP is only 4% down, while NOG GDP is 11% down (Fig. 4.4). The share of oil and gas GDP since 2022 will be much higher, than assessed before February 24th, for the whole timespan to 2060,[118] but particularly in 2022-2024. Thus the economic model based on the reliance on fuels is conserved, followed by a steep decline after 2024, as market niches for the Russian fuels shrink driven by the global decarbonization and energy security policies. Oil exports will never get back to the 2021 level, expected export oil price will decline to 2030-2035.

By 2024 the economic power of the Russian state and of the fuel supply businesses is conserved and still concentrated. The share of government-owned sector in GDP grows at the expense of shrinking private sector, and so the potential to improve overall productivity of the Russian economy is untapped. Export- and import-related sanctions and the conserved dominance of the government in the economy along with the persisting reliance on fuel exports will undermine the potential of the non-oil&gas sector to drive Russian economy. NOG GDP will get back to the 2021 level only by 2027 losing about 20% of the growth potential over those lost years. This will deeply undermine this sector's potential to mitigate the negative contribution from the OG GDP to the economic growth beyond 2035.

The shares of oil and gas in GDP and in the consolidated budget decline rapidly to 10% by 2030-2035 and beyond. The favourable time to support the development of the non-oil&gas sector due to the redistribution of energy export revenues is completely lost. In the longer term this sector faces labour force shortages (as a result of negative demographic trends), low TFP level, lost foreign markets of basic materials and low carbon goods, and is left partially ruined and unprepared to replace the substantially weakened capability of fuel exports to spur GDP growth.

As a result of such developments:

- Russia will lose 10 years of economic growth. The 2021 GDP level will only be back in 2031;
- By 2050, Russia will lose 46% of the previously expected potential GDP growth;[119]
- Russia's GDP in 2060 will only be 21% higher, than in 2021, and it will completely stagnate beyond 2045. The economic revival in the second part of the 2020s will be partially blocked by the labour force shortage. The same situation will be observed after 2045. Low TFP does not fully compensate the annual decline in the labour force, and a slow accumulation of fixed capital in this weakened sector will be the only driver for GDP growth;
- Meanwhile the global GDP will have grown 2.7-fold by 2060, while the share of the Russian GDP will be down from 1.6% in 2021 to 0.7% in 2060, if estimated in exchange rates, and from 3.1% to 1.3%, if estimated in PPP ranking in the middle or closer to the end of the second ten in the list of major economies). Thus the Russian economy will become hardly visible in the global 2060 economic landscape, shadowed by such giants of the time as China, India, and USA. This will deeply undermine Russia's economic security, political role, and the military potential.

Scenario 3. This scenario assumes a much deeper decline in the oil and gas exports by 2027 with a partial revival thereafter (Fig. 3.6 and 3.12) and higher TFP parameters. In 2021-2023, Russian GDP will be 11.4% down (-8% in 2022 and -3.7% in 2023). OG GDP will be 12.8% down, and NOG GDP will be 11.2% below the 2021 level. The OG GDP will be continuously declining (Fig. 3.25) and falling fast to reach 8% by 2030 and drop below 4% by 2060. The current

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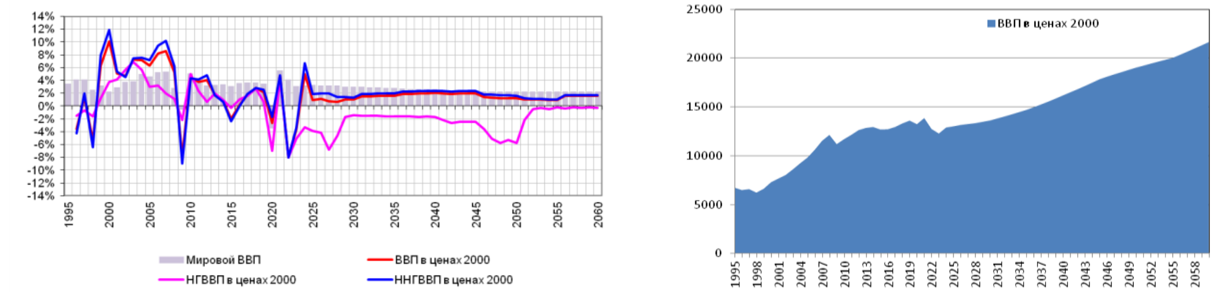
[118] Bashmakov et al. (2021). Russia on the carbon neutrality pathway. CENEf-XXI.

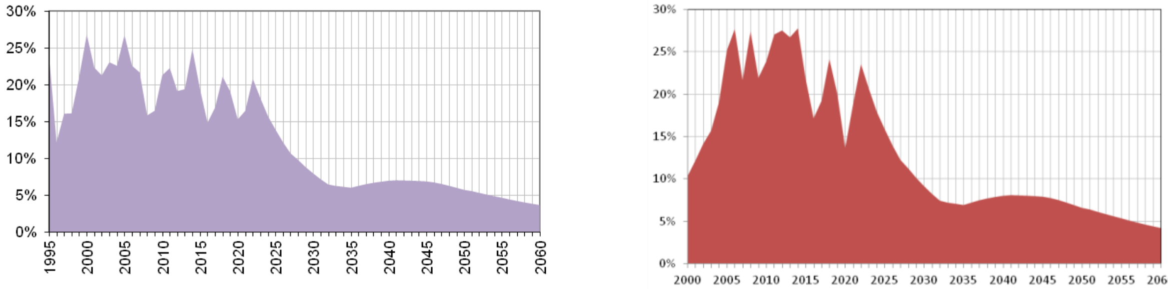
[119] Bashmakov et al. (2021). Russia on the carbon neutrality pathway. CENEf-XXI.

economic model relying on fuel exports will fail to support sustainable growth and will need to be replaced with another model, capable of providing large TFP improvements to save the economy from stagnation by 2060 at the level just 6% above the 2021 GDP.

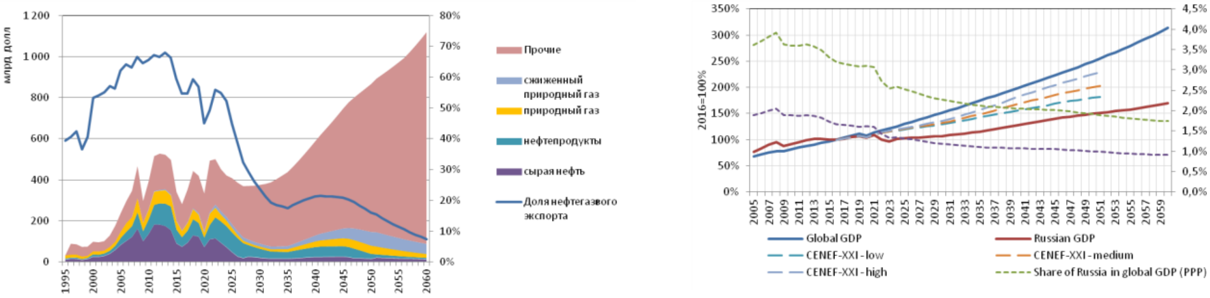
Figure 3.25 **Scenario 3. Parameters of Russian economic development: high fuel export reductions and high TFP growth scenario**



(s) GDP and its components annual growth rates (t) GDP in 2000 prices



(u) Share of oil and gas GDP (v) Share of oil gas revenues in consolidated budget revenues



(w) Structure of goods exports (x) Russian and global GDP growth (2016=100) and Russian share in global GDP

Source: CENEf-XXI.

In this scenario, the economic power of the Russian state and fuel supply businesses declines. The share of the government in GDP first scales up in 2022-2023, yet cannot be sustained much longer. The role of private sector needs to be increased to provide a competitive environment to improve the overall productivity of the Russian economy. As the government dominance declines, export- and import-related sanctions are expected to lax, and Russian businesses will re-enter the global markets of basic materials and enter the new markets of low carbon products. This would enhance the potential for the non-oil&gas sector to expand faster to serve a driver for the whole economy.

As a result of such developments:

- Russia will still lose 10-11 years of economic growth. The 2021 GDP level will only be back in 2031-2032;

- By 2050, Russia will have lost 51% (versus 46% in scenario 1) of the previously expected potential GDP growth;[120]
- In 2060, Russian GDP will be 44% higher, than in 2021 (versus 21% in scenario 1) reaching 1.6% AAGR in 2040-2050 and 1.3% in 2050-2060. This is possible only with an assumption that the economic and institutional models in Russia will change to enable the TFP improvements. A failure to provide new institutional and socio-political frameworks for the economic growth will limit Russian GDP growth to just 6% in 2060 relative to the 2021 level. This would mean four decades of economic stagnation for Russia;
- In this scenario, the share of Russian GDP in the global GDP will still be shrinking from 1.6% in 2021 to 0.9% in 2060, when estimated in exchange rates, and from 3.1% to 1.7%, if estimated in PPP, but the loss in Russian economic role on the global scale will not be as devastating as in scenario 1.

Back in 2008, the author wrote[121], "The current cultural tradition in Russia is *"a focus on the survival of disunited individuals, focusing on solving tactical problems and having little idea of what the future holds for them."* These values are inertial, but not completely static. They need to be changed, and so do the institutions themselves, otherwise regression, even in the most progressive institutional reform, will be inevitable. It would be naive to expect that a bureaucratic state will begin to modernize itself for the sake of the future... Perhaps Russia is in a trap: in order to reach by 2050 the levels of economic development comparable to the current levels of developed countries, it is important to change the cultural traditions and institutions, yet there is no one to change them. If the need for the change is to be recognized and a capable coalition is to emerge, more evidence is required that Russia's current rigid institutions will be holding back Russia's economic growth. The uncertainty of the institutional situation in Russia is superimposed on many other uncertainties and it does not allow for a clear answer to the question of how much Russia's GDP will have grown by 2050". It was echoed by the statement that basic Russian values are defined by the formula *"high value of security and protection by the state with a weak commitment to the values of novelty, creativity, freedom, independence and risk*".[122] With such burden, it is difficult to determine the directions of modernization and to develop coalitions for timely modernization in the key directions. After 14 years, these statements are even more valid, because the efforts to develop effective coalitions for modernization have failed.

The problem with modernization is, that titanic efforts were needed simultaneously in many areas: increasing the birth rates; reducing mortality and prolonging the active working life of Russian citizens; competent migration policy with balanced interethnic concord; fundamental modernization of the technological basis of production and a significant increase, on this basis, in labour and capital productivities and energy efficiency; preventing a collapse in oil production, increasing the uptake of renewable energy sources; accelerated development of export-oriented and import-substituting industries. In all of the scenarios assessed more than a decade prior to February 24th, the share of OG GDP was steadily declining towards 2050 with a subsequent decline in the influence of the oil and gas elites, growing dependency of the state on other businesses, and gradually dissipating illusions of its omnipotence with a real democracy replacing the decorative one. All these processes were expected to be delayed, as the current elites would do anything to maintain their power and influence. Modernization was inevitably associated with a significant potentially conflicting political component.

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[120] Bashmakov et al. (2021). Russia on the carbon neutrality pathway. CENEf-XXI.

[121] Bashmakov I. Russia-2050. *Voprosy Ekonomiki*. 2008;(8):140-144. (In Russ.). https://doi.org/10.32609/0042-8736-2008-8-140-144

[122] Magun V., Rudnev M. Basic Human Values of Russians and Other Europeans (The Results of 2008 Surveys). *Voprosy Ekonomiki*. 2010;(12):107-130. (In Russ.). https://doi.org/10.32609/0042-8736-2010-12-107-130

Discussions on the Russian modernization paths highlighted that the conservation of current institutions along with the present development model based on raw materials exports fail to ensure high economic growth rates. Many areas of modernization have been recognized and voiced. However, the task of promoting the lexical constructor of modernization concepts to a set of real actions to yield the expected results has failed. Back in 2011, in the article "*Will Russia Have Economic Growth in the Mid-XXI Century?*"[123] it was shown that the loss of the ability of the Russian economy to expand in the 2030's and 2040's, or even a transition to the "shagreen skin" economy (the model of continuously declining GDP) may be a painful punishment for the modernization failure in the 2010's. Research has also shown that without effective modernization to increase all factors' productivity Russia will have no economic growth in the middle of the 21st century. If GDP growth is to exceed an average of 1% per year in the 40's, it is essential to have either a sustainable dynamic increase in oil prices or a successful modernization. It was shown that without modernization it would be unfeasible to bridge the economic development gap with the leading countries and increase Russia's share in the global GDP, and even to maintain the current one. The price of unsuccessful modernization is the loss of the economic growth in the 2040's, and possibly in the 2030's. A decade after that paper was published, we see this happening. But now we can add the 2020's to the list and rephrase the paper title: "*Will Russia Have Economic Growth after 2021?*" with many factors against the positive answer to this question.

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[123] Bashmakov I. Will Russia Have Economic Growth in the Mid-XXI Century? *Voprosy Ekonomiki*. 2011;(3):20-39. (In Russ.). https://doi.org/10.32609/0042-8736-2011-3-20-39

4 Scenario storylines

4.1 Challenges related to drawing scenario storylines for Russia's decarbonization pathways

Many think that projections for a distant future are mindless games, because future is hardly possible to predict. Others might want to turn to fortune tellers to learn what future may bring them. In daily business, any investor in durable assets has to play this game. Our analysis[124] (namely, comparison of global energy system evolution projections to 1990-2020 with reality) has shown that, indeed, accurate predictions are probably not feasible, but… by using well-structured models to run scenarios and deploying effective analytical schemes[125] to judge on their feasibility it is possible to outline the contours of the future and to get adequate visions that help learn the lessons of the future. Moreover, only such models ("time machines") enable us to find a balance between improving human well-being and preserving the nature and climate. This balance is also refracted through the prism of public opinion about what is "good" or "bad" in terms of energy and economic policies, while ensuring the reliability and affordability of energy and materials flows. Over the past 30-50 years, the mankind has been following a wrong pathway.

Like continuously repeated in the *"Back to the Future"* movie, "the future isn't written yet". An even more accurate formula is given by Matt Myklusch in his *"Jack Blank and the Imagine Nation"*: "The future is not written. It lies in the choices you make. Our future is ours to decide. Always"). Global climate is a very inertial system, same as the economy and social values. A distant vision is required to foresee remote problems, learn lessons, and choose the right pathway to the future. Multiple attempts have been made to travel to a very distant future, including 1,574 scenarios up to 2100 assembled in the WGIII AR6 scenario database.[126]

The scenario storylines presented below provide visions of possible futures for Russia to 2060. Forty years ahead is a large time spot in which a lot of things may change. Back in 1982, when Brezhnev was still alive, people in Russia could hardly imagine how their stagnating command-and-control economy would go through perestroika and deep market reforms and then move backward to deeper government control alongside social and political changes of the last four decades. It would be equally erroneous to extrapolate the recent developments to the distant future.

It was easier to draw pictures of Russia's future before February 24, 2022, than it is now. In 21st century, we could see some retreat from the market reforms of the 1990s to a more profound government control over the economy. However, Russia's economy was still part of the global economy with a lot of room left for the market forces. The initial intention was to focus on different pathways for Russia to attain the net zero carbon target by 2060 with options to rely more on such options as: low carbon power and electrification, energy and material efficiency improvements, progress towards the circular economy, large-scale hydrogen exports, mass deployment of CCUS, or with an accent on carbon sequestration by Russian forests.

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[124] Bashmakov I.A. Projections of the global energy system evolution 30 years later: Checking the lessons of the future by the past experience. *Voprosy Ekonomiki*. 2022;(5):51-78. (In Russ.) https://doi.org/10.32609/0042-8736-2022-5-51-78

[125] Bashmakov I. A. (1987). On the implementation and analysis of the results of macroeconomic forecasts (method of seven matrices). In: *The system of macroeconomic information processing*. M.: Nauka. P. 117–132. (In Russian).

[126] Riahi K., R. Schaeffer et al. Mitigation Pathways Compatible with Long-Term Goals. In: *Climate Change 2022. Mitigation of Climate Change. Contribution of Working Group III to the IPCC Six Assessment Report (AR6)* [Skea, J. et al., (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

One lesson from the future is that there is no business-as-usual for the years to come; instead business-as-unusual needs to be in the focus.[127] For Russia, there is no business-as-usual even in the short- and medium-term. A few months ago, no one could foresee the Russian military operation in Ukraine and subsequent strong and escalating sanctions. The sanctions will work to deepen the existing technology gap with the global leaders and cutting-edge technologies, leaving little chance to bridge it relying on imports substitution and self-sufficiency. It was equally difficult to anticipate that Russia will be cut off the global supply chains and the world will progress to the future leaving Russia behind. But now such vision of the future becomes feasible and should be considered.

So the task ahead is to develop visions to embrace the range of uncertainty which greatly increased after February 24. Word selection in the title of Fig. 4.1 is not unambiguous anymore. The future may look more like the right-hand part of this figure or more like the past shown on the left-hand side.

Figure 4.1 $\boldsymbol{Future\ is\ \frac{ahead}{behind}, Past\ is\ \frac{ahead}{behind}}$

Source: developed by I. Bashmakov.

Three sets of scenario storylines were developed to cover the abruptly widening uncertainly zone to draw the pathways which may get Russia to the carbon neutrality by 2060:

- 4S – Stagnation, Sanctions, Self-Sufficiency, which may be also titled Forward to the Past (as the opposite to the Back to the Future);
- 4D – Development Driven by Decarbonization and Democratization, which opens the door for Russia to return to the global economy;
- 4F – Fossil Fuels for Feedstock, which builds upon 4D and allows Russia to use its fossil fuel resources for non-energy use.

In all of the scenarios, LULUCF is the last hope option for Russia to meet its carbon neutrality goal by 2060. Therefore, the scale of carbon net stock in LULUCF substantially differs across the scenarios.

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[127] Bashmakov I. Energy for the new Millennium. CENEf. Moscow. 1999.

4.2 4S – Stagnation, Sanctions, Self-Sufficiency – Forward to the Past

This scenario is a projected emissions trajectory modeled in consistent framework, which by no means is BAU-like. Rather, it serves as a reference scenario and is based on the following narratives and storylines:

- strong sanctions persist for Russia's dominating traditional exports, which are considered toxic in the global, and especially G7, markets; the same goes for the ban on high-tech imports to Russia;
- oil and gas exports quickly shrink, with just a limited potential to rebound later by turning to new regional markets, as the global economy is steadily switching to low carbon pathways;
- O&G sector declines, and so does its contribution to GDP, foreign trade, and consolidated budget (after 2025);
- Russia is cut off many global supply chains and forced to rely on self-sufficiency for domestic needs;
- strong government control over the economy with subsequent decline in overall efficiency in the sectors under control;
- poor quality high-tech imports substitution with a low potential to improve total factor productivity in many sectors, which have already suffered from a deeper government control;
- slow economic growth in the NOG sector with low total factor productivity, declining labour force, intensive brain drain, low investment, and limited inflow of foreign capital;
- inability of the NOG sector to fill shortfalls in GDP, foreign trade and consolidated budget revenues, which were historically yielded by fuels and raw materials exports;
- limited potential to expand non-fuel and non-basic materials exports to the global markets, which are dynamically switching to the low carbon pathways;
- poor access to international financing for companies and the public sector will restrict the ability of the consolidated budget to keep the expenditures growing, as beyond 2025 oil and gas revenues will be brought down by both low exports and low energy prices, and the NOG sector will be unable to fill the gap;
- aging production facilities, slow phasing out and low modernization rates;
- lower demand for additional production and low capacity additions, as demand for Russian products, both domestic and international, will be growing very slowly (if at all);
- only a small share of new capacity will meet the BAT (best available technologies) standards; the new capacities built to the BPT (best presently practical technologies) at the best (alternative, which may have lower parameters – Best Available in Russia Technologies-BART) will dominate, since poor competitiveness and lack of high-tech equipment will impede reaching the technology cutting edge.

In contrast to the movie "Back to the Future", this scenario takes Russia "Forward to the Past", or "Back to the USSR". Those who lived in the USSR, can remember the long queues for food, as well as poor quality clothes, cars, flats, and workplace machinery. Generally, any country with a central planning system used to have at least twice lower overall efficiency compared to their market counterparts with similar climate and other geographic conditions, and at least twice lower GDP PPP per capita. The race for the future was lost by countries with central planning which were hiding behind the iron curtain. 4S scenario is an attempt to repeat this historical mistake turning from global integration pathway to global isolation one.

4S scenario captures the demand reduction option not because reasonable sufficiency is achieved, but rather it is based on sufficiency willy-nilly (both on quantity and quality) driven by supply reduction.

4.3 4D – Development Driven by Decarbonization and Democratization is the Door Back to the Global Economy

The task for this illustrative scenario is to draw pathways consistent with the adopted decision to reach net zero carbon status for Russia by 2060. Globally net zero carbon timing for 1.5°C is 2050-2055 and that for 2°C is 2070-2075.[128] So, Russia's commitment lies in between reflecting balance between historical responsibility, expected feasibility and mitigation capacity.

The story lines for this scenario are quite different:

- progress towards termination of Russia's military operation in Ukraine will relax sanctions and enable Russia to regain some of its positions in the global value chains after 2030;
- proactive decarbonization policies in Russia will help the country to get a market niche in some global regions for a variety of products with low or no carbon footprints and get access to the hardware and software needed to produce low carbon products and services. Potential low carbon global markets are expected to reach $US 12 trillion by 2030 (Figure 4.1) and $US 11-16 trillion in green investment by 2050 (Figure 4.2). Getting just 1% of this pie would bring 110-160 billion $US;
- democratization will develop as the role of the oil and gas sector will be shrinking, and reliance on a wider political and social spectrum will become key for sustaining social stability and inspire business activity. All this will bring more competition into the economy (while the role of the government will be declining), free up initiative, reduce migration intentions of qualified workforce, and attract skilled professionals from abroad to work in Russia. It will reduce corruption and provide incentives for investment and rewarding based on skills, rather than on loyalty;
- relaxed or removed high-tech import sanctions, competition-based incentives to invest in new technologies, and re-gained access to international financing will improve total factor productivity and therefore accelerate NOG sector development with a growing potential to fill the income gap resulting from the oil and gas revenues drop;
- growing potential to increase low carbon products/services production will accelerate phasing out obsolete capacities and boost modernization of the remaining capacities;
- higher demand for additional production in the domestic and international markets will significantly scale up capacities additions with performance to the BAT standards;
- low carbon footprint requirements for products and services will provide incentives to reduce scope 1 emissions via improved energy and material efficiency, circular economy, and electrification, CCUS and hydrogen application and scope 2 emissions via promoting low carbon energy penetration, including renewables, both in grid and off-grid systems; hydrogen-based technologies; CCUS; electric vehicles; and other low carbon technologies, as they reach the commercialization stage;
- the need to make low carbon technologies competitive at their initial deployment stages, along with a potentially wide geographical and products-wise spread of CBAM-like

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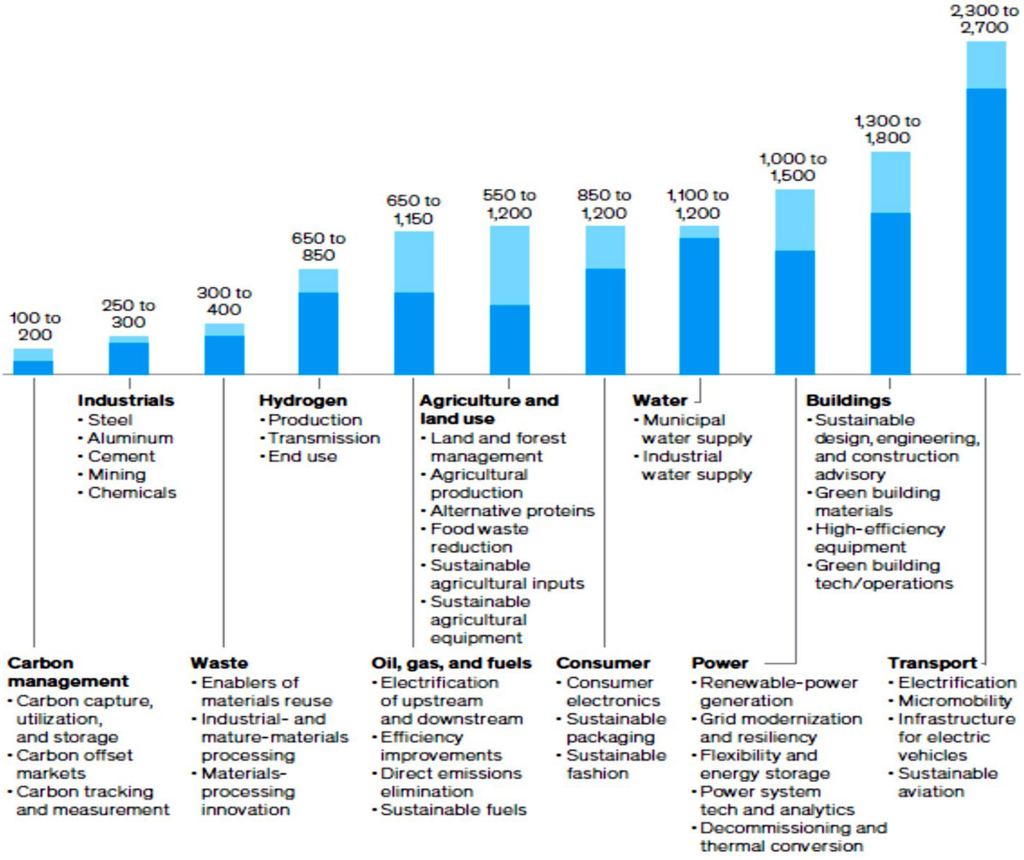
[128] Riahi K., R. Schaeffer et al. Mitigation Pathways Compatible with Long-Term Goals. In: *Climate Change 2022. Mitigation of Climate Change. Contribution of Working Group III to the IPCC Six Assessment Report (AR6)* [Skea, J. et al., (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

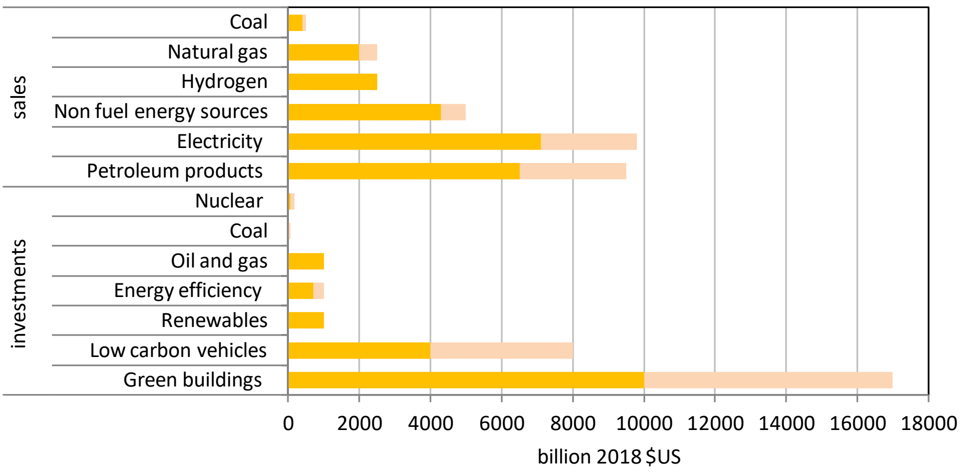
mechanisms supported by the Sakhalin experiment results (if positive) will inspire the launch of the CO_2 price mechanism at the national level.

Figure 4.2 **Eleven high-potential value pools could be worth more than $US12 trillion in annual revenues by 2030 as net-zero transition advances. Addressable market size in 2030, selected categories ($US billion)**



Source: McKinsey & Company. 2022. Playing offense to create value in the net-zero transition. McKinsey Quarterly. April 2022.

Figure 4.3 **Global investments and sales for certain groups of technologies and energy resources in 2050**



Source: Bashmakov I. A., Bashmakov V. I., Borisov K. B., Carvalho P., Drummond P., Dzedzichek M. G., Lunin A. A., Lebedev O. V. (2020). Monitoring of low carbon technologies deployment in Russia. *Ekologicheskiy Vestnik Rossii*, No. 4, pp. 6–11. (In Russian).

This scenario captures the impacts of mitigation options, such as: energy and material efficiency, circularity, electrification of energy end-use with low carbon power, better use of biomass, hydrogen use and CCUS mostly in power generation and industrial processes, carbon pricing policies, measures to reduce emissions from agriculture and waste sectors and to provide sufficient net sinks in LULUCF to attain net carbon neutrality by 2060.

4.4 4F – Fossil Fuels for Feedstock

The storylines for this scenario are mostly builds upon the 4D scenario, but additionally assume more intensive fossil fuels use for chemical feedstock, along with blue hydrogen and ammonia production:

- there is expected meaningful external demand for chemicals and hydrogen produced in Russia;
- an accent on the export of plastics and other chemicals would allow it to use more fossil fuels for feedstock with CCUS deployment;
- ambitious plans to export low carbon hydrogen or ammonia will be implemented on a large scale in Russia using large amounts of natural gas at facilities equipped with CCS.

5 4S – Stagnation, Sanctions, Self-Sufficiency – Forward-to-the-Past

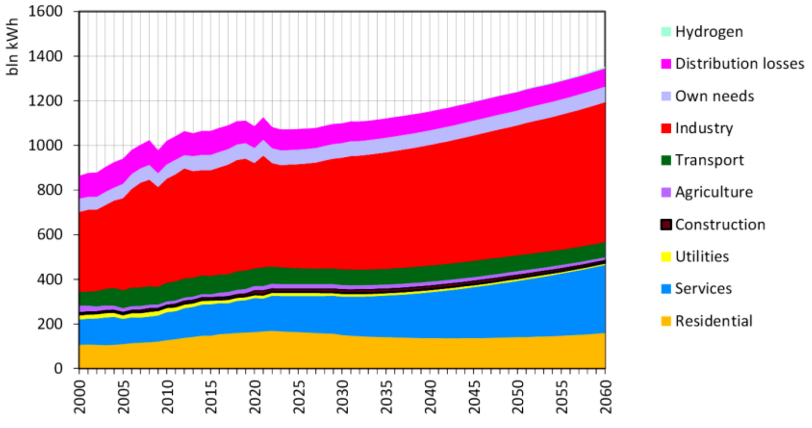
This scenario is modeled in a framework, which is by no means BAU-like. Rather, it is a reference scenario.[129] Unlike in the movie "Back-to-the-Future", this scenario takes Russia "Forward-to-the-Past", or "Back to the USSR". Those who remember living in the USSR, can recall the long queues for food, as well as poor quality clothes, cars, flats, and workplace machinery. Generally, any country with a central planning system used to have at least twice lower overall efficiency compared to their market counterparts with similar climate and other geographic conditions, and at least twice lower GDP PPP per capita. The race for the future was lost by countries with central planning which were hiding behind the iron curtain. 4S scenario is an attempt to repeat this historical mistake.

4S scenario captures the reduced demand options not for the reasonable sufficiency they offer, but rather for the willy-nilly sufficiency (both quantitative and qualitative) driven by supply reduction and policies that cultivate the past values.

5.1 Heat and power sector

In 4S scenario, electricity generation for two decades is practically not growing (Figure 5.1 and 5.3)**. After a decline in 2022-2023, centralized electricity generation slowly recovers to reach the 2021 level only in 2042 and grows to 1,320 billion kWh in 2060**. Economic activity grows in all sectors and is accompanied by electrification, but is partially offset by improved efficiency of electricity use.

Figure 5.1 Electricity consumption in 4S scenario



Source: CENEf-XXI.

Negative effects of the sanctions are observed in all segments of the electricity market. After cooperation between I-REC Standard Foundation and Russian companies was suspended, "green" certificates for approximately 1 billion kWh are at risk.[130] If these certificates are redeemed, Russian companies will be unable to prove at the international level the 'green' origin of the generated energy. This will significantly impede international cooperation in renewable energy and participation of Russian producers of RE energy and products with a low carbon footprint in the global energy transition.

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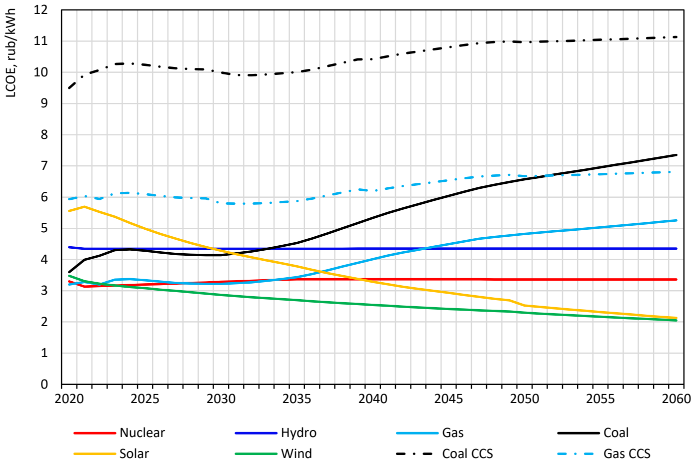
[129] The storylines for this scenario are shown in Chapter 4.

[130] Russia's fuel and energy sector under the sanctions. Energy trends. No. 106, March 2020. The Analytical Centre under the government of the Russian Federation.

For fossil fuel based generation, 4S scenario assumes moderate progress in improving the efficiency of both new and modernized power plants to levels lower than global BAT. Previous plans to improve the local content of General Electric and Siemens turbines will hardly materialize in the near future, as Siemens is terminating its activities in Russia.[131] The RF Ministry of Energy believes that the ban on gas turbines supply will not affect the Russian market.[132] However, even a shortage of imported spare parts or the unavailability of high-quality maintenance of CCGT in place will increase the number of start-stops and lead to a drop in their efficiency. Even if these turbines are replaced with Chinese or other models, this less efficient equipment will have to undergo accelerated certification.[133] Continuous attempts to improve the local content of high-power turbines have not been successful. If a gas turbine is to be recognized as Russian-made, the manufacturer must own the rights to the technology, including methodology, know-how and patents, as well as to the design and technical documentation. The plan was to increase the share of Russian components to 70% in 2020, and to 90% in 2022. According to the RF Ministry of Industry and Trade, construction of Russian 65 and 170 MW turbines is on track, but such statements are continuously repeated every year, which means that the plans are substantially adjusted. “Silovye Machiny” plans to start turbines supply in 2023.[134] Six GTE-170 turbines are currently in production. The GTE-65.1 prototype has been launched. Rostech Corporation claims that GTD-110M turbine is ready for serial production; the Corporation has set up a special company for the production, supply and maintenance of these turbines aiming to produce two turbines per year. Similar difficulties associated with the sanctions are arising along the entire range of power generation and distribution equipment. Their possible impact in terms of impeding the development of different segments of the electricity market is yet to be explored.

There is no simple or unambiguous solution to the problem of low-carbon generation development in Russia to 2060. **However, despite the slow growth in electricity generation, the generation structure changes noticeably.** The share of zero-carbon generation grows from 40% in 2020 to 68% in 2060. An assumption is made, that generation development policies do not favour any particular types of generation. CCS technology is not applied. 4S scenario assumes, that the current government support frameworks for RE development will be maintained to 2035, when wind and solar generation will become competitive (Figure 5.2).

Figure 5.2 LCOE for different types of generation in 4S scenario



Sources: Administrator of the trading system of the wholesale electricity market (https://www.atsenergo.ru); System operator of the unified energy system. (http://kom.so-ups.ru).

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[131] https://press.siemens.com/global/en/news/statement-war-ukraine-and-situation-russia?utm_source=ixbtcom.

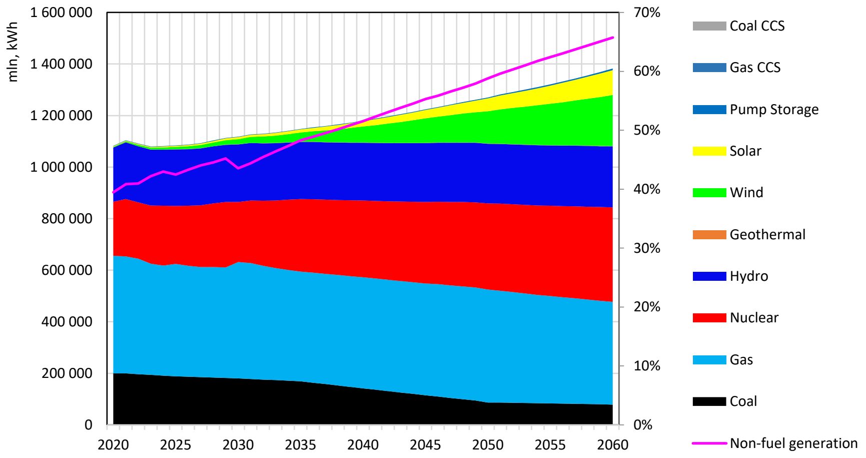
[132] https://neftegaz.ru/news/gosreg/731876-minenergo-rf-predstavilo-mery-podderzhki-dlya-energetikov-v-usloviyakh-sanktsiy/.

[133] https://lenta.ru/news/2022/03/21/energo/?ysclid=l470vpex3d134339030.

[134] https://tass.ru/ekonomika/14619511?utm_source=ixbtcom.

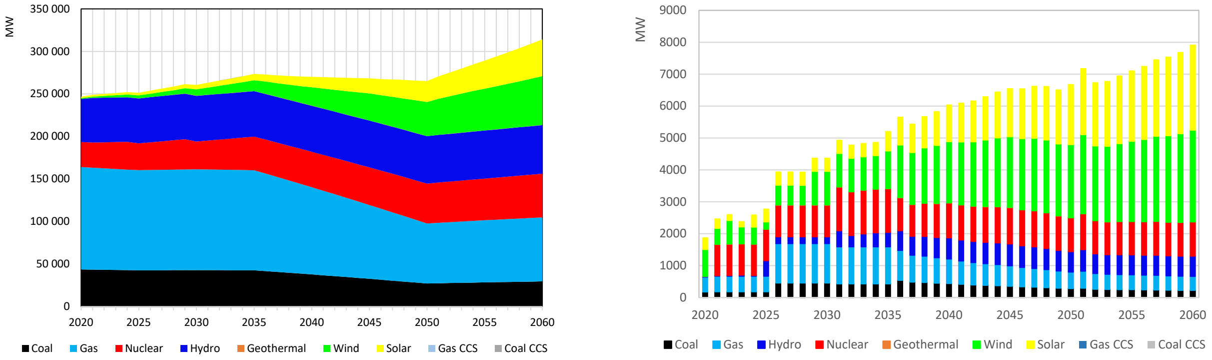
Centralized generation based on variable RES (wind and solar) grows up to 279 billion kWh in 2060, or up to 21% of total generation. The share of non-fuel generation increases from 41% in 2021 to 66% in 2060 (Figure 5.3). Wind and solar capacity is growing, as current plans for renewable capacity construction to 2035 are implemented (these plans may be revised downwards driven by the withdrawal of Fortum[135] and Vestas[136] from the Russian market; however, Gazprombank and Inter RAO are ready to buy their assets), and then, as the costs go down, wind and solar become the key driver for changing the structure of installed capacity. This is due to the economies of scale and learning. As the intake grows, reduction in specific investments and operation costs becomes an important factor spurring RE development. Nuclear and hydro capacities are practically ‘frozen’ at the current level, since phase in mostly replaces retirements. Therefore, fuel generation goes down (Figure 5.4).

Figure 5.3 Electricity generation, 2021-2060 in 4S scenario



Source: CENEf-XXI.

Figure 5.4 Total capacity and commissioning of power plants, 2021-2060 in 4S scenario



a) total power plant capacity b) power plant commissioning

Source: CENEf-XXI.

Due to the slow growth in electricity demand total capacity of power plants grows only slightly to 2060 to 258 GW, including: nuclear – to 43 GW; wind – to 37 GW; solar – to 26 GW. Hydro and geothermal remain at the same level – 50 and 0.2 GW. Total thermal plant capacity declines: gas power plants – to 73 GW; coal power plants – to 28 GW. In 2055-2060, non-fuel generation accounts for 91% in capacity increase (versus 73% in 2020-2025), and solar and wind account for 68% (versus 35% in 2020-2025. In 2021, nuclear generation showed 0.22

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[135] Burning Finnish plans. Kommersant, No. 103/B, 14.06.2022 (https://www.kommersant.ru/doc/5408791).

[136] The wind has changed. Kommersant, No. 103/B, 14.06.2022 (https://www.kommersant.ru/doc/5408833).

GW increase, hydro – 1.75 GW, wind – 0.56 GW, and solar plants – 0.30 GW. Thermal capacity was 6 GW down.

5.2 Industry

The sanctions force Russian companies to change their logistics for both industrial exports and raw materials and components supply. Particularly tough restrictions have affected iron and steel and non-ferrous metals, oil refinery, chemicals, and pulp and paper. Some estimates show that the restrictions may cause a 30% drop in metals sales and 15-35% in chemicals sales (mineral fertilizers). The potential decline in machine building is even more significant. Penetration to the new markets and building new supply chains will take time.

Broken exports logistics result in physical restrictions on exports and higher product prices. Because European ports are closed, Russian enterprises forward their export flows to road and railroad networks. For many of them, this is a large 'transport leg', which is additionally restricted by the capacity of transport systems and port facilities, which cannot be quickly expanded.

Given the limited domestic market, which is shrinking during the crisis, the reorientation of production to the domestic needs can hardly offset export losses. Domestic demand for industrial products will be declining. According to the World Steel Association (WSA), Russian steel consumption in 2022 will drop to 35.1 million tons, or by 20% (vs. 43.9 million tons in 2021), and in 2023 it will not increase.[137]

Some optimists hope for a "powerful leap", which will take 2-4 years[138] and will minimize the effect of the sanctions. However, it is more realistic to think that this process will take decades. Russian suppliers will not be able to meet the high-quality process and energy equipment demand (rolling mills, steel furnaces, converters, electrolyzers, etc.). Rather, it may look like a 'stripped' configuration. The Russian refineries modernization program has already been postponed indefinitely.[139] The sanctions are critical for petrochemical equipment supply, especially polymerization plants. Attempts of Russian factories to copy and manufacture unlicensed products, even if successful, will result in a drop in quality and reliability of equipment in a "stripped" configuration. A critical situation with foreign equipment and technologies supply is observed in the pulp and paper industry (low chance of import substitution). Large domestic plants that used to specialize in machines and equipment for pulp and paper factories (Petrozavodskmash, Izhtyazhbummash) are reoriented to other areas. Manufacturers of paper and board machines also rely on raw materials and chemicals exports.[140]

Limited access to financing means that costly investment projects are postponed indefinitely. They will give way to projects with smaller financial demand (improvement of customer service, automated central planning, maintenance and current repairs).

Success criteria for revised industrial strategies are different now. Success is no longer measured based on the integration in the global economy and expansion of exports, but rather based on the achieved degree of isolation, i.e. reduced share of imports in

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[137] World Steel Association https://www.kommersant.ru/doc/5306914, https://worldsteel.org/media-centre/press-releases/2022/worldsteel-short-range-outlook-april-2022/.

[138] Alexey Mordashov. "In my opinion, we do not completely realize what's going on". https://www.business-gazeta.ru/news/552440.

[139] In 2021, RF Ministry of Energy signed an agreement with oil companies to upgrade 14 oil refineries and build new fuel production capacities. This agreement involves 800 billion rubles in investment to 2027. Oil refineries must retrofit and phase-in 30 plants for secondary oil refinery, auxiliary units, and all-factory facilities. These will increase gasoline production by 3.6 million tons and diesel fuel production to more than 25 million tons per year by 2031, to renovate oil refinery capacity, and to improve the reliability of the Russian oil refinery industry.

[140] Russian pulp and paper under sanctions: has imports substitution failed or is it still possible? https://zen.yandex.ru/media/zetta/celliuloznobumajnaia-promyshlennost-rf-pod-sankciiami-importozamescenie-provaleno-ili-esce-vozmojno-62876a8acb920e4aba4d1b4a.

production (Table 5.1). Some industries, which are the worst affected by the sanctions, have already launched revision of their strategies and programs. *Draft Strategy for RF metallurgical industry development to 2024 and 2035* has specified the key goals as sustainable development of the metallurgical sector to 2035 through incentivizing the domestic demand; better positions in the international markets and adaptation to a tougher environmental legislation and carbon regulations.

The conservative scenario assumes that new long-term projects and programs cannot be implemented, and the overall technology competitiveness of the sector will be declining. The forecasts of metals production and consumption are based on current trends.

The baseline scenario assumes an increase in domestic metals demand and partial implementation of the previously scheduled investment projects and programs (delayed projects and programs; construction or reconstruction of production facilities of lower capacity).

The target scenario is based on the assumption that the growth in domestic metals demand will result from both economic development and a reduction in indirect metals imports.[141] The share of exports will be declining through the reorientation to the domestic market. The target scenario assumes a complete implementation of companies' investment projects and programs. In the target scenario, the share of exports is minimal for all products.

Table 5.1 Projected metals production

	Scenario	Units	2020 (actual)	2024 (projected)	2030 (projected)	2035 (projected)
Coke						
Production	Conservative	mln tons	27	26.9	25.9	24.5
Domestic consumption			24.5	24	24	22.5
Exports			2.6	3	2	2
Share of exports in production		%	9.6	11.2	7.7	8.2
Production	Baseline	mln tons	27	26	25	24.9
Domestic consumption			24.5	24	24	24.4
Exports			2.6	2	1	0.5
Share of exports in production		%	9.6	3.8	4	2
Production	Target	mln tons	27	26.7	25.8	25.5
Domestic consumption			24.5	23.7	22.8	22.5
Exports			2.6	3	3	3
Share of exports in production		%	9.6	11.2	11.6	11.8
Pig iron						
Production	Conservative	mln tons	52	53	54	54.2
Domestic consumption			47.8	48.5	49.2	49.8
Exports			4.2	4.5	4.8	5
Share of exports in production		%	8	8.5	8.9	9.1
Production	Baseline	mln tons	52	54	55.5	57
Domestic consumption			47.8	49	50.5	52
Exports			4.2	5	5	5
Share of exports in production		%	8	9.3	9	8.8

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[141] According to WSA, 2019 Russia's indirect steel imports (steel embedded in imported products) were nearly 9 mln tons. 2021. World Steel in Figures. World Steel Association. 2021.

	Scenario	Units	2020 (actual)	2024 (projected)	2030 (projected)	2035 (projected)
Production	Target	mln tons	52	54	56	58.3
Domestic consumption			47.8	49	51	53.3
Exports			4.2	5	5	5
Share of exports in production		%	8	9.3	8.9	8.6
Crude steel						
Production	Conservative	mln tons	73.8	78.5	80	86
	Baseline		73.8	78	81.5	89.8
	Target		73.8	80	86.5	92.7
Rolled iron and steel						
Production	Conservative	mln tons	61.8	64	66.8	71.7
Domestic consumption			40.3	45	48.6	54.9
Exports			25.8	24	22	20
Share of exports in production		%	41.7	37.5	32.9	27.9
Production	Baseline	mln tons	61.8	65	70	75
Domestic consumption			40.3	46.2	55.2	62
Exports			25.8	22.8	18.5	16
Share of exports in production		%	41.7	35.1	26.4	21.3
Production	Target	mln tons	61.8	67	72.2	77
Domestic consumption			40.3	48.5	58.5	66.5
Exports			25.8	22	16	12.2
Share of exports in production		%	41.7	32.8	22.1	15.8
Primary aluminium						
Production	Conservative	thou. tons	3928	4200	4340	4356
Domestic consumption			1246	1285	1354	1339
Exports			2698	2955	3017	3046
Share of exports in production		%	68,6	70	70	70
Production	Baseline	thou. tons	3928	4200	4350	4564
Domestic consumption			1246	1288	1356	1393
Exports			2698	2955	3024	3192
Share of exports in production		%	68,6	70	70	70
Production	Target	thou. tons	3928	4300	4356	4709
Domestic consumption			1246	1240	1373	1500
Exports			2698	3026	2954	3189
Share of exports in production		%	68,6	70	68	68

Source: Draft Strategy for RF metallurgical industry development to 2024 and 2035.

In 4S scenario, key carbon-intensive products manufacture and exports are adjusted to the scenario storylines (Chapter 4) and estimates of how the sanctions will affect Russia's economic development (Chapter 3). An assumption is made, that the technical level of production capacities will be slowly changing by limiting the old capacities phase out to 0.5% per year and upgrading 1% of the remaining capacity per year. The commissioning of new capacity is determined by the growth in output and the retirement of the existing capacity. Both these factors set significant restrictions.

An assumption is made that new capacities are built to meet at best the BPT (best presently practical technologies) or the Best Available in Russia Technologies (BART) level. In terms of exports, it is assumed that they will rebound by 2031 to the 2021 level and then are fixed on this level for a number of basic materials, such as iron and steel and cement, to 2060, and for others, such as pulp and paper, chemicals, aluminum, it grows by 1% per year.

4S scenario assumes, that hydrogen use for DRI production will start in 2031 to progress based on additional steel capacity demand and DRI-H2 cost competitiveness. Ammonia exports for feedstock and energy uses in addition to the traditional use for fertilizers production will start in 2040 from 1 Mt capacity and double in 2060. The split for SMR and H_2-based technologies is based on the costs assuming that no subsidies will be provided to support H_2-based ammonia production. Ammonia production via SMA-CCS cycle will start in 2042 and DRI-natural gas-CCS production will be launched in 2031 with a subsequent scale up based on comparative materials costs competition.

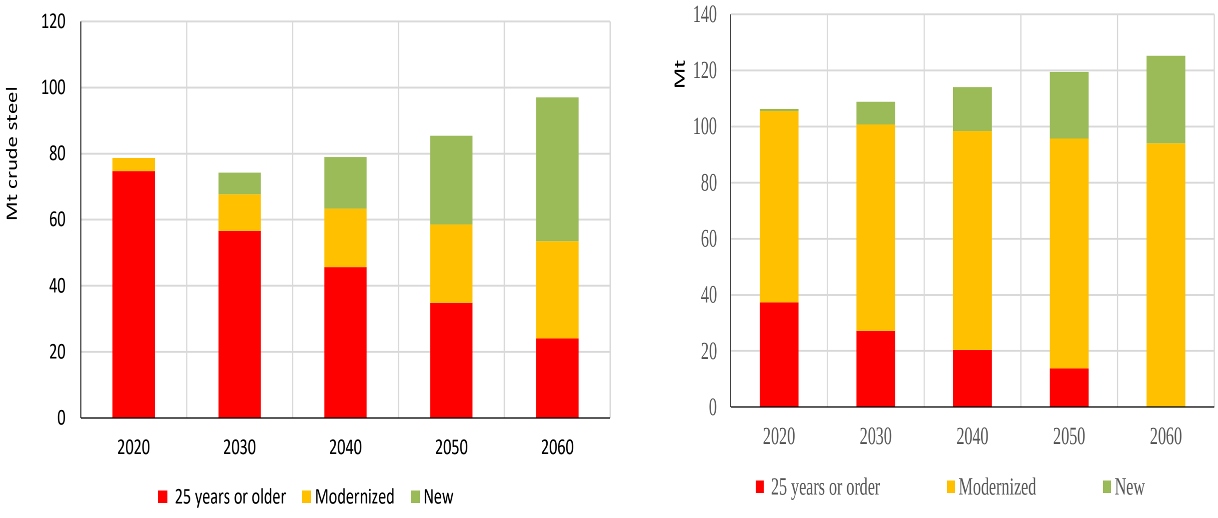
The evolution of the capacity age structure in 4S is slow, however, many of the existing obsolete facilities will have to be replaced and/or deeply modernized before 2060 (Figure 5.5). The 2020s' economic crisis and related drop in the domestic and foreign markets accompanied by reduced access to capital impedes capacity additions and the modernization of the capacity in place forcing business to run old, uncompetitive, and inefficient technologies. The reliance on self-sufficiency in 4S scenario provokes two questions:

- whether Russian equipment manufacturers and/or suppliers from countries, which did not impose any sanctions, will be successful in supplying sufficient amounts of high-quality equipment to replace the obsolete capacities with expired service life?
- which technological level (BAT, BPT, BATR) will these capacity additions have and how far will this technological level be behind the best available technologies?

Two decades – the 2020s and 2030s – which have the crucial role in accumulating the know-how and developing skills related to the application of industrial technologies with high GHG mitigation potential may be wasted. Path dependence – when future emission trajectories are determined by the investment decisions taken in the past – may impede emissions decline close to the mid-century if newly commissioned or modernized industrial capacities are not up to the BATs and so high carbon intensities may be locked-in for the decades to come. By 2060, nearly all industrial capacities are to be either new or modernized.

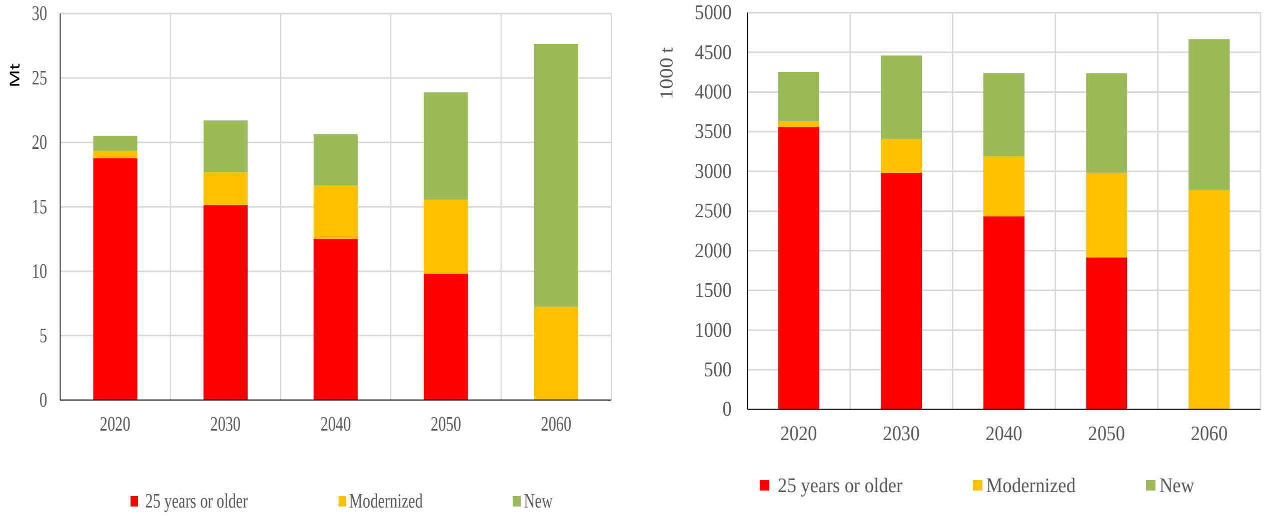
The decades 'lost' in terms of technological development can make assets commissioned in the 2020s and 2030s stranded (suffering from unanticipated and premature right-offs) in the 2040s and 2050s. Climate regulation will further develop worldwide with a wider geographical and product coverage of CBAM-like mechanisms blocking access to the global markets for highly carbon intensive products. Many industrial facilities' lifetime varies between 30 and 60 years, therefore, if highly carbon intensive capacities are commissioned in the 2020s and 2030s they may become stranded well before their lifespan expires.

Figure 5.5 Production capacity structure in 4S scenario



steel

cement



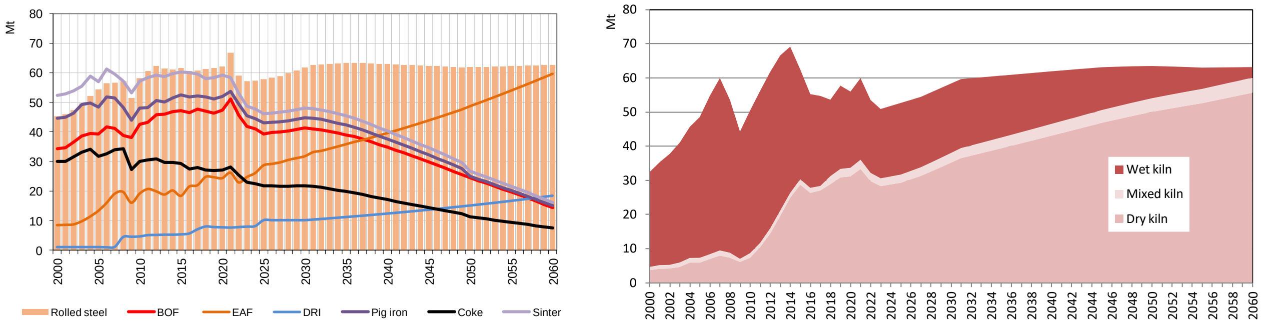
ammonia

aluminium

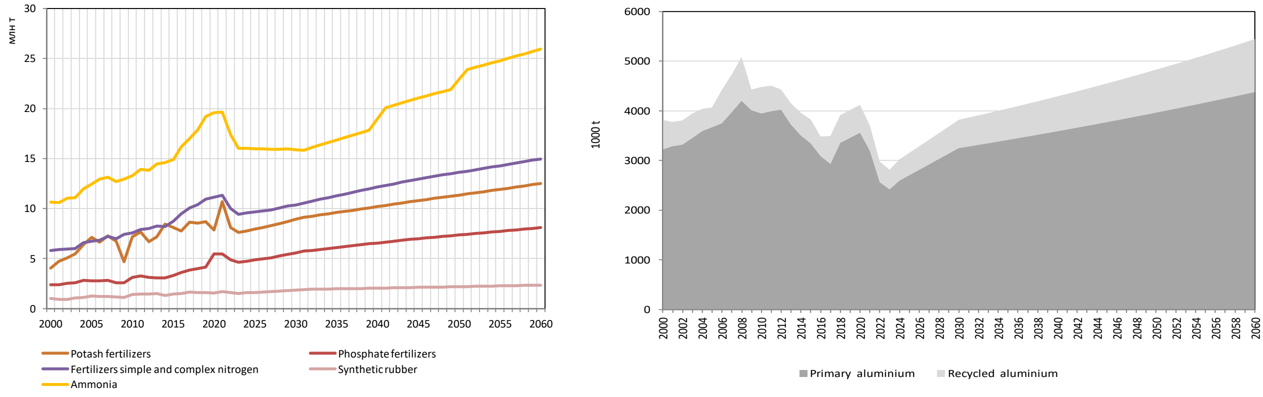
Source: CENEf-XXI.

After a rebound to the 2021 level in 2031-2032, basic materials demand in 4S scenario is expected either to stay nearly stable (steel and cement) or slowly grow (pulp and paper, chemicals and aluminium) (Figure 5.6). The products structure for integrated industries, like iron and steel, will be slowly evolving to 2031, and then, as the age capacity structure evolves, the penetration of new technologies by 2060 will be captured in structural changes across the supply chains. These structural and technological changes are expected to be much behind the global regions.

Figure 5.6 Basic materials production in 4S scenario



iron and steel cement



chemicals aluminium

Source: CENEf-XXI.

In 4S scenario, Russian industry has a long way to go to attain the net-zero GHG or net-zero carbon status by 2060 (Figure 5.7). Industrial GHG emissions in Russia will be 19% down in 2031 driven by the economic crisis and later by technological change, as new and modernized capacities will be commissioned on a large scale, and will reach 42% of the 2021 level in 2060. Overall decline over 2021-2060 for CO_2 direct combustion-related emissions will be 64%, for CH_4 63%, for N_2O 43%, and for indirect CO_2 emissions 50%. CCS is used on a limited scale in steel, cement, and ammonia production and will reach 22.5 $MtCO_2$ by 2060. Sinks in urea production will stay mostly unchanged. The sponge effect in concrete structures allows for a capture of nearly 26 $MtCO_2$, which is more than the CCS contribution. Carbon price in 4S will reach 30 $US/$tCO_2$ providing a limited impulse for large-scale low carbon technologies penetration.

Slow decarbonization in the Russian industry in 4S scenario impedes access to the international markets for traditional Russian basic materials, because global economy is becoming less carbon-intensive plus beyond 2023 oil and gas revenues will be steadily declining. This leaves no chance for a dynamic rebound of traditional markets. Russia's isolation from the global supply chains and its self-reliance for the manufacture of new products will block the country's penetration to emerging trillions-of-dollars-worth markets outlined in Chapter 4. This will squeeze Russia out of the global economy and halve its contribution to the global GDP (Chapter 3). At this stage, carbon intensities of many Russian basic materials, which dominate in the country's export revenues (Chapter 3), are quite close to those in the EU and worldwide.[142] But lagging behind in the decades to come will drastically widen the gap, especially in the 2020s and 2030s. Slow economic progress to 2060

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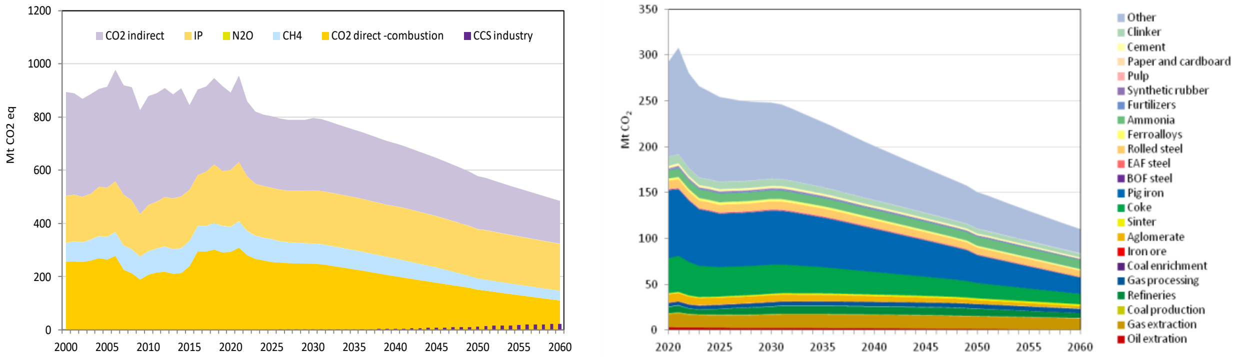
[142] Bashmakov I.A. CBAM and Russian exports. Voprosy Ekonomiki. 2022;(1):90-109. (In Russ.). https://doi.org/10.32609/0042-8736-2022-1-90-109; Bashmakov, I., et al., 2021a: *CBAM: Implications for the Russian economy. Center for Energy Efficiency – XXI.* Moscow, Russia, 22 pp.

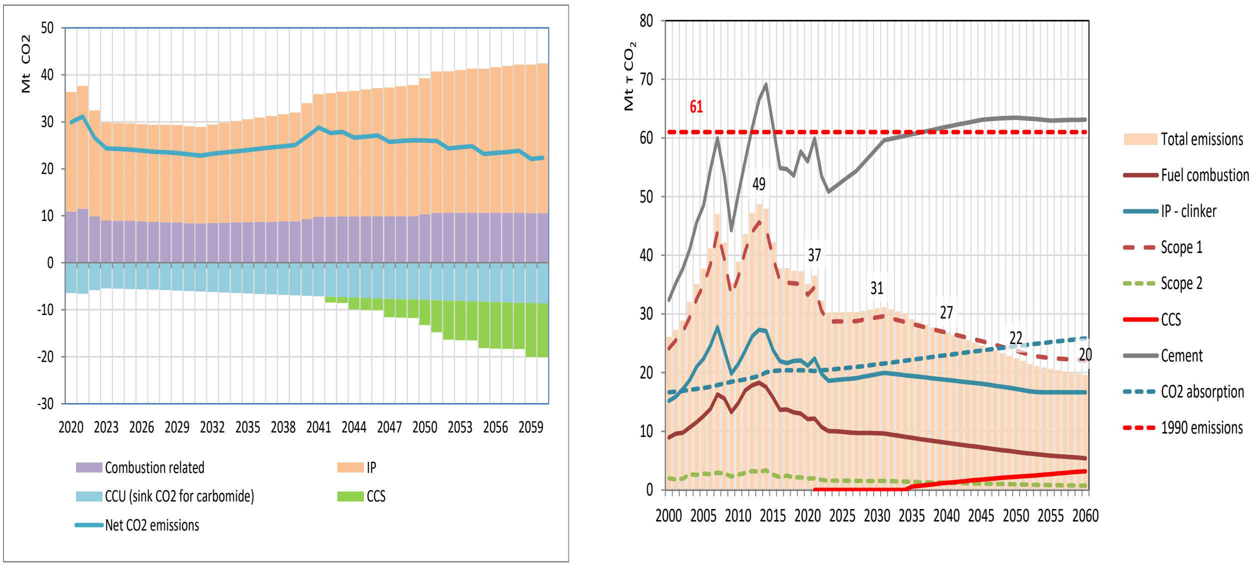
will make it highly challenging to bridge this. There are decades of evidence that integration in the global supply chains always drives technological progress stronger, than a closed command economy can ever hope to drive it.

Figure 5.7 GHG emissions from industry in 4S scenario



(a) direct and indirect industrial GHG emissions by gases

(b) direct combustion-related CO_2 emissions by industries



(c) CO_2 emissions and sinks in ammonia production

(d) CO_2 emissions from cement production

Source: CENEf-XXI.

5.3 Transport

In 4S scenario, transport faces declining demand determined by both freight and passenger transportation drop coupled with reduced supply of cutting-edge transport equipment (due to the ban on the imports of new vehicles and parts; extended lifetime for already operating vehicles along with the growing amount of out-of-service units; lower rates of fuel efficiency improvements for fleet additions and thus to overall fleet, and less active policies to promote low carbon equipment, such as PHEV and BEV, and to support a switch towards less GHG intensive transport modes.

Recently, the share of imported LDV and trucks in new sales used to be 15-16%, and about 5% for buses. For many years, localization of transport equipment has been in the focus of the government, but only limited progress was achieved:[143] in 2017, **only 29% of LDVs were produced based on Russian automobile platform designs**, and the level of localization for the

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[143] Automobile sector development strategy of the Russian Federation to 2025. Approved by the RF government decree of April 28, 2018, No. 831-r.

whole industry was limited to 60% (vs. 40% in 2008); for trucks to only 25% (vs. 10% in 2008). The share of imported ICEs is 26% (vs. 2% in 2008). The new sanctions have ruined both automobile imports and local production (lack of components), and new LDV sales can be expected 30-70% down to 600-1,000 thousand in 2022. The lower end of the range is more likely. This is 2,5-4 times less, than the amount sold back in 2000-2010. Therefore, in the years to come the number of cars with expired service life will significantly exceed new sales leading to a temporal reduction in the car fleet.

Another problem is equipment maintenance with poor supply and higher costs of components. This will negatively affect the ratio of technically sound vehicles and the average millage. This may affect, for example, the number of electric buses in service in Moscow. The share of electric vehicles in the fleet was expected to reach 5% by 2025. Their penetration rate was lower, than planned, and reached only 0.03% in 2021. Due to the declining costs and persisting support policies (yet limited by financing demand to promote penetration) some progress with the intake of PHEV, BEV, and gas-driven vehicles is expected, but much delayed.

Russian aircraft industry, highly relying on the imports, was also severely hit by the sanctions. As stated by the RF government:

> "Low performance of the domestic civil aircraft industry is determined by long development and manufacture cycles for new aircrafts; insufficient technical performance in a highly competitive environment; poor after-sales maintenance, technological marginalization in a number of areas, as well as "insufficiently effective actions by authorized federal agencies and manufacturers to promote aircrafts".[144]

The recent revision of the government's aircraft industry development strategy was supplemented with the following:

> In recent years, foreign sanctions have become a negative factor for the development of the Russian aircraft industry leading to restrictions in terms of critical technologies imports, decreased possibility of purchasing foreign components, materials, and equipment. High reliance on imports of the domestic aircraft industry has led to delays in the development of, or failure to develop, new aircraft technologies and equipment.

New sanction packages have made the situation much worse, and the goal of the *Strategy*, which is 30% of PMT in domestic flights by Russian-made planes by 2030, has become unrealistic. To continue moving in this direction, the RF Ministry of Industry and Trade has developed a 1.84 trillion of rubles-worth project aiming to manufacture *"competitive products in the aircraft industry"* to produce 735 new civil aircraft (preset fleet is close to 7 thousand). Financial problems and unavailability of financing options will hardly allow it to raise this money though. Therefore, domestic aviation is expected to face severe problems with the availability of the fleet in service.

Equipment for other transport modes (rail, pipeline, water, urban electric) is expected to face similar problems: lack of new additions and poor technical condition of the vehicles in place, as their service life expires and appropriate maintenance cannot be provided for the lack of imported parts.

The most important effect of 4S scenario for freight transport is the reduction of activity on the whole time horizon to 2060. In 2060, freight turnover per unit of GDP will be 45% below the 2021 level. This is not a new phenomenon: the 1991 level of freight turnover was back only in 2021. The 2021 level is not expected to be reached in 2060. While in 2022-2031 the reason is mostly the effect of the sanctions and decline in industrial activities, especially in bulk materials production, beyond 2031 and especially 2045 this will be determined by the decarbonization of the global and Russian economy and resulting reduced demand for fuels transportation (which currently dominates – 67% of cargo) and stabilization of, or slow growth

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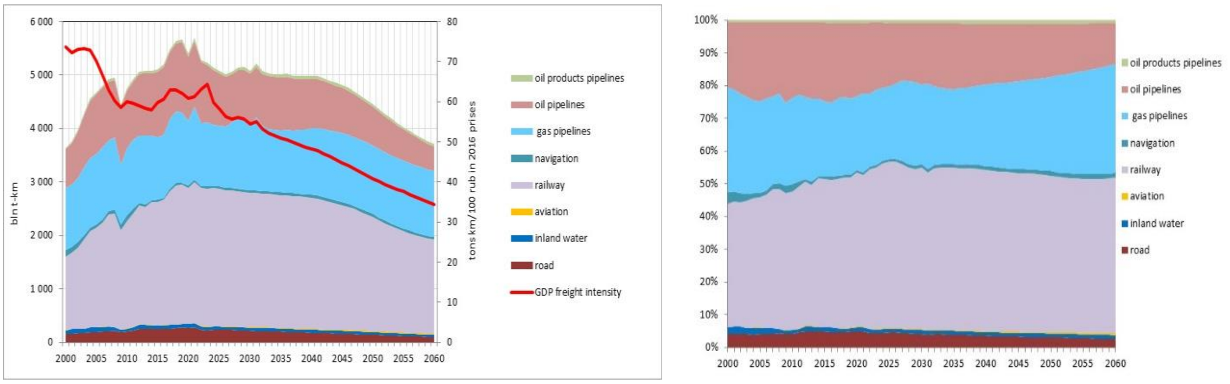
[144] RF Government, Decree of April 15, 2014, No. 303 "On the approval of the RF national programme "Aircraft Industry Development" (with amendments as of December 7, 2021).

in, global demand for basic materials (Figure 5.8). It will be only partly counterbalanced by longer transportation distances, as freight is shifted eastbound. Rail transport will be strengthening its position to 2025 and then will maintain it till 2060. The decline in fuel (presently 48%) and basic materials (another 38%) transportation by railroad will be only partly offset by growing transportation of finished products. Oil pipelines are losing it out to natural gas. The role of Russia's road transport in the overall freight turnover is about the lowest in the world and will continue declining.

Figure 5.8 Freight turnover by transport modes in 2000-2060 in 4S scenario

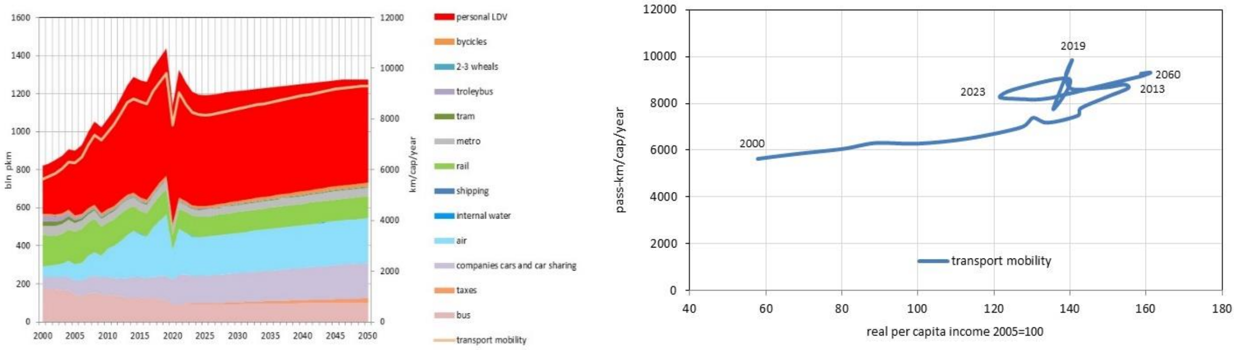


(a) freight turnover evolution (b) structure of freight turnover

Source: Data for 2000-2021 – Rosstat. Projections – CENEf-XXI.

Following personal incomes decline, personal mobility and passenger turnover will drop by 2025 and then grow very slowly to 2060 never reaching the pre-COVID 2019 level. The evolution of passenger mobility depends on the changes in real incomes and lifestyles (Figure 5.9). The slope of this income-driven function is relatively stable interrupted by flips and flops in personal incomes after 2013. Therefore, moderate increment in mobility is a result of a continuous and deep decline in personal incomes. As population is steadily declining and aging, overall demand for personal transport grows even slower, than personal mobility. Despite some shift towards public transport, its turnover never gets back to the 2019 level which, in turn, was 15% below 1991. In 2060, the share of cars in passenger turnover (58%) will exceed that in 2019 (55%), but the ownership structure shifts towards taxi, company cars, and carsharing, while the share of personal cars shrinks from 46% in 2019 to 40% in 2060.

Figure 5.9 Passenger turnover by transport modes in 2000-2060 in 4S scenario



(a) passenger turnover evolution (b) passenger turnover as a function of disposable income

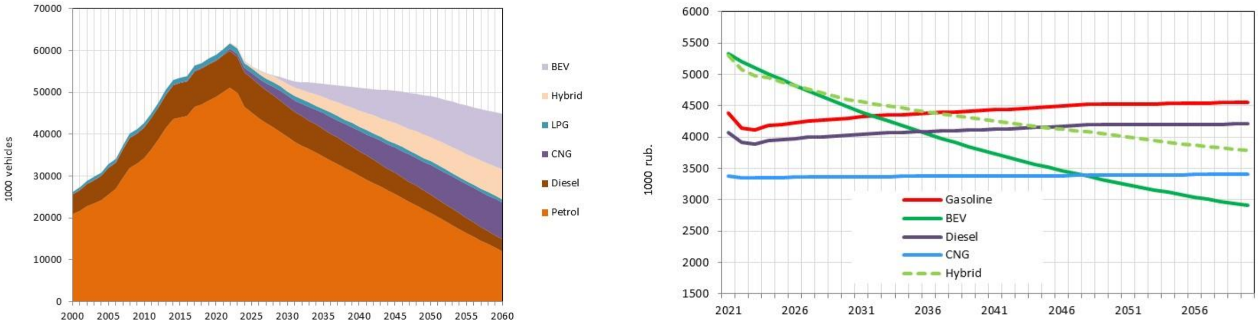
Source: Public transport data for 2000-2021 – Rosstat. Road transport for 2000-2021 – CENEf-XXI. Projections – CENEf-XXI.

Russians will have fewer cars, which, in addition, will be continuously aging to become less reliable and less fuel efficient. The share of imported second-hand cars is expected to grow.

In 4S scenario, road transport fleet (at least the technically sound part of it) will be falling down by 2030 as the sales of new cars will be much lower compared to those with expired service life (added to the fleet 15-20 years ago). Therefore, the size of the 2021 road transport fleet (over 60 million) is an absolute peak. Russian experts had expected road transport to peak much later – in 2035-2040 – and at a much higher level – about 75 million.[145] However, the LDV fleet peaked in 2022 at 49 million (Figure 5.10), then also fell down and stabilized, as its evolution is restricted by low incomes, lack of new cars supply, and a continuous shift towards more intensively used cars, such as taxis, company cars, and carsharing. In this scenario, new sales are expected to have lower fuel efficiency compared with other countries, and the overall fuel efficiency will be improving slowly, as the fleet will be aging and the service life will be extended beyond normal levels.

Fleet structure by power train will be slowly evolving towards less carbon intensive models, but in this race, Russia will be lagging far behind the technological leaders. Since locally produced or imported from China or elsewhere PHEV and BEV are winning the costs competition from ICE (Figure 5.10), they will penetrate the Russian market. According to some estimates, PHEV and BEV will become competitive in Russia by 2031-2036. The Russian government is providing support for the development of the charging infrastructure, free parking for EV, reduced or even cancelled EV vehicle tax rate, free use of toll highways, setting “zero emission” zones with a ban for ICE vehicles. In 2021, the RF government projected 217 thousand domestically produced EV, 8573 slow-charging stations and 5815 fast-charging stations.[146] There were plans to set minimum requirements for car producers and importers in terms of the EV share in total sales effective from 2029. In addition, there are policies in place to promote compressed gas-driven vehicles to expand local natural gas markets. These policies and those under development, as well as better economics of low carbon vehicles and a carbon tax for fossil fuels will bring the share of CNG gas-driven vehicles to 19%, PHEVs to 16%, and BEVs to 29% in 2060. In its earlier “1.5°C” scenario, Moscow Automobile and Road Technical University expected the share of EVs to reach 77% in 2050, and Petromarket expected EVs to reach 100% in new sales by 2050.[147] In 4S, it is expected to reach 50% in 2060.

Figure 5.10 LDV fleet by power train (a) and cost of car ownership (b)



(a) LDV fleet (b) cost of car ownership

Source: CENEf-XXI.

Transport activities decline, along with slowing down fleet modernization strongly relying on domestic cars production, will slow down fuel efficiency improvements and deployment

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[145] Center for Transport Innovations, LLC. Brief research paper “Science-based projection for automobile sector adaptation to expectable implications of climate change and potential decarbonization scenarios in the Russian Federation”. Moscow, 2021.

[146] The concept of electric road transport development and use in the Russian Federation to 2030. RF Government Decree No. 2290-r of August 23, 2021.

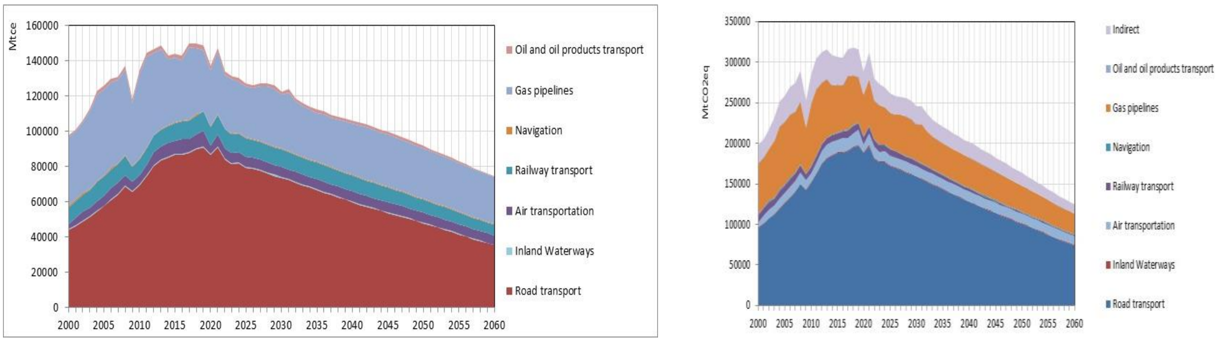
[147] Center for Transport Innovations, LLC. Brief research paper “Science-based projection for automobile sector adaptation to expectable implications of climate change and potential decarbonization scenarios in the Russian Federation”. Moscow, 2021; Petromarket, 2021. GREEN REVOLUTION IN EUROPE: IMPLICATIONS FOR RUSSIA. Part 1. Road transport. Moscow, June 2021.

of low carbon fuels by all transport modes. The SECs were growing in 2000-2021 for railroads, urban electric transport, internal water, and oil pipelines. Every year, the fleet will be replenished with smaller amounts transport equipment, which will be less efficient, albeit locally designed and produced, while the service life of the remaining cars will be extended at the expense of lower efficiency and reliability and lower quality service. All these factors will halt fuel efficiency improvements in aircraft, rail, pipeline and urban electric transport.

Total energy consumption by transport in 4S scenario will be halved in 2021-2060 dropping from 148 to 73 Mtce (Figure 5.11). Road transport will maintain its dominance, while the energy use will shrink from 91 to 37 Mtce. The former number is the absolute peak. Energy use in the aircraft sector will be 22% down, in railroad 43% down, in gas pipeline 34% down.

In 4S scenario, GHG emissions from transport already peaked at 284 million tCO_2eq. in 2018 and will be steadily declining to 113 million tCO_2eq. in 2060. The share of fossil fuels in the transport energy balance will be moderately declining from 91% in 2021 to 80% in 2060. Therefore, GHG emissions adjusted for the declining carbon intensity will follow the energy use pattern. Indirect emissions also peaked in 2018 at 33 million tCO_2eq and by 2060 they will be halved to 16 million tCO_2eq. Road transport continues dominating GHG emissions (Figure 5.11). New realities and emerging trends make it possible first to stop GHG emission growth due to activities reduction and then to reverse it against the background of slow economic recovery and a limited progress in transport decarbonization.

Figure 5.11 Energy consumption by transport in 4S scenario



(a) energy consumption (b) GHG emissions

Source: CENEf-XXI.

5.4 Buildings

In the coming years we should expect a decline in housing construction. The sanctions will negatively affect residential construction (growing mortgage rates, decreasing household incomes and poor access to loan financing for construction companies, rising costs of construction materials, supply restrictions for construction and housing equipment, etc.). The Russian government will have to make a substantial effort to stabilize and gradually restore housing construction. The availability of living space will be increasing not only through housing additions, but also through population decline.

The plan is to gradually strengthen energy efficiency standards for new residential and public buildings on the 2028-time horizon: specific energy heat consumption should be 35% down from the baseline. RF Ministry of Construction’s draft order “On approval of energy efficiency standards for buildings, structures, and facilities and Rules for specifying energy efficiency categories” sets a fairly soft schedule for strengthening these requirements. In 4S scenario, the target parameters of this document are fixed until 2060. The assumption is that the share of buildings with low energy consumption and ‘passive’ buildings will be insignificant due to the rising construction costs.

In 4S scenario, energy efficiency of the apartment buildings in place will be declining. In the recent years, the share of capital retrofits associated with energy efficient projects has not exceeded 0.15% of the total residential floor space. In the coming years, this share may significantly decrease due to the rise in materials and equipment costs[148] and because a decline in real incomes makes it hardly possible to increase the price of capital retrofits. Public subsidies for energy efficient capital retrofits are canceled and are not considered in this scenario. These trends will result in a continuous decline in capital retrofits which will yield only small energy-savings. The assumption is that only a package of measures with low energy efficiency effects will be implemented in this scenario.

The sanctions might much less affect the energy controls market due to the high local content of energy meters. Russian manufacturers meet 85% and 77% of electric and water meters demand respectively[149]. The remaining amounts are mostly imported from countries that have not introduced any sanctions. This scenario assumes a further increase in the amount of meters and controls in place.

Another assumption is a total phase out of incandescent lamps by 2035. The local content of LED-lamps is quite high. While there is a risk of restrictions for crystals supply from Taiwan, it is not very high, for there are many manufacturers in China.

Heat pumps production is established in Russia (Henk and Smaga companies have their factories), yet all of the components are imported from the West. One can hardly expect that component production can be established in Russia in the short-term. In the distant future, heam pumps production will be based on domestic components and/or imports from the countries that have not imposed any sanctions. Therefore, 4S scenario assumes low heat pumps deployment.

A substantial part of the heating boilers and water heaters used in buildings are produced abroad or using foreign components. The sanctions made some manufacturers leave the Russian market and their place may be eventually occupied by domestic and/or alternative suppliers (including parallel imports). However, this may result in a decrease in space heating and water heating efficiency. This factor was taken into account when specifying prospective efficiency levels.

It will not be possible to 'import' the energy efficiency of appliances on the previous scale, because the sales of appliances, especially of energy efficient appliances, will be decreasing in the coming years. Then a slow recovery at a lower technical level can be expected through imports substitution. The situation in the appliances markets will depend on the reliance on the imports of components from the countries that have imposed sanctions. The share of TV sets produced in Russia with different local content is 80%, of monitors is 35%, of washing machines is 90%, of refrigerators is 90%[150]. At the same time, for some positions domestic manufacturers completely rely on imported components. Only imported compressors are used for refrigerators and freezers production, and 32.4% of the compressors used to be imported from the EU[151]. A similar situation is observed in the washing machines market, where domestic producers almost fully rely on imported engines and electronic units.

The use of renewables in buildings and transformation of Russian households into prosumers will be developing, even if at a slower rate. In Russia, high local content requirements are set for solar and wind powerplants production. In the Russian market, there are both domestic manufacturers and those from countries that have not imposed any sanctions (China, etc.).

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[148] In April 2022, the prices are 31% above the last year's level. https://www.interfax.ru/business/840751.

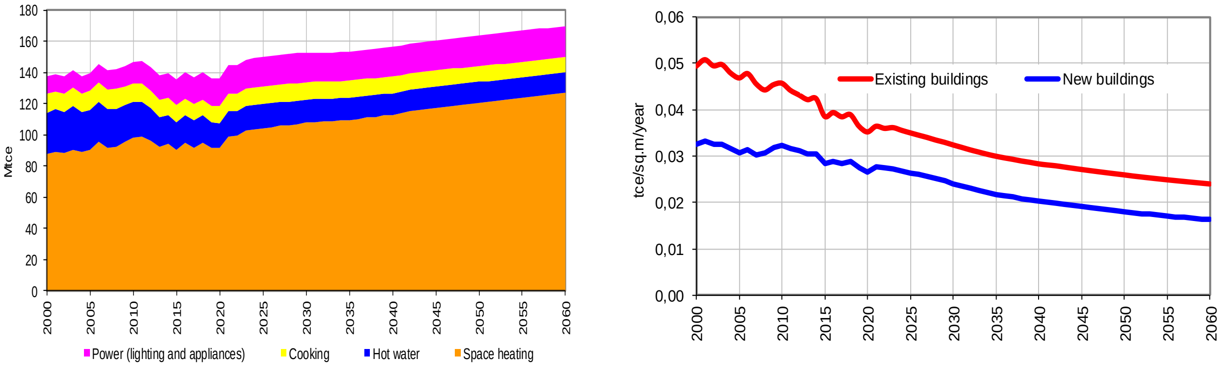
[149] https://lenta.ru/news/2022/06/07/schetchiki/.

[150] https://www.vesti.ru/finance/article/2703623.

[151] https://holodcatalog.ru/entsiklopedii/obzory-i-analitika/rynok-kholodilnogo-oborudovaniya-v-rossii-2022/.

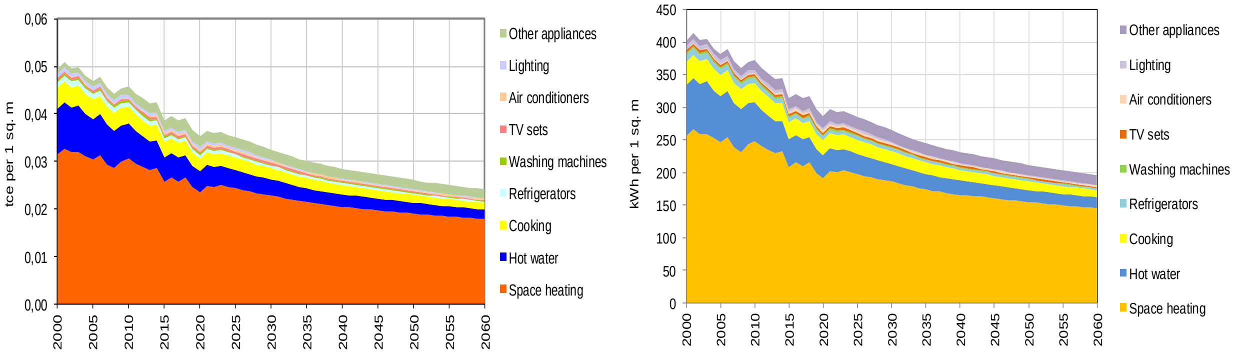
In this scenario, after a continuous stabilization in 2000-2020, residential energy consumption will be 24% up from the 2020 level by 2060 (Figure 5.12a) to reach 170 million tce. By 2060, energy consumption per 1 sq. m will be down to 16.3 kgce for new buildings and to 24.1 kgce for existing buildings (Figure 5.12b). Average energy consumption per 1 sq. m will be 32% down by 2060, and average energy consumption for space heating will be 24% down (Figure 5.12c). Space heating will keep dominating in the structure of energy consumption: 74% in 2060 (Figure 5.12d).

Figure 5.12 Residential energy consumption in 4S scenario



a) Structure of residential energy consumption

b) Specific energy consumption in new and existing buildings



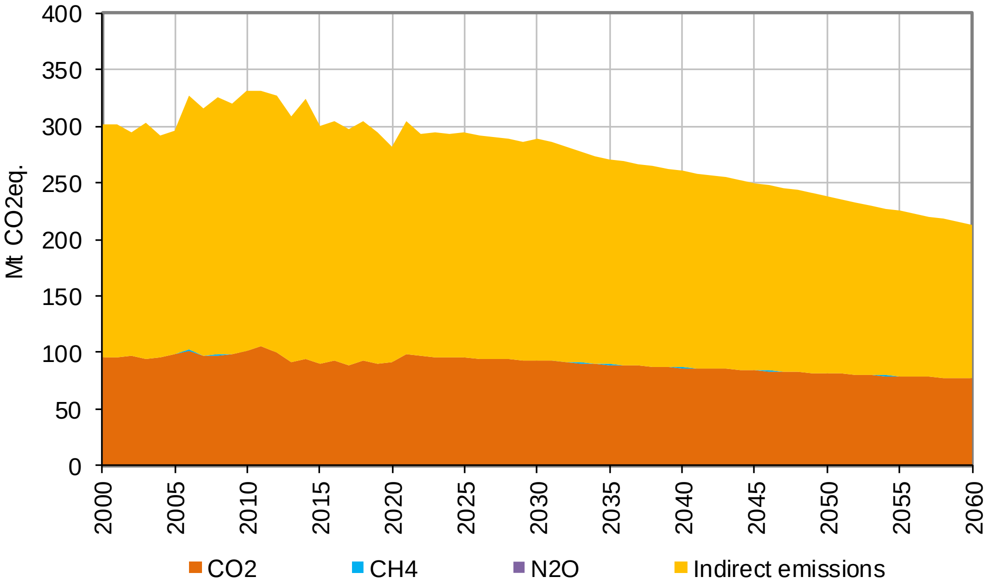
c) Specific residential energy consumption by processes

d) Specific residential power consumption by processes

Source: CENEf-XXI.

Direct GHG emissions from residential buildings will slightly increase in the short term, and then will drop to 77 million tCO2eq. by 2060 (Figure 5.13). Unlike in other sectors, the decline in housing construction in the 2020s will not terminate the floorspace and energy consumption growth. However, as energy efficiency and electrification of residential buildings are improving, even if slowly, and indirect emissions from electricity and heat use are declining, overall GHG emission will be going down. Natural gas consumption for space heating, DHW, and cooking is responsible for the larger part of direct emissions. GHG emissions from the combustion of other fuels (coal, LNG, etc.) are small and will be also going down. Specific direct GHG emissions will drop to 10.8 kgCO2eq./m^2 of total residential floorspace by 2060, or by 45%. Ultimately, cumulative (including indirect) GHG emissions will be down to 32.8 kgCO2eq./m^2 by 2060, or by 58%.

Figure 5.13 **Evolution and structure of residential GHG emissions in 4S scenario**



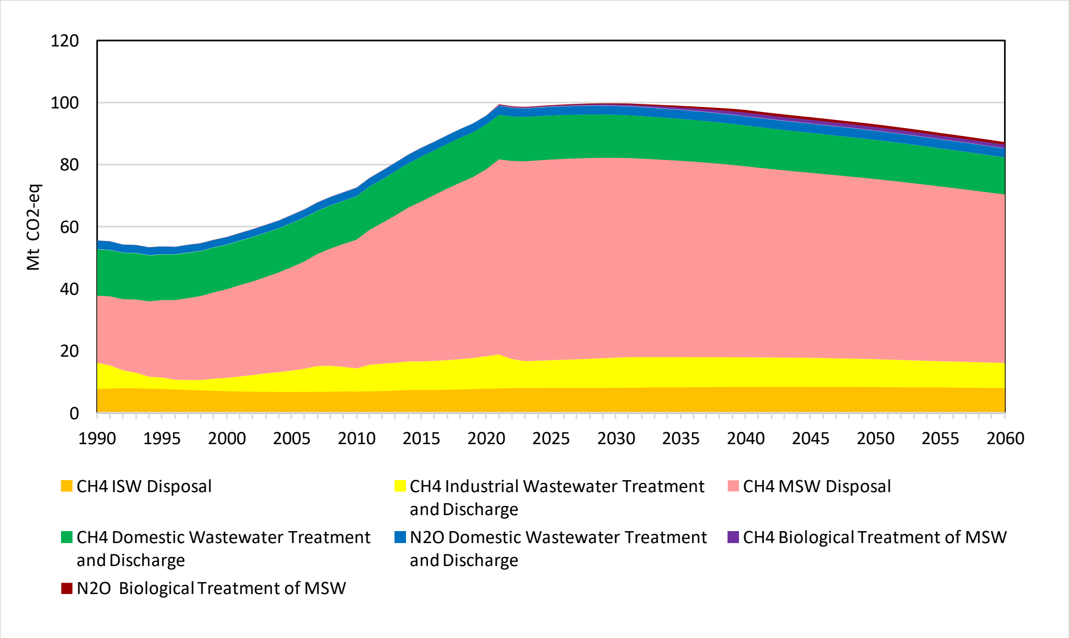
Source: CENEf-XXI.

5.5 Waste

A limited set of measures in the waste sector allows it to freeze GHG emissions to 2030 at a level close to that in 2020 with a subsequent 9% decline. The waste sector will be suffering from the shortage of technologies. The following assumptions were made. The volume of combustible unsorted MSW will not change between 2020 and 2030. All phased-in waste-to-energy plants will keep working. Five more waste-to-energy plants with the total 3.35 million tons/year capacity will be commissioned for sorted MSW. The degree of MSW sorting will be growing to reach 100% in 2030. Deep sorting will reach 44% through separate waste collection. Other MSW will undergo superficial sorting. The methane produced will be burnt at all landfills only in the territory of Moscow and Moscow Oblast requiring efficient degasification for the reclamation of most landfills in Moscow oblast. An assumption was made, that resource efficiency and waste recycling technologies for pulp and paper, textile, leather, food, and wood industries, as well as for construction and agriculture, will bring down solid and liquid waste by 1% per year to 50% below the initial level. By improving the efficiency of centralized aerobic waste treatment facilities, the degree of anaerobicity can be reduced by 1% per year.

The major driver for waste-related emissions is generation of MSW, which is the function of population size, income level, and waste collection, sorting, and treatment technologies. The first two factors will stay below the 2020 level until 2031 (Figure 5.14). The decline is not as deep as back in the 1990s, so emissions will not decline till 2031. Beyond that the population will continue to decline, while incomes will be slowly growing. Ultimately, steadily but slowly, new technologies uptake will allow it to reverse the emission growth trend which manifested in 2000-2020.

Figure 5.14 GHG emissions from waste in 4S scenario



Source: CENEf-XXI.

5.6 Agriculture

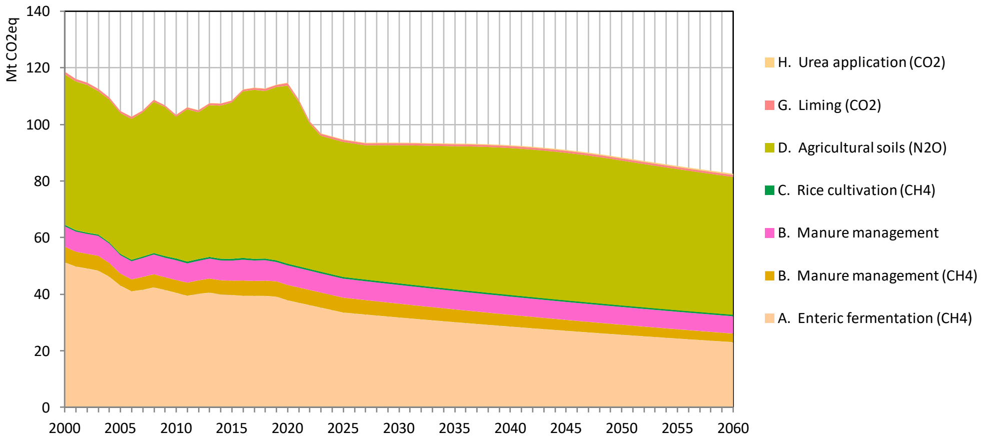
In Russia, there are no long-term models to assess the prospective evolution of GHG emissions from agriculture, nor there are any long-term agriculture development programmes. Therefore, the ENERGYBAL-GEM 2050 model has a simplified calculation block to obtain such estimates. For the agricultural sector, GHG emissions from animal husbandry and crops production. The calculations accuracy could be improved through a thorough analysis of livestock population and fertilizers demand and of other parameters involved in switching to alternative diets and environmental friendlier agricultural technologies.

The larger part of GHG emissions from this sector include livestock enteric fermentation and emissions from agricultural lands (mostly from non-organic and organic fertilizers). The contribution from other sub-sectors is only moderate. After the GHG emission halved in 1990-2000, agricultural emission practically stabilized. However, a growth trend formed after 2007 (Figure 5.15). Over the recent decade, emission from livestock enteric fermentation showed practically no change, while emission from agricultural lands has grown up.

Only one scenario for agriculture was considered, which assumes that the 2005-2020 GHG emissions growth trend will be reversed through a package of measures from both demand and supply side. Supply side measures will aim to reduce GHG emissions from livestock enteric fermentation and indirect emissions from agricultural lands and N2O emissions from manure management. Demand side measures include diet control and reduction in food waste.

One key measure to reduce livestock enteric fermentation is to replace low-yielding breeds of dairy cows with high-yielding ones and to reduce the pig livestock. N2O indirect emissions from agricultural lands can be attained through measures aiming to reduce the leaching from soils of nitrogen brought in through mineral and organic fertilizers, including more accurate account of soil&climate conditions; better application timing and watering regimes; application of slow-acting mineral fertilizers; combating soil erosion and deflation; etc.

Figure 5.15 Evolution and structure of agricultural emissions in 4S scenario



Source: CENEf-XXI.

If agricultural emissions are to move down from peak, it is important to implement demand-side measures, including food waste reduction and alteration of diet. In Russia, food waste can be estimated at 20-30 million tons. On average, it takes some 20 kg of fertilizers to produce 1 ton of food.[152] If food waste is halved, fertilizers uptake in Russia could be 0.4-0.5 million tons down (4-5%). The Committee on Climate Change estimates, that 20% reduction in food waste and 20% reduction in the consumption of cattle meat and dairy products, could bring agricultural emissions 15% down.[153] New food technologies, such as cell-based fermentation, cultivated meat, or plant-based alternatives to animal products, can substantially reduce GHG emissions in addition to reducing land and water demand.

Bringing down the share of food products with a high carbon footprint (as carbon footprint estimation and reduction practices develop) and replacement of some products with their alternatives, for example, replacement of beef with poultry meat, could become important directions for GHG emission reduction. Reduction in the consumption of carbon intensive agricultural products along with higher crops yields could take large areas from agricultural use and eventually turn them from a source into a sink. A rational approach and reduced meat and dairy consumption can substantially decrease the cattle population and reduce GHG from livestock enteric fermentation, wastewater, manure management, manure use in pastures, and will clear out pastures and territories taken by forage crops. A substantial reforestation potential can be tapped by reducing the pasture uptake through improved beef production efficiency and reduced beef share in the diet.[154]

Diet control may be more effective, than GHG emissions mitigation in agriculture.[155] However, because of a substantial diet patterns inertia, this option is less realistic. A decline in the consumption of carbon intensive agricultural products and reduction in their carbon

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[152] Material Economics. (2019). Industrial Transformation 2050: Pathways to net-zero emisisons from EU Heavy Industry.

[153] UK Committee on Climate Change. July 2019. Reducing UK emissions. 2019 Progress Report to Parliament.

[154] Ritchie, H., Reay, D.S. and Higgins, P., 2018. The impact of global dietary guidelines on climate change. Global environmental change, 49, pp.46-55.

[155] Popp A, Lotze-Campen H and Bodirsky B (2010). Food consumption, diet shifts and associated non-CO2 greenhouse gases from agricultural production. Global Environmental Change 20(3), 451–462. doi: 10.1016/j.gloenvcha.2010.02.001; Bajzelj B, Richards KS, Allwood JM, Smith P, Dennis JS, Curmi E and Gilligan CA (2014). Importance of food-demand management for climate mitigation. Nature Climate Change, Nature Publishing Group 4(10), 924–929. doi: 10.1038/nclimate2353; Smith P, Haberl H, Popp A, Erb K, Lauk C, Harper R, Tubiello F N, de Siqueira Pinto A, Jafari M, Sohi S, Masera O, Böttcher H, Berndes G, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig E A, Mbow C, Ravindranath N H, Rice CW, Robledo Abad C. How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? DOI: 10.1111/gcb.12160.

footprint[156] can bring down GHG emissions from all sources in the agricultural sector and might also affect other sectors, such as energy sector (by reducing fuels, power, and heat demand and by substituting fossil fuels with biogas[157]), waste sector, and LULUCF (through the transition of released territories into other categories).

In this scenario, GHG emissions from agriculture appear to have already peaked, and will be declining to reach 100 Mt CO2eq. In most cases, improving the efficiency of agricultural production and reducing food waste do not incur any additional spending. Such investments payback fairly quickly. Where the cost-effectiveness is improved in animal husbandry, the emissions are more than 50% down. Nearly all of the measures aiming to stabilize or reduce GHG emissions from agriculture pay back even net of the climate effect.

5.7 LULUCF

2F (Forest First) is the pathway to carbon neutrality favoured by the Russian Government. It implies a large additional sequestration in LULUCF (by adding 665 Mt CO_2eq. of net sinks in 2019-2050), while emissions reductions in other sectors will be moderate (-289 Mt CO_2eq. reduction in 2019-2050).[158] Russian mitigation policy is based on the hopes that it will be possible to provide science-based evidence that current net sinks in LULUCF are highly underestimated and that in reality they are much larger and can be substantially and cost-effectively scaled up by the mid-century. At the same time, it is recognized that the scarce data on CO_2 flows in natural systems is a weak ground for the *Strategy*. Looking to lay down a more solid scientific basis for these aspirations, in 2022 it was decided to allocate large resources to support extensive research in this direction.[159] The Russian Low Carbon Development Strategy to 2050 builds on the assumption that net sinks in LULUCF can be up to reach 1,200 MtCO2eq by 2050.

The goal of the Russian Low Carbon Strategy – to more than double net sinks by 2050 – looks extremely ambitious. While Russian forests are huge, the country does not have reliable data on their qualitative and quantitative characteristics. Therefore, the role of the LULUCF sector in the implementation of the carbon neutrality strategy is the least defined. Recent trends show,[160] that:

- net CO_2 emissions from LULUCF were 150 Mt CO2 down in 2010-2020: from 754 to 604 Mt CO2;
- net CO2 emissions from only forest lands were 133 Mt CO2 down: from 782 to 649 Mt CO2;
- carbon sink in forests has stayed about stable since 2009 and the forest-covered territory has been stable since 2005;
- net sink in forests is declining driven by CO2 losses. This decline equals 140 Mt CO2 in 2010-2020;
- carbon losses have been steadily growing since 2005 resulting from clearcuts and forest fires, for which there is a clear upward trend reaching 4-7 Mha/year in the recent years.
- as a result, net sinks reduction in LULUCF contributed 79% to the total net GHG emission increments in 2010-2020 and exceeded 100% (over-offsetting the reductions in other sectors) for total CO_2-only emissions increment.

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[156] Methane and N2O emissions dominate in many agricultural activities, while CO2 emissions are not significant.

[157] According to the data available, biogas plants in Russia generated 22 mln kWh in 2020.

[158] Russian Low Carbon Development Strategy to 2050. RF Government Decree No. 3052-r of October 29, 2021.

[159] The most important innovation project of national importance "Unified National Monitoring System for Climate-Active Substances".

[160] National Inventory Report of the Russian Federation on anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by Montreal Protocol for 1990 – 2020. Part 1, Moscow, 2022.

Extrapolation of these trends for 2050-2060 sets LULUCF net sink decline baseline, against which the LCS goal for LULUCF net sinks looks even more ambitious.

In this paper, evolution of net emissions in LULUCF was estimated as the additional net sink demand (LULUCF plus) to attain carbon neutrality in 2060. A CO_2 net sink baseline was set for 2021-2060 as extrapolated declining trend which formed in 2010-2020. It scales net sinks down to 115 $MtCO_2$ in 2060. These baseline values were deducted from the emissions remaining in the other sectors. The residual is an additional net sink for CO_2-only – LULUCF plus – needed to get net zero balance to ensure carbon neutrality in 2060. The LULUCF part of the Russian national inventory is based on the ROBUL model.[161] However, there are alternative estimates as well.[162] Only recently the participants of vibrant debates turned to the discussion of information availability and reliability.

Net LULUCF sink includes two parts: baseline trajectory and additional net sequestration required to attain carbon neutrality by 2060. The first one extrapolates declining net CO_2 sink trends formed in 2010-2020 to 2060. It will be down to 115 Mt CO_2 due to the increasing average age of forest stands along with decreasing carbon sequestration.[163] Similar dynamics was revealed by applying the Canadian model CBM-CFS3.[164] This agrees with the earlier projections obtained using the ROBUL-M model,[165] which were based on the hypothesis that as Russian forests mature, net sinks are declining. Reduction in Russian forests carbon sinks is a natural process. Total carbon stock in all pools continues to grow, yet the growth rate (annual increase) is continuously declining.[166] Proactive measures are required even to merely maintain carbon sinks in the Russian forests. The second LULUCF net stock component is estimated as the amount required to capture emissions left in the other sectors less the first component. It shows how much additional effort is required for LULUCF to attain net carbon neutrality in 2060 – not against the 2019 net sink level, but compared to the steadily declining sequestration baseline.

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[161] Developed by Center of Forest Ecology and Productivity, Russian Academy of Science.

[162] According to space monitoring data, average annual carbon balance in forest phytomass was 292.6 million tC (or 1,072.8 million tCO2eq.) in 2005-2015. Bartalev C.A. Recent carbon balance estimates for Russian forests as obtained through remote sensing. Russian forests: sustainable forest use and climate change resilience webinar, World Bank and Center for sustainable nature use of the Geography Institute of the Russian Academy of Science. April 7, 2021.

[163] Zamolodchikov D.G., Grabovsky V.I., Korovin G.N., Guitarsky M.L., Blinov V.G., Dmitriev V.V., Kurz V.A. 1990-2050 carbon balance in Russian managed forests: retrospective estimates and projections. Meteorology and hydrology. 2013. No. 10, pp. 73-92. Supplemented with recent estimates by D.G. Zamolodchikov using ROBUL-M.

[164] Zamolodchikov D.G., Grabovsky V.I., Korovin G.N., Guitarsky M.L., Blinov V.G., Dmitriev V.V., Kurz V.A. 1990-2050 carbon balance in Russian managed forests: retrospective estimates and projections. Meteorology and hydrology. 2013. No. 10, pp. 73-92; Zamolodchikov D.G., Grabovsky V.I., Kurz V.A. Carbon balance management for Russian forests: the past, the present, and the future. Sustainable forest management. 2014. No. 2. Pp. 23-31.

[165] Zamolodchikov D.G., Grabovsky V.I., Chestnykh O.V. ROBUL-M as a new tool for forest carbon balance projections. Russia’s forests: policies, industry, science, and education. Proceedings of the second international scientific and technical workshop. Volume 2. St. Petersburg: SPbGLTU, 2017. Pp. 125-128; Zamolodchikov D.G., Ivanov A.V. Retrospective and projected carbon balance for Primorsky Krai forests. Agrarny vestnik Primoria. 2018. No. 3. Pp. 62-65.

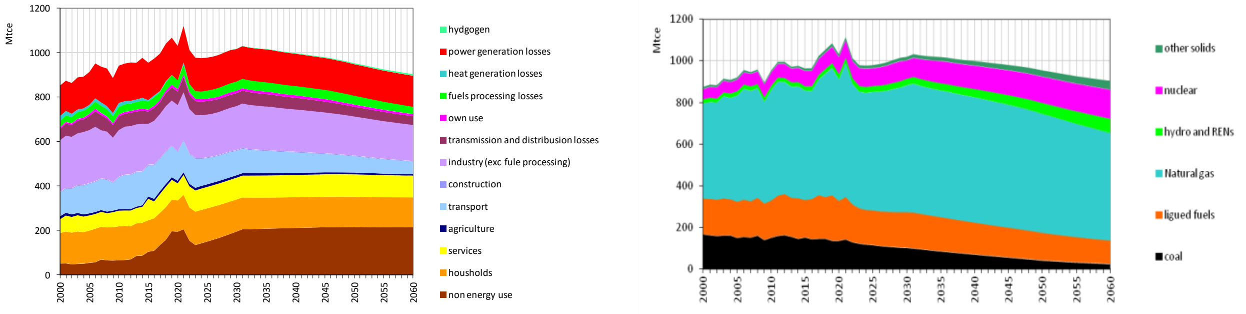
[166] Forest sector development projection for the Russian Federation to 2030 (UN Food and Agriculture Organization. Rome, 2012) specifies, that in all of the scenarios, wood stock in the forests will plateau before 2030, i.e. wood stock increase will drop from the 2000-2015 levels.

5.8 4S emission pathway

5.8.1 Energy and fuels use

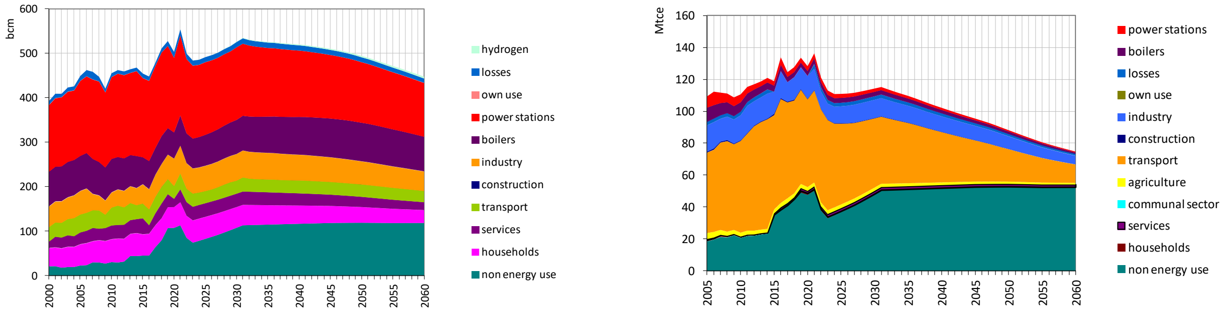
In 4S scenario, total primary energy consumption (TPES) peaked in 2021 at 1121 Mtce, will fall down to 975 Mtce in 2024 to rebound to 1,030 Mtce in 2031 with a subsequent decline thereafter down to 80% of the 2021 level. A major decline is expected in industry and transport. It will be partly offset by some growth in the services sector and non-energy fuel use (Figure 5.16).

Figure 5.16 Primary energy and fuel use in 4S scenario



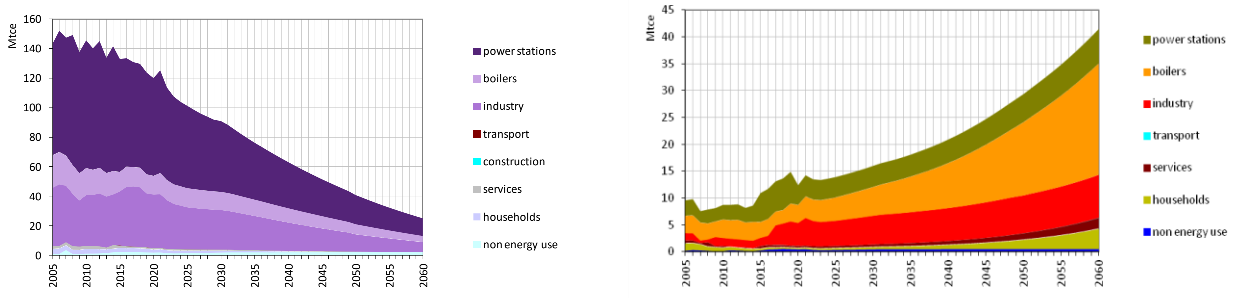
TPES by sectors

TPES by energy sources



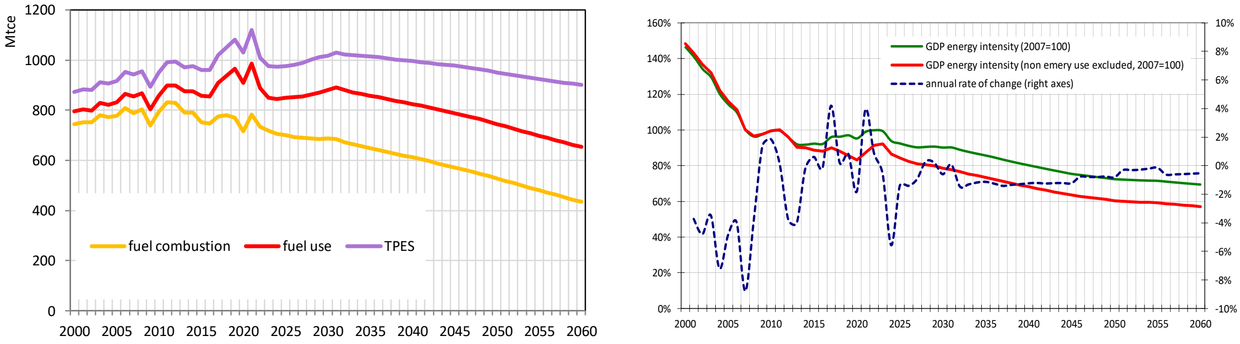
natural gas

liquid fuels



coal

other solid fuels



fossil fuels use

GDP energy intensity

Source: CENEf-XXI.

Energy efficiency does not contribute much to mitigation: in 2021-2060, GDP energy intensity (non-energy use excluded) will be declining only at 1% per year on average. With an account of non-energy use the decline will be 0.6% per year. GDP energy intensity reduction shows an uneven evolution with some growth in 2022-2023 followed by a decline, which slows down with time, as the modernization demand and availability of more efficient technologies are limited. Energy intensity in sectors and subsectors varies in 2021-2060 between 10-20% growth in fuel production and processing and nearly 50% drop in the residential sector, but the dominant reduction will be close to one third of the 2021 level.

As RENs, hydro, and nuclear power generation grows, fuel consumption will be 25% down in 2021-2060, and fuel combustion will be down by a third. Domestic natural gas consumption will be 15% down to 448 Mtce, and gas combustion will drop by 22% to 330 Mtce. Cumulative extraction will reach 23.5 trillion m^3 in 2021-2060, while 44.8 trillion m^3 are required to maintain the 2060 production level. This is in excess of proven resources as reported by BP (37.4[167]), so proven resources additions will be required. Liquid fuel consumption will be 44% down, and liquid fuel combustion will be 74% down, mostly due to transport consumption decline. Cumulative extraction will reach 13.2 billion tons in 2021-2060, while 16 billion tons are required to maintain the 2060 production level. This is in excess of proven resources as reported by BP (14.8[168]), so proven resources additions will be required.

As RENs, hydro, and nuclear power generation grows, fuel consumption will be 25% down in 2021-2060, and fuel combustion will be down by a third. – resulting from a switch to natural gas, which is seeking to squeeze coal out of power and heat generation and from the industry, as required by environmental regulation. Other solid fuel use, dominated by biomass, will nearly triple driven by larger uptake in boiler houses and individual heating units in the tertiary and housing sectors. Hydrogen use in this scenario will be slightly over 1 Mt in 2060. District heat is nearly stable to 2045 with a subsequent steady decline.

5.8.2 Emission trajectories towards net-zero carbon by 2060

In 4S scenario, Russia may reach carbon neutrality by 2060 only under the condition that strong and effective policies in LULUCF are implemented to block the net sequestration declining trend of the last decade and then to scale up LULUCF capacity substantially to capture additional CO_2. Alternatively, LULUCF stock might be proven to be much larger with no declining trend. Net emissions remaining in all other sectors (except LULUCF) will decline to 800 Mt CO_2 by 2060 (Figure 5.17). To fully offset this decline, net sink in the LULUCF sector will have to be up from the present 605 to nearly 800 Mt CO_2, or by about 200 Mt CO_2. If compared with the baseline set by extrapolating the LULUCF net sink decline trend (down to 115 Mt CO_2 by 2060), then net additional LULUCF sequestration needs to be 685 Mt CO_2 larger, which will be higher than the current net LULUCF sequestration. In the Russian Low Carbon Development Strategy, the LULUCF sector is expected to capture 1,200 Mt CO_2,[169] or about 600 Mt CO_2 above the 2020 level, and 1,085 Mt CO_2 above the declining baseline. No delay can be accepted for this large-scale afforestation activity, as it takes time for the forest to mature (10 year or more) to a level when it reaches intensive sequestration. Therefore, in this scenario, which is so greatly favoured by the RF government, the 2F pathway – ***Forest First*** – is the dominant mitigation option leading to the net zero carbon goal. In the Sakhalin experiment, LULUCF sequestration is the dominant option, but it is region-specific and can hardly be expanded to the whole country. According to Roslesinforg, Russian forests annually absorb up to 1.6 billion tons of CO_2, or about 1 Gt CO_2 above the value reported in the 2022 inventory. If this is proved and accepted by the UNFCCC, it will mean that Russia will reach carbon neutrality in

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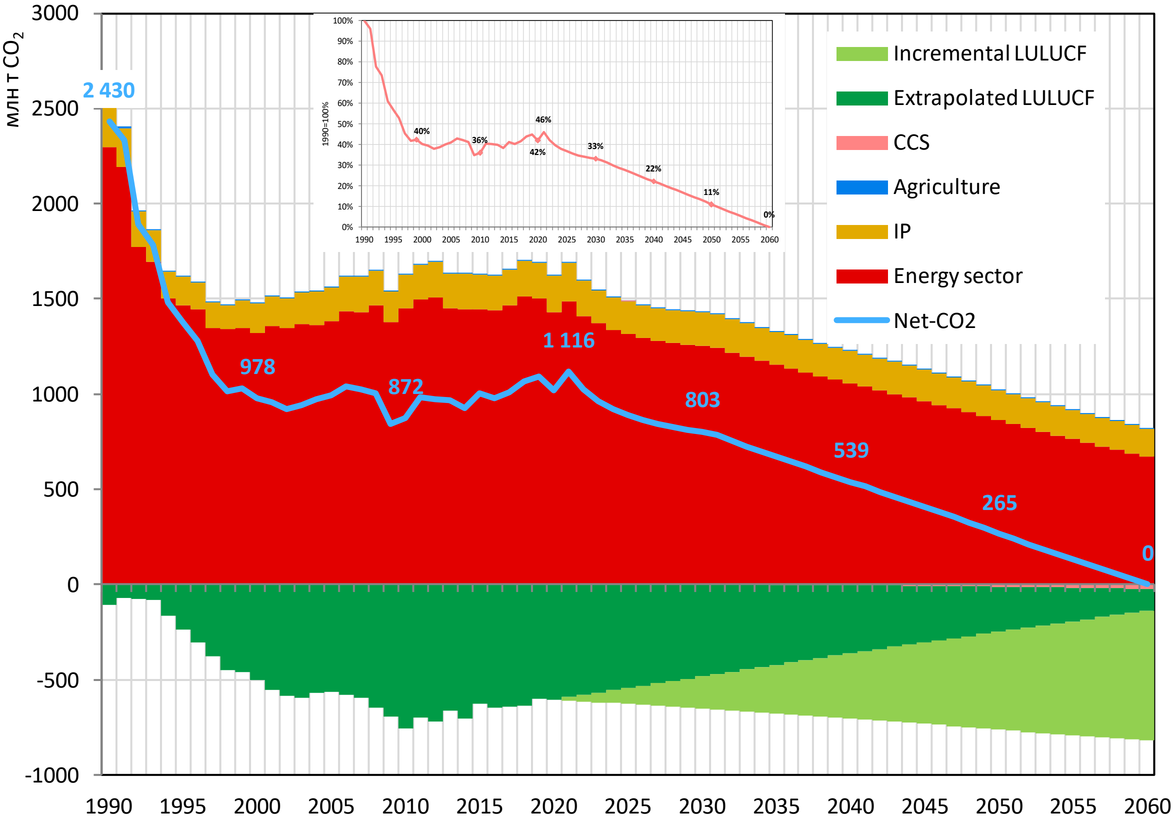
[167] BP Statistical Review of World Energy July 2021.

[168] BP Statistical Review of World Energy July 2021.

[169] Russian Low Carbon Development Strategy to 2050. RF Government Decree No. 3052-r of October 29, 2021.

2023-2024. The question about the LULUCF sink trend is still on the agenda. If these sinks dynamically decline, then this decline will have to be offset by mitigation in other sectors.

Figure 5.17 CO2 emission pathway in 4S scenario



Source: CENEf-XXI.

2F pathway– *Forest First* – as the Russian LTS pillar carries high risks of non-compliance.[170] Mitigation costs for reforestation projects are high, amounting to 37 US/tCO_2.[171] To capture 1 tC (3.7 tCO_2), forests planted on 2.5 ha have to be at least 10 years old. This means, that if additional 800 Mt CO_2 need to be captured in 2060, 540 Mha must be planted by 2050. According to Rosstat, the total land area in Russia is 1,712 Mha, total agricultural lands are 222 Mha, forest lands are 871 Mha, and other lands are 393 Mha. So, even if all agricultural lands, as well as other lands, are planted with forests (which is not possible at least in tundra), it will still be not enough to absorb 800 Mt CO_2 If the forest part of *The most innovative project of national importance and Federal Scientific technical program 'Unified National Monitoring System climatically active substances'* can prove that Russian forests carbon absorption capacity is more than twice larger, and only 1 ha is needed to capture 1 ton of carbon, still 216 Mha, or nearly as much as the total agricultural land, will be required to reach

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[170] Forest projects involve significant risks in terms of reliability and long-term results development. The potential of forest projects is determined by which specific types of projects will be legitimate. The most cost-effective type of forest projects is the conversion of previously unmanaged forests into managed ones. Reforestation is the least cost-effective type of forest projects in the RF. If 100% of forests are considered managed land, the potential of forest projects will drop significantly, and not all of the projects will be cost-effective. Theoretically, overgrown agricultural lands with limited infrastructure accessibility have the best perspectives in terms of forest projects/forest plantations. Carbon offset schemes are causing a lot of criticism. Offsets are being viewed as 'moving sun loungers while the Titanic is sinking'. Korotkov V.N., Romanovskaya A.A. Forest climate projects in Russia: opportunities and risks. Yu.A. Izrael Institute of global climate and ecology. CENEf-XXI workshop 'Russia's Long-Term Low Carbon Development Strategy'. April 27, 2021.

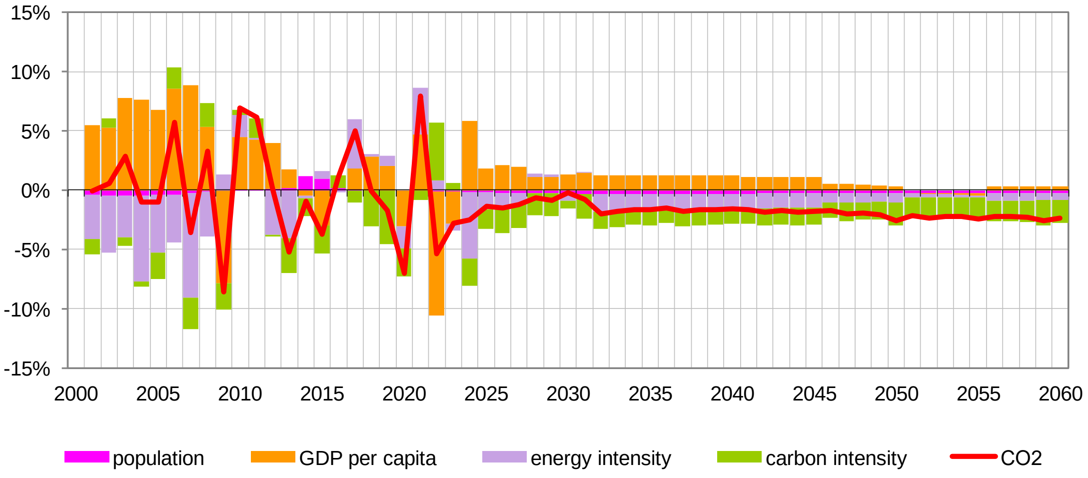
[171] Ibid.

net carbon neutrality by 2060. Forest fires, diseases and pests make the outcome of afforestation projects even less certain.

LTS needs more pillars to make a solid basis for the net-zero carbon pledge. In 4S scenario, emission reduction in all sectors (excluding LULUCF), which is 870 Mt CO_2 in 2021-2060, overweighs the additional net sequestration by LULUCF. It is three times the reduction specified in the LTS for 2050. Even in this scenario – with slow economic growth and slow modernization in many sectors (see above) – it is expected to bring CO_2 emission down through a decline in fuel combustion and restructured production processes to reduce IP-related emissions. In many instances, emission reduction may be achieved at a negative cost. CENEf-XXI estimates show, that in order to get a mitigation effect equivalent to that obtained as a side effect of heat and electricity savings yielded by energy efficiency retrofits of multifamily buildings in Kemerovo, forests must be planted to cover an area which is 16-50 times the total Kemerovo municipality area with emission reduction costs in excess of 37 US/tCO_2$.

Progress in energy supply decarbonization would give momentum to CO_2 reduction in sectors other than LULUCF. Population dynamics drives combustion-related CO_2 emissions down (Figure 5.18). Slow growth in per capita GDP offsets this small effect leaving the emission growing. Slowly, but steadily, energy efficiency improvements bring the emission growth rates below zero. However, the impact of this factor is nearly exhausted close to 2060 and carbon intensity takes the lead in the decarbonization race.

Figure 5.18 **Kaya decomposition of combustion-related CO_2 emissions in 4S scenario**



Source: CENEf-XXI.

Fit for 60. Russian CO_2 and GHG emissions peaked in 2021. Russia is expected to be ahead of the EU in cutting GHG emissions by 2030. Expected GHG emission reduction is 63% and that for CO_2 is 67% (Figure 5.19). In 2021-2023, Russian GDP is expected to be 12-14% down, and net CO_2 emissions reduction will reach 10% or more. GDP is expected to return to the 2021 level only in 2031, but CO_2 and GHG emissions will not get to the 2021 level. Subsequent economic rebound will slow down, but not stop, the subsequent CO_2 emissions decline.

In the early 2020s, Russia is repeating the negative experience of the 1990s by reducing its GHG emissions through a deep activities (demand) reduction, which is the most expensive "mitigation" option costing 1,137 US/tCO_2$eq. Back in the 1990s, Russia already paid the highest ever price for GHG mitigation – $400-870/t$CO_2$eq.[172] While policymakers across the

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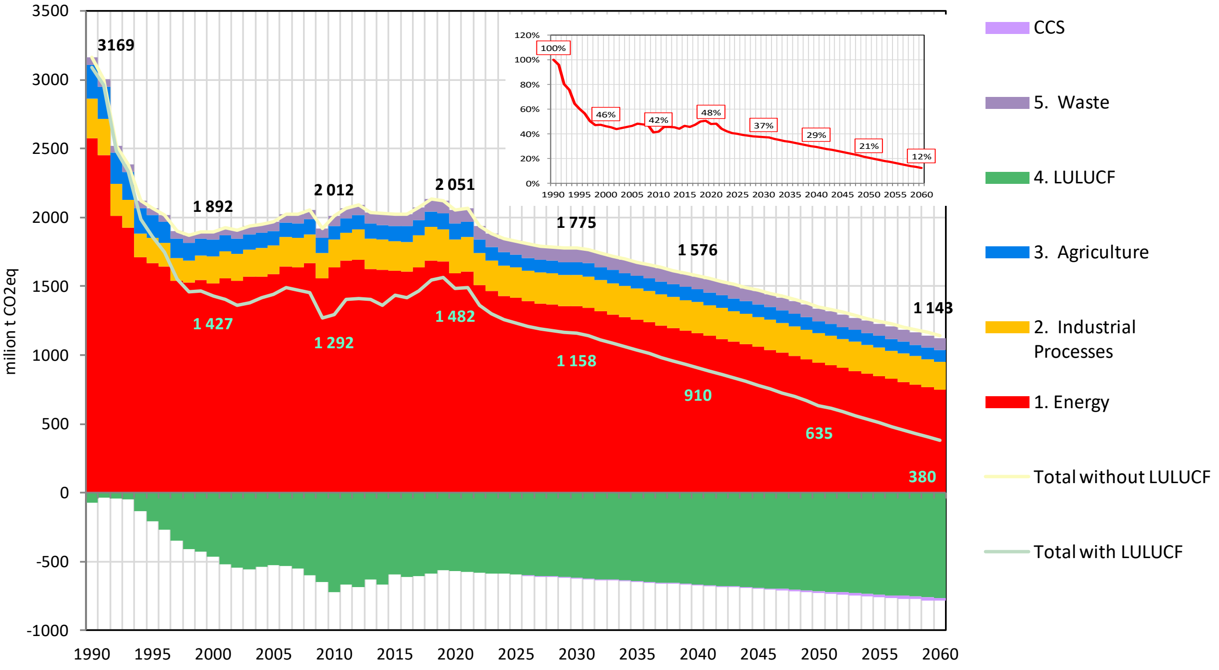
[172] Bashmakov I. Costs and benefits of CO2 emission reduction in Russia: presentation at a Workshop 'Costs, Impacts, and Benefits of CO2 Mitigation', 28-30 September, 1992. IIASA // Kaya Y., Nakichenovich N., Nordhouse W., Toth F. editors. – Laxenburg, 1993. P. 453-474.

globe are looking for a least costly pathway to attain carbon neutrality and trying to minimize potential GDP losses, Russia is going to bring down its CO_2 emission through an economic crisis. Arguing for a weak mitigation policy, many Russian policymakers and experts express fears that mitigation activities may slow down GDP growth.[173] Ironically, mitigation policies have never hampered economic growth in Russia, while policy-driven activity declines have yielded large emission reductions. Russia has learned how to reduce GHG emissions through GDP losses (in the 1990s and after 2022) and how to keep emissions relatively stable with fast (2000-2007) and slow (2008-2021) GDP growth. One thing yet to explore and learn is a pathway that ensures GDP growth and GHG emissions reduction.

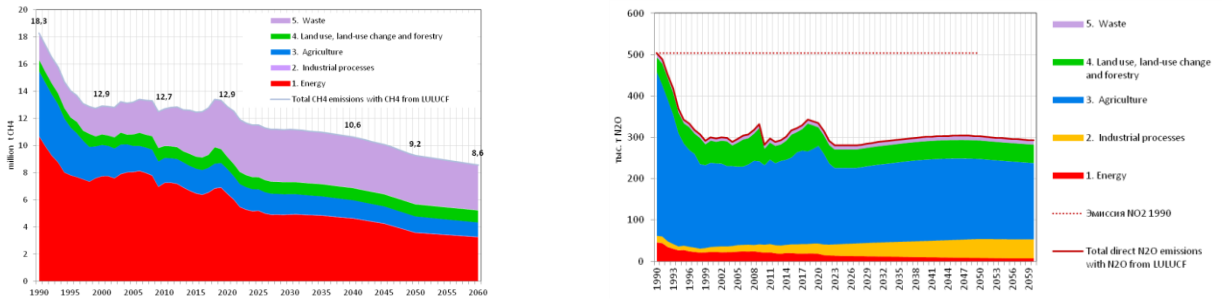
Figure 5.19 GHG emission pathway in 4S scenario



Source: CENEf-XXI.

In 4S scenario, Russia will not attain GHG neutrality by 2060. GHG emission reductions will reach 88% of the 1990 level. CO_2 emissions will get down to net zero. CH_4 emissions will drop by a third by 2060, while N_2O emissions will be nearly stable in 2020-2060 (Figure 5.20).

Figure 5.20 CH_4 and N_2O emissions in 4S scenario



CH_4 emissions

N_2O emissions

Source: CENEf-XXI.

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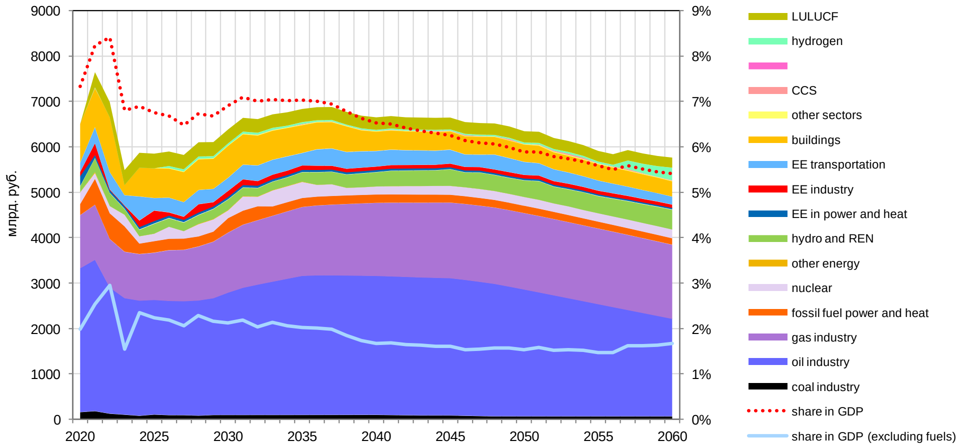
[173] See the discussion in Bashmakov I. Low carbon development and economic growth. Neftegazovaya Vertikal, No. 19-20/2021.

5.8.3 Mitigation costs

In 4S scenario, investments in low carbon projects amount to 78 trillion rubles. This is twice below the investments in fuels supply (169 trillion rubles). Total investments in the energy sector equal 198 trillion rubles (Figure 5.21). The costs for low-carbon technologies in the power industry total to 20 trillion rubles. Incremental capital investment in energy efficiency is 37 trillion rubles. Investments in the LULUCF sector are close to 11 trillion rubles. Total capital expenses in 2022-2060 amount to 247 trillion rubles in 2021 prices.

Figure 5.21 Total investments in 4S scenario



Source: CENEf-XXI.

The share of investments in low-carbon transformation (total investment less investment in fuel production and processing) of GDP will be gradually decreasing from 2.1-2.2% in 2021-2025 to 1.5-1.7% in 2050-2060. Investments in the oil and gas sector continue to dominate, but their share will be steadily declining from 5.7% in 2021 to 3.7% in 2060. This will release investment resources for the development of other sectors. The share of the Russian fuel and energy sector in investments in fixed assets is high. If we directly sum up Rosstat's data for investments in the extraction, concentration and processing of coal, oil and gas, in power and heat generation, and in the transport of oil, oil products and gas, we will get 5.3 trillion rubles in 2018, or 30% of the total investment. These estimates should be supplemented with capital investments in wholesale solid, liquid and gaseous fuels trade and services related to oil and gas production). In all, the above components will add another 700 billion rubles, and in general the share of the fuel and energy sector in investments will increase to 6 trillion rubles (34% of total investments), of which 5 trillion rubles are for activities related to fuels production, processing, transport, distribution, and trade. Shirov estimates the fuel and energy sector's share in investments at 27%, and with an account of indirect investment at 41%. These investments have low return on capital.

Carbon price in 4S scenario will be 1 US/tCO_2$ in 2031, slowly growing to 30 US/tCO_2$ in 2060. It will bring 1.7 trillion rubles, or 0.6% of GDP. To some extent, this increase will offset the reduction in excise taxes from liquid fuel use by road transport. Therefore, introduction of a carbon price may be fiscally necessary. If carbon pricing mechanisms are introduced to offset profit tax reductions, the overall tax burden on businesses will not increase. The funds collected through these mechanisms (20 trillion rubles) might be used as a leverage to finance the identified mitigation option (78 trillion rubles) with the leverage ratio close to 1:4.

6 4D – Development Driven by Decarbonization and Democratization is the Door Back to the Global Economy

4D scenario is based on economic scenario 3 (Chapter 3) with a deeper decline in the oil and gas exports by 2027 followed by only partial recovery thereafter and enhanced TFP parameters driven by democratization and competition with a more substantial role of market drivers. This scenario assumes that after Russia's military operation in Ukraine is over, the sanctions will be lifted or relaxed, and Russia will eventually regain some positions in the global value chains beyond 2030. The Russian government will recognize the need for decarbonization in all of the sectors in addition to the importance of increasing sinks in LULUCF, in order to:

- Reduce the 2060 carbon neutrality non-compliance risks;
- Maintain fuels and basic materials exports to the global and regional decarbonizing markets, where low carbon footprint is becoming critical, while carbon price mechanisms undermine the competitiveness of carbon intensive products;
- Export high-tech products and services to emerging trillions-worth low carbon markets (see Chapter 4). These products and services, placed at the end of value chains, will be less affected by carbon prices, but they will obtain financing and markets only if they meet the requirements of emerging regional taxonomies and end-users;
- End up the 2020s break in modernizing obsolete and degraded production facilities in all sectors. After it becomes clear that the self-sufficiency carriage has turned into a pumpkin, it would allow it to avoid being locked-in for decades in outdated carbon intensive technologies – less efficient and more expensive – that were developed during the decade of reliance on imports substitution;
- Rely on less costly technology solutions, as it is expected that in the 2020s and 2030s low carbon technologies will become less expensive compared to the traditional counterparts (RENs versus traditional power generation, ICEVs versus EVs, DRI-H2-EAF versus BF-BOF etc.).

These considerations will encourage Russia to implement proactive decarbonization policies to combat climate change and at the same time get the Russian economy back on the development track. To make this happen, new institutions will be needed. Democratization will develop, as the role of the oil and gas sector will be shrinking, and reliance on a wider political and social spectrum will become key for sustaining social stability and inspiring business activity. All this will bring more competition into the economy and free up initiative, as unanimity and doublethinking will be replaced by dissent and sanity.

Many policies and measures assumed in 4D are listed in the LTS[174] and in the Action plan (operational plan) for the LTS implementation.

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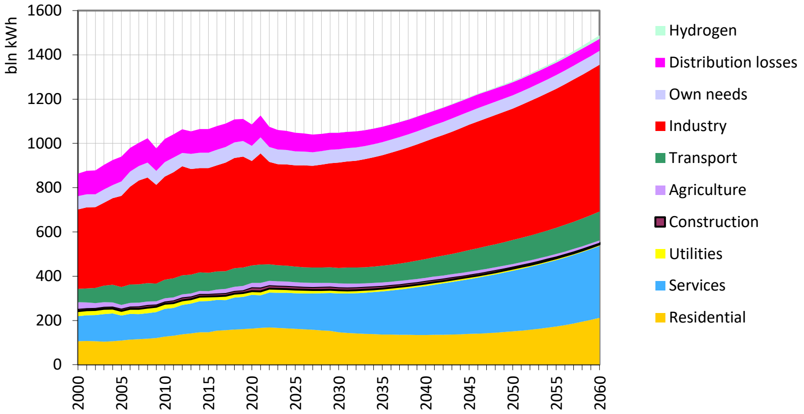
[174] Russian Low Carbon Development Strategy to 2050. Decree of the RF Government No. 3052-r of October 29, 2021.

6.1 Power and heat sector

In 4D scenario, electricity generation will be stable for 2 decades, and the 2021 generation level (1,159 billion kWh) will not be reached until 2041. Beyond 2041, it will quickly scale up to reach 1,516 billion kWh in 2060, driven by the electrification of end-use. This figure breaks down into 1,471 billion kWh for centralized generation 45 billion kWh generated by prosumers (Figure 6.1). The greatest power demand increments originate in 2021-2060 in industry (202 billion kWh), transport (52 billion kWh), and services sectors (207 billion kWh). An assumption is made in this scenario, that the power market will change significantly to promote low carbon electricity in all sectors as a mitigation strategy, and to promote distributed generation by prosumers in all sectors, but above all in the building sector. Power business will be split into traditional and RE generation and will be dispatched based on the costs and system services; utilities will be increasingly providing end-use services, including attractive billing schemes and tariffs, and also assist with energy efficiency projects ("white certificates"[175]), demand-side management, etc. In the 'electrified future', traditional boundaries between electricity generation, transport, storage, distribution, and consumption will be blurring and shifting towards end-use sectors (buildings, industry, and transport). As RE sources are becoming more important, and the electrification of end-use sectors is progressing, as is the decentralization of electricity generation and the development of storage systems, power supply to consumers will be transformed most noticeably.

Figure 6.1 Electricity consumption in 4D scenario



Source: CENEf-XXI.

Current business models in the power industry will be changing due to the growing role of system service providers associated with the need to integrate a high share of renewable energy and to the growing role of aggregators who manage distributed energy units. The latter will be buying excess electricity from prosumers and selling it to the grid, managing and operating small power plants and micro- and nanogrids. Future energy systems will include several dozens of centralized power plants and dozens of thousands of largely distributed small generation units – solar power plants, wind farms, and other renewable energy sources. "Smart" networks will help integrate, control, and synchronize their work. The assumption is that by the 2030s, a full-fledged wholesale and retail electricity market will be formed, where consumption and supply will be price-dependent, cross-subsidies will be eliminated, electricity prices will be set in a deep interaction with consumers.

Electricity supply should be integrated with the development plans of individual end-use sectors. Prosumers are starting to play an increasing role, including in pricing. Energy storage

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[175] Russian legislation allows for an equivalent of a legal instrument – an energy supply agreement with energy service elements (FZ No. 261). However, this tool has not been developed and is not being used so far.

systems, both on the utility and the consumer side, are becoming an important market segment. Utilities are increasingly managing consumer installations through smart grids. In many cases, a barrier to the development of distributed generation where consumers will supply excess electricity to the supplier's network is the fact that outdated distribution networks cannot receive energy in the opposite direction. Energy systems development plans will become substantially more complicated due to the increasing number of small generation assets and the large share of renewable energy. The use of smart grids and communication technologies is becoming critical to manage such complex energy systems. Smart grids will also integrate energy storage systems. The system operator will need many more information resources for the optimization of management. New market models are still being formed. There are no final decisions yet. The contribution of RES to electricity generation will largely depend on which decisions will be made.

If we want to see more competition in the power market, it is important to move to a single price market with a focus on non-regulated bilateral agreements between suppliers and consumers to ensure preference for low carbon electricity; develop multiple options in the power and capacity pricing menu in bilateral agreements, including demand-side management and other services; develop an infrastructure and regulation for bilateral agreements (financial, physical, derivative instruments, such as standardized contracts, 'green certificates', etc.) to ensure supply from the most efficient plants; develop derivative instruments to improve liquidity, increase access to financing and improve competition; promote investment through long-term bilateral agreements to replace capacity supply agreements; introduce real and easily implemented competition between retail power suppliers.

In 4D scenario, increased low carbon power generation is based on carbon pricing for fossil fuels-based power, support for power storage and networks development to accommodate intermitted RENs, which are becoming cost-competitive (used to rely on subsidies), as economy of scale and learning rates bring the LCOEs down. LCOEs for new fossil fuel-based power sources are growing driven by carbon prices, while LCOEs for RENs are declining. For new onshore wind they are already cost-competitive, and for solar are expected to become cost-competitive later in the 2020s. Low carbon generation policies will bring 25% and 20% subsidies for wind and solar CAPEXes to 2029 and 15% and 10% respectively thereafter to 2040. Nuclear is cost-competitive compared to fossil fuel generation with an assumption that CAPEX is 2,500 $US/kW.[176] For Russian nuclear true CAPEX is difficult to estimate, as data from open sources are not available and a large public support is provided in different forms to build new plants. If true CAPEX for nuclear can be taken equal to 4,000 $US/kW, they reach parity with gas generation in the early 2040s.

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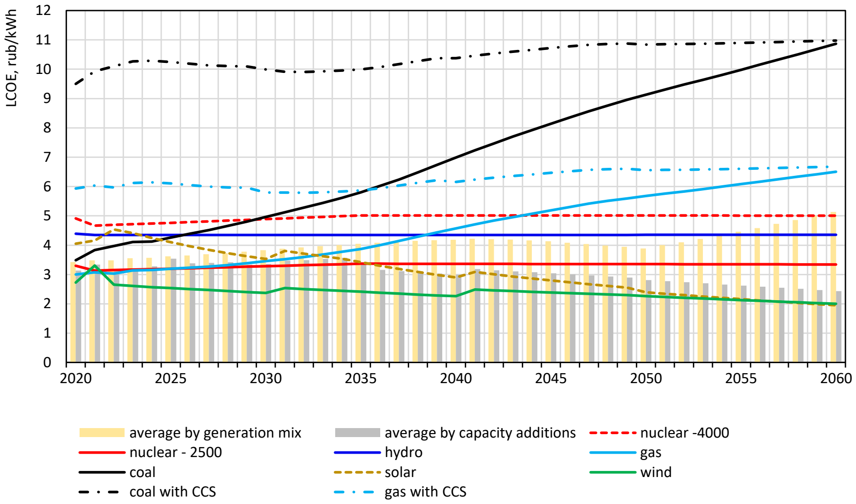
[176] Veselov F., A. Solyanik, L. Urvantseva. Low-carbon transition of the Russian power industry to 2035: potential of emission reduction and its «costs» for consumers. Energy Policy 156 (2021). IEA provides nuclear CEPEX for US at 5000 $US/kW in 2020 declining to 4500 $US/kW by 2050; for European Union 6000 and 4500 $US/kW, for China 2800 and 2500 $US/kW, and for India 2800 $US/kW for 2020-2050. Table B4.a Technology costs in selected regions in the Stated Policies Scenario. World Energy Outlook 2020. IEA.

Figure 6.2 LCOE for different types of generation in 4D scenario



Sources: CENEf-XXI.

When weighted by new capacities additions, average LCOE after a small growth in the 2020s will be steadily declining to 2060 to reach a level below that of 2021. This decline opens the door for tariff increments in transmission, distribution and systems services, as these become more costly. So overall power prices may grow, but the growth will be slower compared to the case when all capacity additions, whether or not equipped with CCS, are fossil fuel-based.

In 4D scenario, low carbon power will be provided by nearly all new capacity in 2021-2060 compensating for phased-out fossil fuel capacities (Figure 6.3). It will reach 75% of installed capacities. Total installed capacity in 2060 will reach 317 GW, including 59 GW of nuclear; 65 GW of wind, and 49 GW of solar. Hydro and geothermal will only slightly increase to 55 and 0.2 GW. The total capacity of thermal power plants will decline: to 64 GW for gas and to 23 GW for coal. During the 2022-2041 generation growth pause, new capacity additions will only replace the phased-out inefficient capacities. There will be some new gas generation and very small coal-based capacity additions. Small, mostly coal-fired CHP plants are expected to replace the phased-out units in regions, where no gas is available and (or) there is limited potential for RENs. For fuel-based generation, 4D scenario assumes energy efficiency improvements for both new and modernized power plants to BAT levels. In 2021, the average age of thermal power plants in Russia was 34 years, of hydro power facilities 44 years, of nuclear plants 27 years.[177] More than 30% of installed equipment is older than 45 years (according to Inter RAO). 20% of CHP will run out of service before 2040 (according to the RF Ministry of Energy). So substantial new capacities are needed to merely replace those, whose service life is coming to an end. In fossil fuel-based generation, the deployment of CCS technologies will start in 2035.

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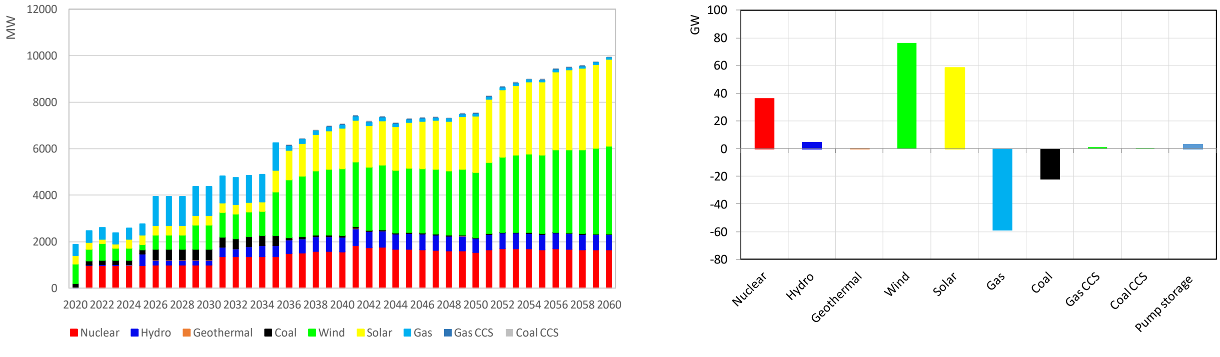
[177] Forum. Atlas of investments of Russian-Chinese energy cooperation. 2021.

Figure 6.3 Commissioning of power plants in 4D scenario



a) commissioning of power plants b) installed capacity change in 2021-2060

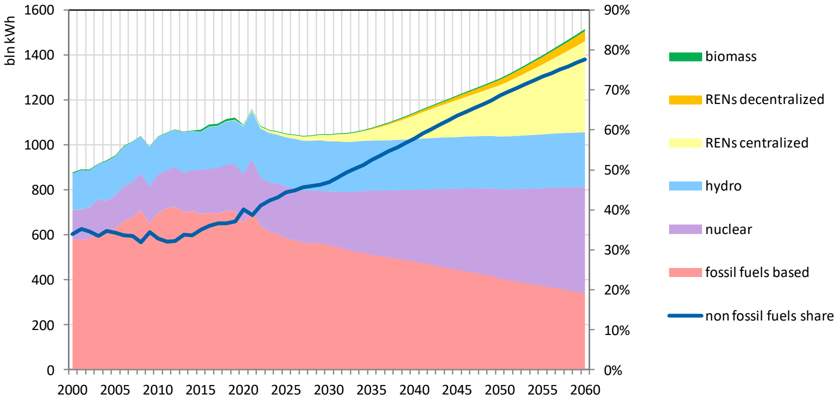
* Capacity additions are shown as annual increments, as in reality they are commissioned in proportion to block units capacities.

Source: CENEf-XXI.

By 2060, the share of low carbon sources in installed capacity will scale up from current 34% to 75%. Wind and solar capacity will approach 40% in 2060. High levels of variable RES (VRE) penetration can significantly affect energy systems parameters, such as load profiles; regional market patterns, and wholesale prices. In order to accommodate more variable RENs, the storage capacity will grow over 5 GW, including pumped storage over 4.3 GW, and battery storage over 0.8 GW.

In 2060, the power system will not be zero carbon yet, but the share of low and no carbon power sources will scale up from the current 40% to 78% (Figure 6.4). In the 2020s, a temporal decline in power generation will be accompanied by a reduction in fossil fuel-based generation, as nuclear and hydro will keep close to the current generation levels. The local content in large gas turbines is very low. At a later stage, this pressure will be supplemented by wind and solar. But the decade-long delay in power sector modernization and low population densities in regions rich in coal, yet poor in RENs, will limit the potential for full power sector decarbonization. It would allow it to resolve potential problems with earlier commissioned capacities running the equipment supplied by companies, such as General Electric and Siemens. However, the challenge for the decades to come is, that "Silovye mashiny" and "Rostech" are planning to launch 65-70 MW localized gas turbines production. If they succeed, the demand for new gas turbines will be limited to 1 unit per year in this capacity range, as RENs will be getting more cost-effective. Therefore, new production facilities may become stranded assets with no chance for capital recovery.

Figure 6.4 Electricity generation in 4D scenario



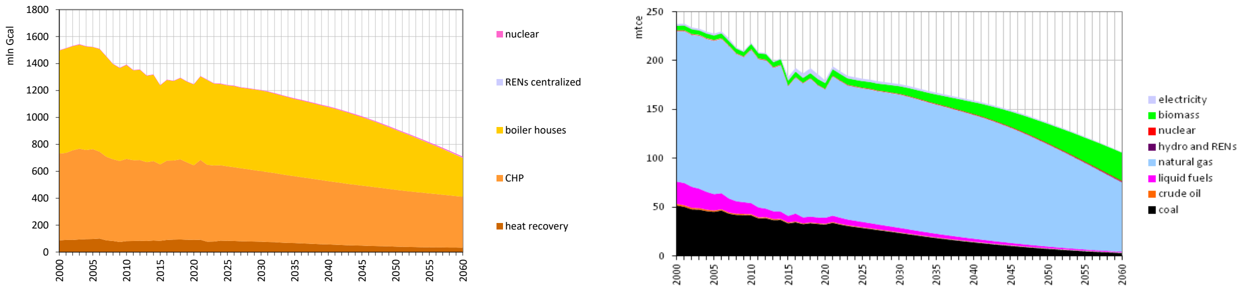
Source: CENEf-XXI.

Centralized variable RENs (wind and solar) power generation will approach 332 billion kWh, or up to 24% of total generation, in 2060. WPP and SPP capacities will be growing in accordance with the current plans to 2035 and then will become competitive, as the costs of generation will drop driving change in the structure of installed capacity. The economics of renewable energy projects will improve significantly, while gas prices will be up driven by carbon price instruments.

District heating will continue to decline (by 43% in 2021-2060) despite the fact that a lot of heated space will be added (Figure 6.5). This pattern was observed in 2000-2021. Heat generation at CHP will be 34% down, and in boiler houses it will nearly halve. Some decline in heat recovery will be associated with the reduction in both high temperature heat intensive basic materials production and change in their technological base.

Fossil fuels use for heat generation will be 60% down from the 2021 level. Gasification of some regions currently dominated by coal will allow for dynamic coal substitution, but at the same time will lock in gas-fired heat supply for decades to come. Deeper reliance on biomass, than expected in this scenario, will allow for deeper decarbonization. The issue is biomass availability and the balance with LULUCF sink targets.

Figure 6.5 District heat generation in 4D scenario

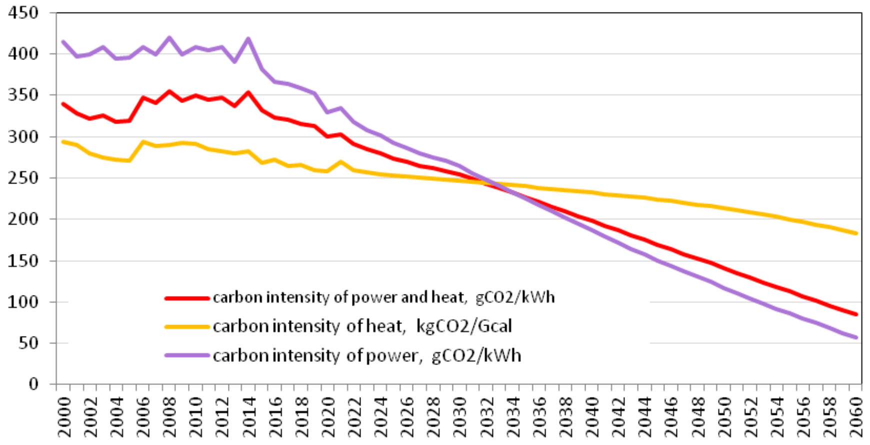


(a) district heat generation by sources (b) district heat generation by energy carriers

Source: CENEf-XXI.

Carbon intensity of power generation will go down to nearly 50 gCO_2/kWh, but not yet to zero, in 2060 (Figure 6.6). Not so much progress in carbon intensity can be expected for heat. District heating is mostly ignored by government policies leaving the risk of locking in carbon intensive solutions. By 2060, district heat generation even in 4D scenario will be responsible for 140 mln tCO_2 (37% of then remaining combustion-related emissions). This will impede attaining carbon neutrality, unless more active decarbonization policies are developed and implemented.

Figure 6.6 Carbon intensities of power and heat generation in 4D scenario



Source: CENEf-XXI.

European standards assume that in the next 25-30 years, district heating systems will be transformed into the fourth generation heat supply systems.[178] Such systems will have substantially improved performance, use low-temperature water, and should be able to ensure very low heat distribution losses; they will integrate heat supplied from low-temperature renewable sources, such as solar and geothermal, into the system; incorporate heat supply into smart energy supply systems, including smart cooling. The development of such systems should start from the development of long-term strategies, which Russia hasn't even started to consider.

6.2 Industry

In 4D scenario an assumption is made, that Russian industrial companies will spend the 2020s to find new markets and to change the logistics for materials and components supply, and after the decade-long crisis is over Russian industrial companies will benefit from lifted sanctions. The government, facing shortage of revenues, will on the one hand, reduce its presence in the economy, and on the other, create more favorable conditions for the private sector hoping to compensate for the falling oil and gas revenues with more diverse income sources from non-oil and gas sector.

In 4D scenario, growing domestic and international competition will strongly encourage Russian companies to double the intensity of capacities modernization. After a decade of experiments with self-sufficiency in isolation, existing facilities will date further facing the risk of full degradation. In order to stay in business, they will require intensive and profound modernization. Capacity additions will be built to meet BATs performance levels.

4D scenario assumes, that the government will start implementing large and effective decarbonization policy packages in industry, such as[179]:

- Carbon pricing to motivate businesses towards carbon footprint reduction and to reduce the risks of economic losses incurred by CBAM-like mechanisms. This would require the development of effective carbon intensity benchmarking systems and tools to estimate and certify GHG footprint of products;
- Planning transition pathways and long-term strategies to coordinate mitigation activities in individual industries (especially in basic materials) with subsequent major policy elements to:
    - ❖ encourage material efficiency and high-quality circularity;
    - ❖ provide "supply push" by supporting R&D and early commercialization (including subsidies for new low carbon products so they can compete at early production stages – similar to the ones provided to RENs);
    - ❖ provide "demand pull", including government and private low GHG procurement to develop a low carbon market to promote the emerging technologies;
    - ❖ balance carbon pricing and regulations with competitiveness to promote innovation and systemic GHG reduction, giving time to industries to adjust;
    - ❖ mobilize long run, low-cost finance mechanisms to encourage investment and reduce risks;
    - ❖ time infrastructure planning and construction (including CO_2 transport and disposal, electricity and hydrogen transmission and storage);

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[178] Lund H. et al. 4th Generation District Heating (4GDH). Integrating smart thermal grids into future sustainable energy systems. https://www.sciencedirect.com/science/article/abs/pii/S0360544214002369

[179] Bashmakov I, L. Nilsson et al. 2022. Industry. In: Climate Change 2022. Mitigation of Climate Change. Contribution of Working Group III to the IPCC Six Assessment Report (AR6) [Skea, J. et al., (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

    - ❖ support new institutions capable of managing long-term strategies; develop and adjust regulation and monitor the progress, etc.;

- Performance standards and codes, especially for cross-industrial technologies, such as electric motors or steam supply systems, to increase the durability of products and materials;
- Require extended producer responsibility for their products end of life service and to cover the cost of materials recycling or otherwise responsibly manage problematic wastes.

An assumption is that subsidies for low carbon products will be provided to:

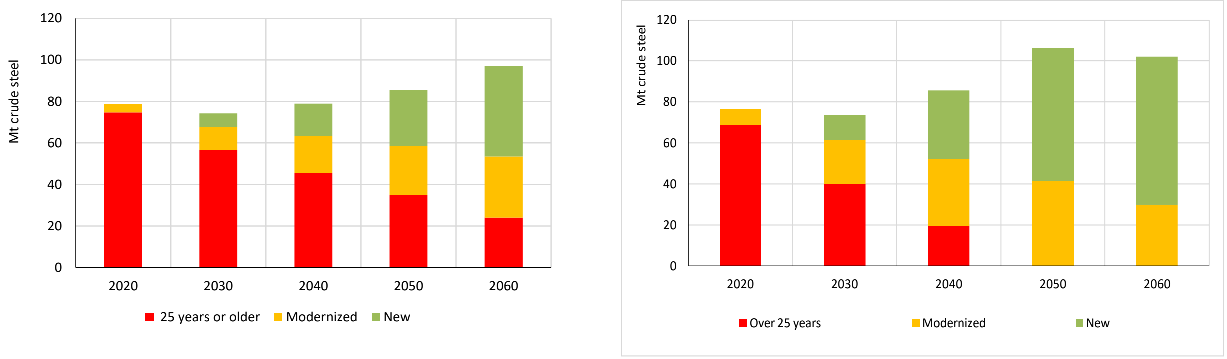
- cover 50% gap between steel produced by DRI-EAF-gas+CCUS and DRI-EAF-hydrogen and steel produced by BF-BOF technology;
- cover 50% gap between cement production with and without CCS;
- cover 100% gap for ammonia production with CCS or using hydrogen as feedstock and SMR ammonia.

These subsidies will be canceled, when the costs of new processes become similar to those of traditional production, which are driven up by carbon prices.

It is also assumed, that performance standards, white certificates-like programs, access to cheap financing will be available to promote energy efficiency. Some of these may be incorporated in the Energy Efficiency Program to 2035, which is now being developed.

Since the economic development is faster, than in 4S, and goes with a severer competition, none of the current capacities aged 25 or older will still be in operation in 2060 to produce basic materials, unless deeply modernized and supplemented with new capacity additions after 2021 to dominate in the 2060 capacity balance. Old capacities and stranded assets expected to be commissioned during the period of isolated self-sufficiency (2021-2031) will lose it out to competitors and will have to be either decommissioned or deeply modernized. Greater basic materials demand from both domestic and international markets will require new capacity additions. If they are to win the markets, they will have to be advanced and low carbon. For this reason, the share of new capacities with improved performance and low GHG emissions in 4D scenario by far exceeds that for 4S scenario for all basic materials (Figure 6.7 illustrates this point for crude steel production). This will allow it to avoid the locked-in effects for decades after 2030. Such modernization is only possible if there is access to low carbon BAT technologies.

Figure 6.7 Crude steel production capacity age structure in 4S and 4D scenarios



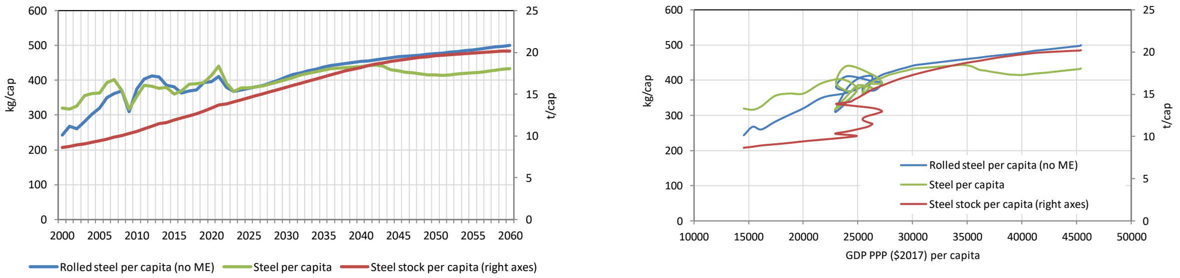
scenario 4S scenario 4D

Source: CENEf-XXI.

Improved materials efficiency across all sectors and promoting circular economy will keep virgin basic materials demand growth moderate, but allows for an increasing contribution from secondary materials (metals, paper and plastics). End of life segments of accumulated material stocks (Figure 6.8) will serve a resource base for secondary materials. If 80% of the

2020 vehicle stock are scrapped in 2040 and average steel and iron embedded in one vehicle (LDV, truck or bus) weighs one ton, then 40-47 million tons of steel scrap will become available only in this scrap segment. Expected reduction in vehicles stock will reduce scrap supply. At the same time, as annual vehicle sales decline (assuming 50% of cars are produced from domestic steel), domestic steel demand will be 6 million tons lower in 2060, if compared to maintaining constant stock case. Similar, but much smaller, effects are relevant for aluminium and plastics. In the power sector, the impact is opposite: RENs are more material intensive per kW, than traditional generation. Our assessment[180] shows, that new power capacity additions as described above will additionally require only 0.1 million tons of steel compared with fully fuel-based generation. The balance of material demand change from the above examples allows for a lower steel demand with higher incomes (Figure 6.8).

Figure 6.8 Steel stock and steel demand with and without material efficiency and demand reduction (ME) in 4D scenario



Source: CENEf-XXI.

New low carbon technologies penetration scales up substantially, when carbon price and subsidies for low carbon steel production are introduced. Transformation of steel industry is based on investment decisions which are driven by cost competition (Figure 6.9). BF-BOF route for steel production loses competition, as the carbon price rises and the facilities in place retire either as a result of the 2020s sanctions or because their service life is over. New facilities will be built based on DRI-EAF and Scrap-EAF routes, as BF-BOF becomes more expensive.

The costs of DRI-gas-EAF technology will be the rise as well, even if at a moderate rate, yet gaining a market share. The costs of DRI-gas with CCS-EAF and DRI-H2-EAF routes will get close to DRI-gas-EAF only in 2060. Therefore, the uptake of these processes will be limited and they will be mostly oriented to foreign markets with higher steel costs. Overall costs will be 200 $US/t crude steel, or 56%, up (1.1% per year). This moderate annual growth will provide sufficient incentives and time for material efficiency improvements to offset the growing steel costs. Steel costs increase is important for the competition between steel producers. As for final products (for example, cars), the rising costs of steel will only contribute 1%. Cumulative 2022-2060 subsidies to support DRI-gas with CCS-EAF and DRI-H2-EAF are limited to 3.5 billion rubles, as reference BF-BOF route costs will skyrocket driven by carbon prices. The learning process for DRI-gas with CCS-EAF and DRI-H2-EAF will start early in the 2030s and will depend on the carbon price and the architecture of carbon pricing mechanisms for industry.

Low carbon strategy for iron and steel needs to be developed to identify low carbon transition pathways. It should develop the market-based instruments architecture which will address the competitiveness issues and set benchmarking systems to measure carbon footprint for a large variety of products in a way consistent with benchmarking systems adopted in other regions and countries.[181]

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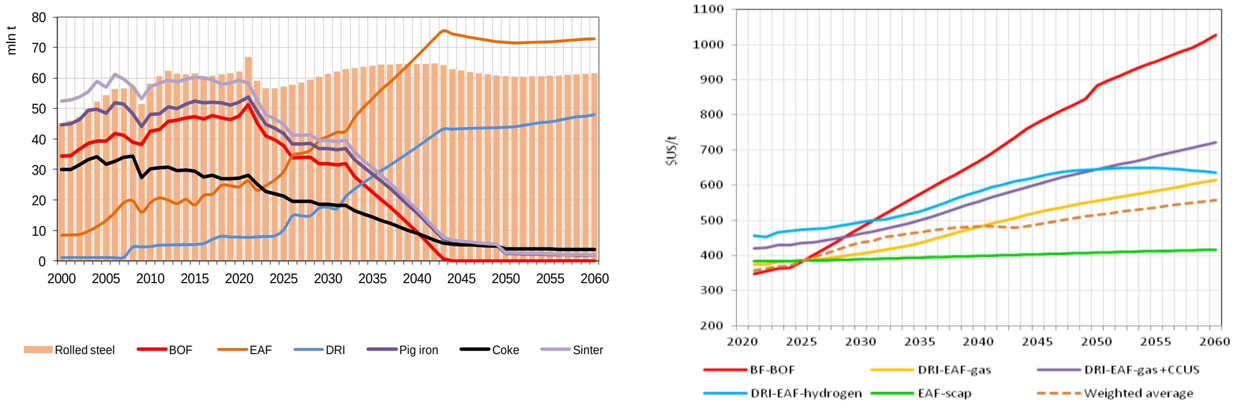
[180] Specific materials use per MW are borrowed from: Deetman S., H.S. de Boer, M. Van Engelenburg, E. van der Voet, D.P. van Vuuren. Projected material requirements for the global electricity infrastructure – generation, transmission and storage. Resources, Conservation & Recycling 164 (2021) 105200.

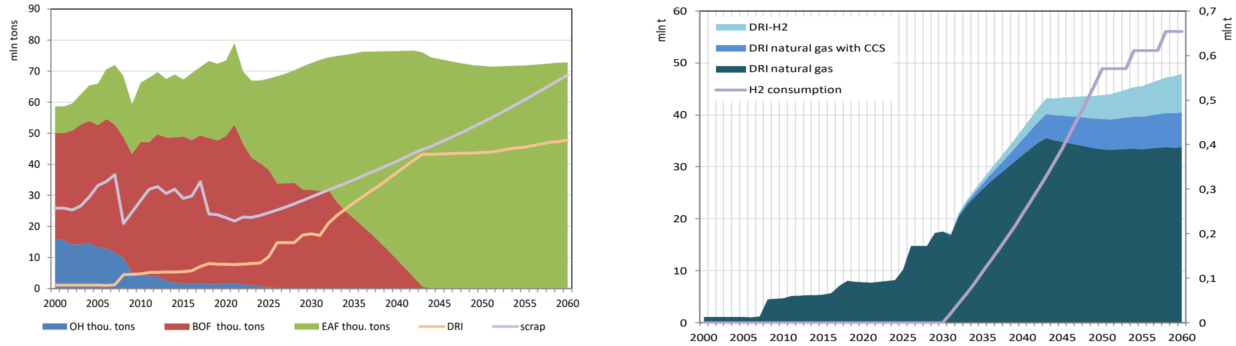
[181] Bashmakov I.A, D.O. Skobelev, K.B. Borisov, T.V. Guseva. 2021. GHG benchmarking system in the iron and steel industry // Chernaya Metallurgia. 2021. Vol.77, No. 9.

Figure 6.9 Transformation of steel industry in 4D scenario



(a) mix of iron and steel products

(b) costs of steel production by different production routes



(c) crude steel production by technologies

(d) DRI production by technologies

Source: CENEf-XXI.

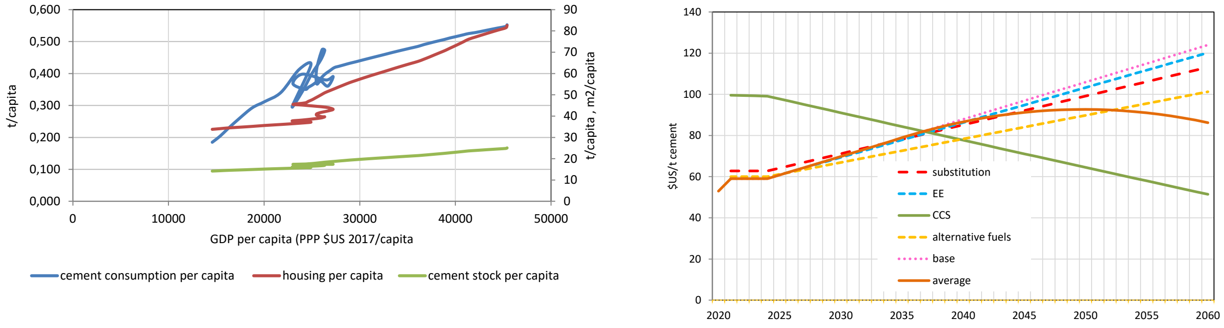
CO_2 emissions in the cement industry will be two thirds down in 2021-2060, and if the sponge effect is accounted for, the industry may become a net CO_2 sink in the 2040s (Figure 6.10). As the economy develops, and new facilities are built to replace technically obsolete ones with expired service life, demand for cement will rebound in 2031 and continue to grow thereafter. So both accumulated cement stock per capita and cement use per capita are not yet saturated. But since the population will be declining, cement demand growth will be moderate. CO_2 absorption by accumulated cement stock may reach 27 million tCO_2. If this effect is accounted for in national inventories, then net CO_2 emissions will become negative and reach -15 $MtCO_2$ in 2060.

Carbon pricing will make technological options with improved energy efficiency, clinker substitution, alternative low carbon fuels and CCS cost effectivet, and new production facilities will be based on these technologies. Deployment of CCS at cement plants and 50% subsidies in contracts for difference will improve the cost competitiveness of this technology and allow it to build new, and upgrade existing, plants with CCS. In 2060, cement production with CCS will reach 52%, and about half of the remaining CO_2 emissions (mostly from calcination) will be captured. Deployment of both new and existing technologies with carbon pricing would make cement more expensive. Average cement costs from newly built plants will grow from 60 $US/t in early 2022 to 93 $US/t in 2050 with a subsequent reduction to 86 in 2060. Steady costs growth will allow it for cement users to adjust and use the large potential to improve the efficiency of cement use in construction. Higher cement prices will only incrementally affect the costs of buildings and infrastructure (less than 1%).

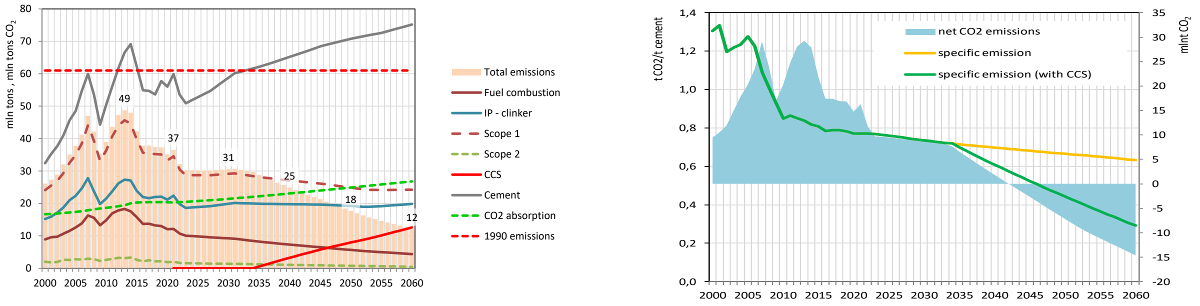
Cement industry needs a long-term low carbon strategy to outline the transition pathways. This strategy should assess the impacts on the competitiveness that these pathways may have;

designs for market-based and other policy instruments, such as contracts for difference (CfDs); develop benchmarking and reporting systems; etc.

Figure 6.10 Transformation of cement industry in 4D scenario



(a) cement stock and consumption per capita (b) cement production costs

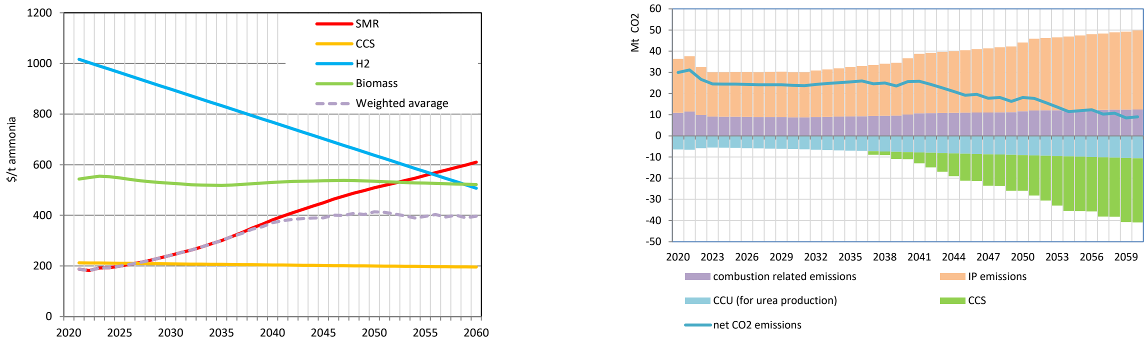


(c) CO$_2$ emissions from cement industry (d) specific CO$_2$ emissions and net emissions (accounting for sponge effect)

Source: CENEf-XXI.

Carbon pricing, subsidies for CfD green ammonia supply contracts and technological progress will allow it to cut net emissions from ammonia production by 3 times (Figure 6.11). The CCU option for urea production in place will be supplemented with SMR ammonia production with CCS and with hydrogen using facilities. As the carbon price grows, SMR technology will be getting more expensive. Hydrogen-based ammonia production will reach 6% in 2060 supported by subsidies covering the costs gap with SMR technology. In 2060, 58% of ammonia production will be equipped with CCS. New low carbon technologies will make ammonia more expensive in 2040, but then average costs will stabilize and slightly decline closer to 2060.

Figure 6.11 Transformation of ammonia production in 4D scenario

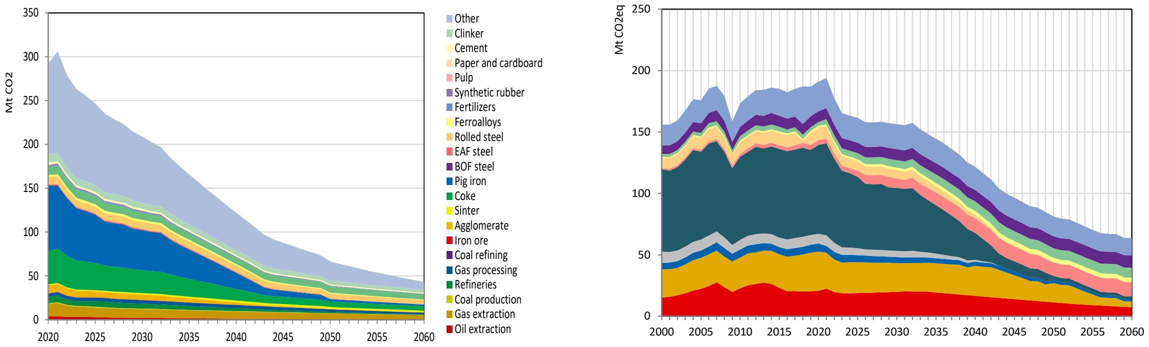


(a) ammonia production costs (b) emissions and sinks in ammonia production

Source: CENEf-XXI.

In 4D scenario, Russian industry will significantly progress towards carbon neutrality. In 2021-2060, combustion-related emissions will be down from 305 to 45 MtCO₂, and industrial emission – from 194 to 62 MtCO₂ (Figure 6.12). Carbon price in 4D will reach 180 $US/tCO₂ in 2060. Together with other policy instruments it will give momentum to low carbon transformation of the Russian industry and large-scale low carbon technologies penetration. Some technological trends as discussed above will be supplemented with new technologies in other sectors, such as introduction of inert anodes in aluminium production – a technology being tested by RUSAL in Russia[182] – and large-scale paper and plastics recycling.

Figure 6.12 CO₂ emissions from industry in 4D scenario



(a) combustion-related emissions (b) process-related emissions

Source: CENEf-XXI.

Low carbon transformation of the Russian industry will improve the competitiveness and allow for stronger positions in the global markets. Carbon intensities of many Russian basic materials and carbon footprints for other manufactured products will be significantly lower in 4D versus 4S. Entering markets with carbon pricing mechanisms like CBAM, allows for lager shares for least carbon intensive products and (or) products manufactured in countries with carbon pricing schemes. So, after sanctions are relaxed, there will be no new iron curtain blocking return to OECD markets and expanding sales to other markets.

6.3 Transport

In recent years, Russian transportation policies were focused on promoting less polluting and low carbon solutions. Transition to electric transport was declared a priority on the Russian transport policy agenda. *Concept for the development of production and use of electric road transport in the Russian Federation to 2030* was adopted by the RF Government Decree of August 23, 2021, No. 2290-r. To implement this Concept, 804 billion rubles were allocated to provide soft loans and lease of EV, co-finance installation of charging stations, launch local production of components, including batteries for EVs. The goal was for domestic EVs to reach 10% of all manufactured vehicles, install 72 thousand charging stations and 1,000 hydrogen charging stations. Many initiatives were launched at the regional level as well. Moscow is implementing a comprehensive program "Energy of Moscow" aimed at the electrification of urban transport. The city has an ambitious program for electric buses; the owners of electric vehicles are allowed to park for free; the municipal government supports the development of electric carsharing and electric taxis, installs charging stations looking to increase the number to 600 in 2023, creates new integrated electrical infrastructure to accelerate the electric transport development. In St. Petersburg, electric vehicles are exempt from the transport tax. *Concept for the development of production and use of electric road transport in the Russian Federation to 2030* specifies several cars, trucks and buses manufactures, who have already launched, or are about to launch, EV production. The Russian Railways Holding has 20 projects to set more than

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[182] Inert Anode Technology (enplusgroup.com)

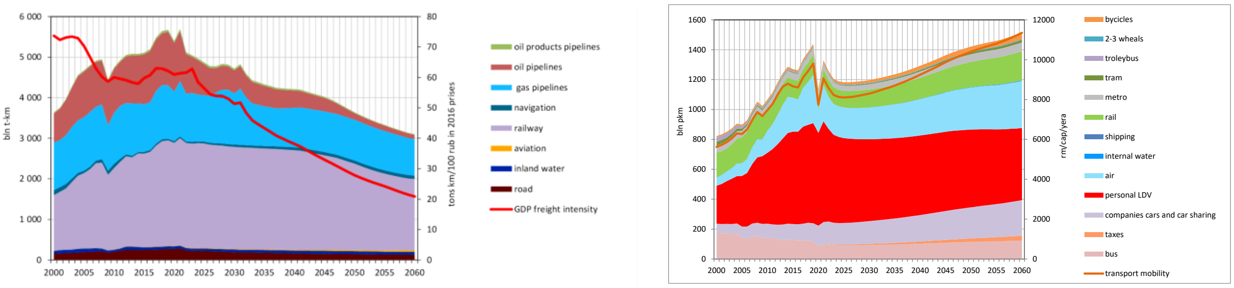
50 high-speed rail routes to make 84 million trips per year reaching 11 thousand km of high speed lines in 2030.

The sanctions have blocked some of the plans and delayed the implementation of others making some of the mitigation policy options not feasible on the initially expected time horizon. Ban on new ICEV sales, as proposed by some experts, as well as proposed introduction of EV quotas for car manufacturers to reach 100% will unlikely be introduced before 2040. Introduction of mechanisms to reduce vehicles life cycle will face the lack of new vehicles supply for at least a decade. Development of high-speed rail to reduce the use of air transport and development of infrastructure for comfortable electric public transport will be also delayed, as fewer buses and trains will be available.

4D scenario assumes that the low carbon transport transition policies will persist, even if with lower intensity, to 2031 and will intensify thereafter to come back on track. The wide policy mix includes: government and private procurement of low carbon fleet; carbon intensity standards; municipal planning and enabling creative foresight; charging infrastructure development; regulation of EVs grid integration; R&D support, education; net zero strategies development for different transport subsystems; development of alternative fuels (hydrogen, ammonia, biofuels, synthetic fuels); financing schemes (lease, subsidies, soft loans) to support the purchases of low carbon transport equipment; public and private investment in the relative infrastructure.[183]

Economic assumptions of 4D scenario imply that smaller amounts of oil, gas, and coal will be produced and transported, and the economy will be somewhat dematerialized. Along with effective supply chains management all this will work to bring down the freight turnover. At the same time, higher incomes will drive personal mobility up from the 4S reference scenario (Figure 6.13). Freight turnover will be dominated by rail (57-59% after 2035) and gas pipelines (29% in 2060). In the passenger turnover, the share of personal LDVs will scale down from 52% in 2021 to 32% in 2060. This will be partly compensated by taxis, company cars, and car sharing. Their contribution will grow from 12% to 18%. Therefore, LDVs will be contributing 40% of passenger-km travelled in 2060, which is much below 64% in 2021. Bicycle rides will amount to 3% of passenger turnover in 2060, while 57% will be provided by public transport, including 21% by aviation and 13% by rail.

Figure 6.13 Freight and passenger turnover by transport modes in 4D scenario



(a) freight turnover by mode

(b) passenger turnover by mode

Source: Data for 2000-2021 – Rosstat. Projections – CENEf-XXI.

Electrification of transport is the key GHG mitigation policy. The share of electricity in transport energy balance will grow from the present 7% to nearly 40% in 2060. For rail, it will reach 85%, for pipelines 44%, and for automobiles 32%. It was assumed in 4D scenario, that 0.5 million rubles in purchase subsidies will be provided until the costs of ownership

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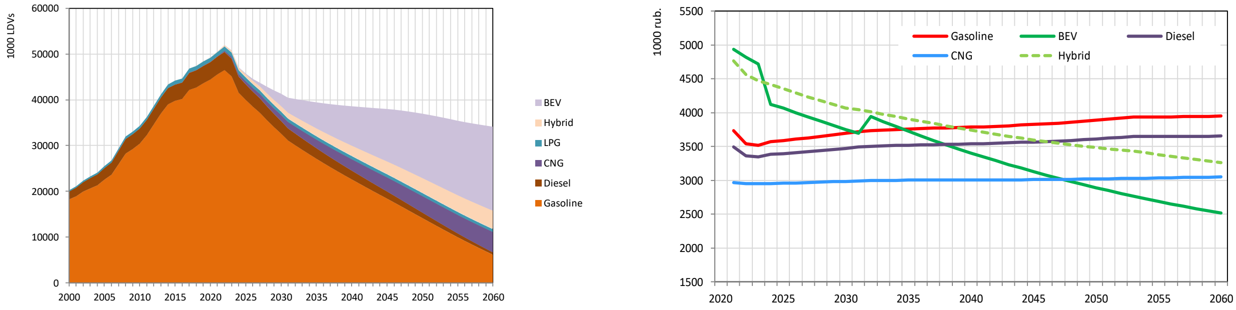
[183] Jaramillo P., S. Kahn Ribeiro, P, Newman et al. Transport. In: Climate Change 2022. Mitigation of Climate Change. Contribution of Working Group III to the IPCC Six Assessment Report (AR6) [Skea, J. et al., (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

become equal to those for ICE, to spur the penetration of currently expensive BEVs. With such subsidies and carbon prices the BEV/ICE cost of ownership parity will be reached in 2031 (Figure 6.14); if the subsidies are not provided, it will be delayed until 2035. BEVs/ICEs cost of ownership parity will be reached, if the BEVs purchase price exceeds that for ICEs by $US 20,000 at the maximum. Presently, the average price of a mid-sized BEV worldwide varies between $US 30,000 and $US 50,000.[184] Therefore, in many global markets BEVs are already approaching the cost parity with ICEs, depending on fuel and power prices. In Russia, this will be some 10-15 years delayed.

The 2060 LDV fleet structure will evolve towards electric power train, and EVs will amount to 70% in new sales (12% PHEVs and 58% BEVs), followed by gas-powered vehicles (13%) and only 17% left for ICEVs. In the total fleet, EVs will amount to some two thirds. These values are smaller, than projected before February 24th, but they are much higher compared to the 4S scenario. This can be attributed to the international cooperation in car manufacturing, policy support, and higher fuel prices driven by carbon prices. Fuel cells-based vehicles are more expensive and are not considered at this stage of the analysis. In 2060, the share of EVs in the total fleet will reach 55% for BEVs and 12% for PHEVs, 43% for trucks: 43% for BEVs and 20% for PHEVs; for buses: 72% for BEVs and 16% for PHEVs.

Figure 6.14 LDV fleet by power train (a) and cost of car ownership (b) in 4D scenario



(a) LDV fleet (b) cost of car ownership

Source: CENEf-XXI.

Total transport energy consumption in 4D scenario will be 3 times down in 2060 from 148 to 51 Mtce versus 73 Mtce in 4S scenario (Figure 6.15). Road transport energy use will drop to 24 Mtce, for civil aviation it will stay between 6 and 7 Mtce in 2022-2060, for railroad it will decline from 10 to 4 Mtce, and for gas pipeline it will be down from 35 to 15 Mtce.

In 4D scenario, CO_2 emissions from transport will be more than 200 $MtCO_2$ down over 2021-2060, yet 70 million tCO_2 will be unabated in 2060. Total, including indirect, GHG emissions from transport will drop from 309 to 83 million tCO_2eq. The share of fossil fuels in the transport energy balance will be declining from 91% in 2021 to 57% in 2060. Despite the deep electrification in 4D scenario, indirect emissions will drop by two thirds, as power decarbonization goes much faster, than in 4S scenario. The 4D scenario results indicate, that the unabated emission in 2060 is consistent with the meta-analysis of IAMs and IEA scenarios for transport, which suggest that the transport net zero carbon status is not achievable before 2050 and is hardly achievable even in 2100.[185]

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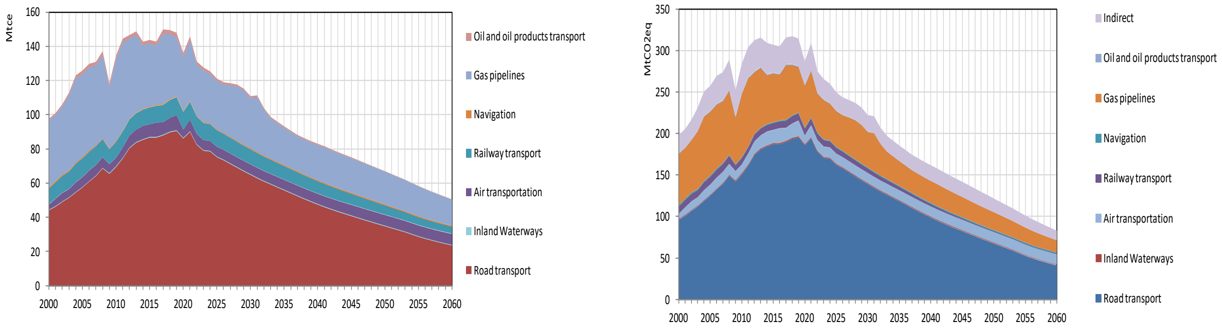
[184] Ibid.

[185] Jaramillo P., S. Kahn Ribeiro, P, Newman et al. Transport. In: Climate Change 2022. Mitigation of Climate Change. Contribution of Working Group III to the IPCC Six Assessment Report (AR6) [Skea, J. et al., (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA; IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector.

Figure 6.15 Energy consumption by transport in 4D scenario



(c) energy consumption (d) GHG emissions

Source: CENEf-XXI.

6.4 Buildings

In this scenario, housing construction will be larger, since a faster economic recovery is expected. The drivers will include: lower mortgage rates; higher real disposable incomes; availability of loan financing for building companies; cheaper construction materials, machinery, in-house equipment; and other factors. The removal of restrictions on goods and technology transfer will increase the imports of more energy-efficient construction materials, equipment and machinery to meet the higher demand from new apartments. On the other hand, new construction will be accompanied by a faster demolition of old inefficient buildings thus accelerating reduction in the average specific energy consumption by buildings.

From 2029 onwards, energy efficiency requirements for new buildings will be stricter. Introduction of more stringent requirements will encourage the deployment of advanced insulation and energy supply technologies (information modeling, ‘smart’ houses); introduction of ‘smart’ controls; application of high-tech, energy-efficient equipment and materials with a low carbon footprint; building materials recycling. Energy efficient architectural and space planning concepts and climate controls, architectural bionics approaches and solutions, and renewable energy sources will be deployed in buildings design. In addition, the principles of circular economy will be increasingly claimed by the construction industry contributing to greater decarbonization. Cheaper construction materials, technology transfer, government programs will encourage the construction of low energy and ‘passive’ buildings increasing their share in the buildings stock.

Energy-efficient capital retrofits in buildings and their effects will increase significantly. At the national level, energy efficiency standards for capital retrofits will be set, a compliance monitoring system will be set to include penalties for incompliance encouraging contractors to meet the requirements, to focus on the packages of measures with larger energy-savings yields, and to make decisions based on life-cycle costs comparison. In this scenario, public subsidies for energy-efficient capital retrofits under the government support programs will persist for the whole time horizon. Introduction of the “white” and “green” certificates, promotion of energy service companies, and growing real disposable incomes will increase the effects and significantly scale up energy-efficient retrofits projects.

Normalization of trade, cost reduction and household income growth will promote the emergence of new, more efficient light sources in the domestic market. Government support will contribute to the construction of new facilities producing highly energy-efficient light sources, leading to cost reduction and increased penetration. For this reason, an assumption is made that replacement of lamps with more efficient models will be going at a substantially higher rate, than in 4S scenario, and there will be greater uptake of automatic controls (motion detectors, light sensors, etc.).

In this scenario, an assumption is made that more energy-efficient household appliances will be purchased resulting in a faster decline in average specific energy consumption. A similar assumption is made with regard to heating boilers, water heaters and cooking stoves, leading to a faster efficiency improvement across the entire stock. To this end, the government extends the scope of household appliances and equipment subject to mandatory labeling and sets minimum efficiency requirements at least at the "A" level. In addition, state programs will be implemented to encourage the purchase of highly efficient household appliances and equipment. On the other hand, consumer behavior will be getting more rational to additionally reduce power consumption, other things equal.

One direction to reduce energy consumption and greenhouse gas emissions from buildings in this scenario is a better uptake of non-conventional renewable energy sources, specifically:

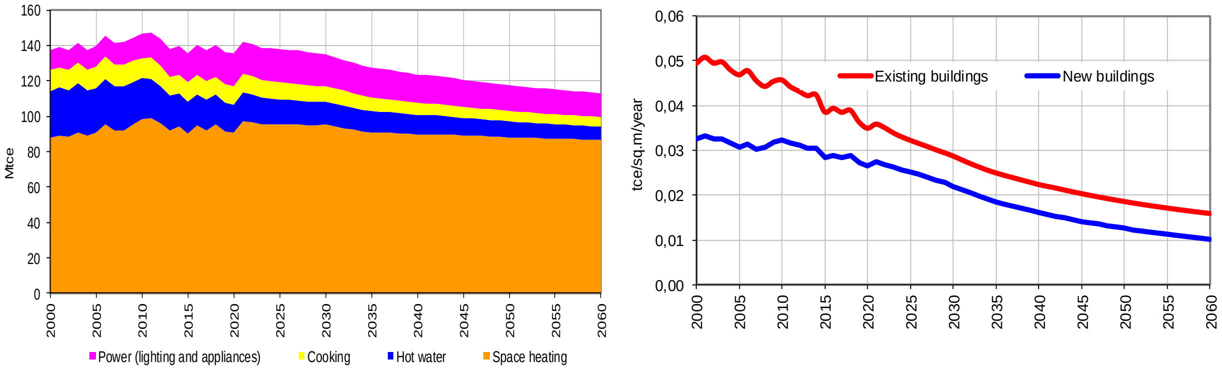
- solar thermal equipment (solar collectors) for DHW supply;
- solar photovoltaic installations (panels) for power generation;
- heat pumps, including hybrid systems, for heat supply (DHW and space heating);
- heat recovery units and heat pumps for heat recovery from ventilation emissions;
- apartment- and building-level equipment for wastewater heat recovery.

Government policies (tax exemptions, feed-in tariffs) will encourage decentralized power generation and the emergence of a large number of prosumers leading to a significant increase in micro-generation in buildings. Financing RE deployment under state programs against the background of LCOE decrease will lead to better penetration of solar collectors, heat pumps, and other RE technologies at the building level.

In this scenario, despite 80% increase in space to be heated and household appliances ownership, residential energy consumption is 20% down from the 2020 level in 2060 (Figure 6.16) to reach 108 million tce. Energy consumption per 1 sq. m will be noticeably down compared to 4S scenario and will reach 10.3 kgce for new buildings and 16.0 kgce for existing buildings. Average energy consumption per 1 sq. m will be 57% down in 2060, and average specific energy consumption for space heating will be 48% down. The share of space heating will keep dominating in the energy consumption structure: 75% in 2060.

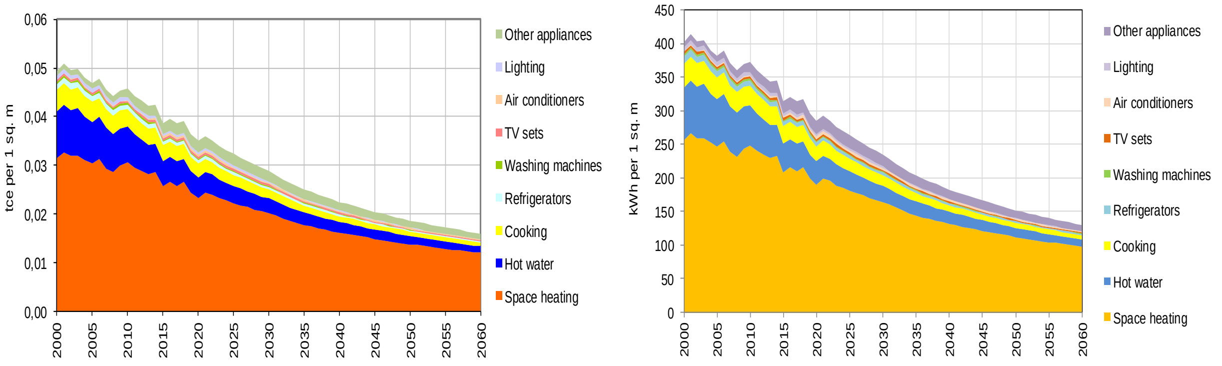
Direct GHG emissions from residential buildings in this scenario will be significantly lower and drop down to 47 million tCO2eq. in 2060 (Figure 6.17). More intense energy efficiency improvements and electrification of residential buildings, coupled with a reduction in indirect emissions from the electricity and heat use processes, will essentially reduce greenhouse gas emissions. Specific direct GHG emissions will drop to 6.5 kgCO2eq./m^2 of total residential floorspace in 2060, or by 63%. Ultimately, cumulative (including indirect) GHG emissions will be down to 15.2 kgCO2eq./m^2 in 2060, or by 69%.

Figure 6.16 Residential energy consumption in 4D scenario



Structure of residential energy consumption

Specific energy consumption in new and existing buildings

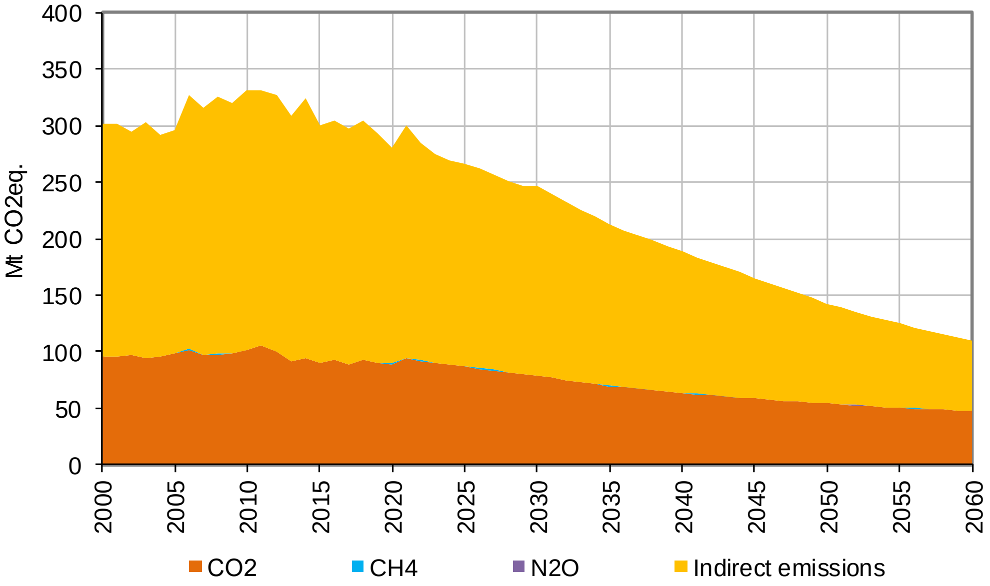


Specific residential energy consumption by processes

Specific residential power consumption by processes

Source: CENEf-XXI.

Figure 6.17 Evolution and structure of residential GHG emissions in 4D scenario

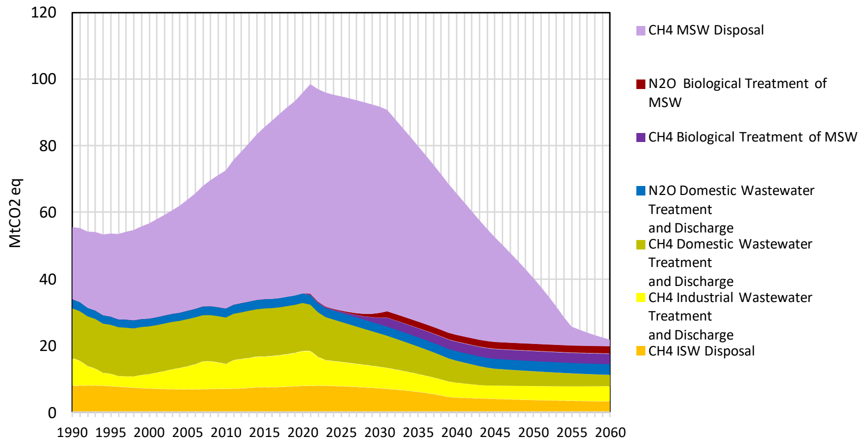


Source: CENEf-XXI.

6.5 Waste

Additional set of measures in the waste sector allows it to reduce GHG emissions from 96 MtCO_2eq in 2020 to 23 MtCO_2eq in 2060 (Figure 6.18). In addition to 4S scenario, the following assumptions were made. The volume of combustible unsorted MSW will be 50% down in 2030. The methane produced will be burnt at all landfills in the large cities. Resource efficiency and waste recycling technologies uptake will be growing at 5% per year to reach 30%; the relevant infrastructure will be built. By improving the efficiency of centralized aerobic waste treatment facilities, the degree of anaerobicity can be reduced by 10% per year to reach 100%. Combustion of the methane produced by digesters will be growing at 2% per year to reach 100% resulting in no additional emission due to the deep modernization of the facilities. The share of population using systems of purification/runoff will be annually 0.3% up (for centralized aerobic systems with digesters); 0.2% up (for centralized aerobic systems); and 0.1% down (for septic tanks). The share of population using latrines is determined as the residual. In other words, the growth in population connected to centralized sewage will be faster, than before 2020.

Figure 6.18 GHG emissions from waste in 4D scenario



Source: CENEf-XXI.

6.6 4D emission pathway

6.6.1 Energy and fuels use

In 4D scenario, total primary energy consumption (TPES) is 27% down from 1,121 Mtce in 2021 to 818 Mtce in 2060. The major decline is expected in transport (98 Mtce) followed by industry (76 Mtce). The only sector with growing consumption is non-energy fuel use (i.e. fuel used as feedstock, mostly for chemicals production (Figure 6.19). IEA also expects a global TPES reduction from the 2019 peak.[186]

Energy intensity of GDP (non-energy use excluded) will be on the rise in 2022-2024 and will show some 60% decline to 2020 with 2.5% per year AAGR, which is twice the level in 4S scenario. With an account of non-energy use, GDP energy intensity decline will not exceed 1.6% per year. GDP energy intensity reduction will go unevenly and will be slowing down as SECs (specific energy use) approach BATs values in many activities.

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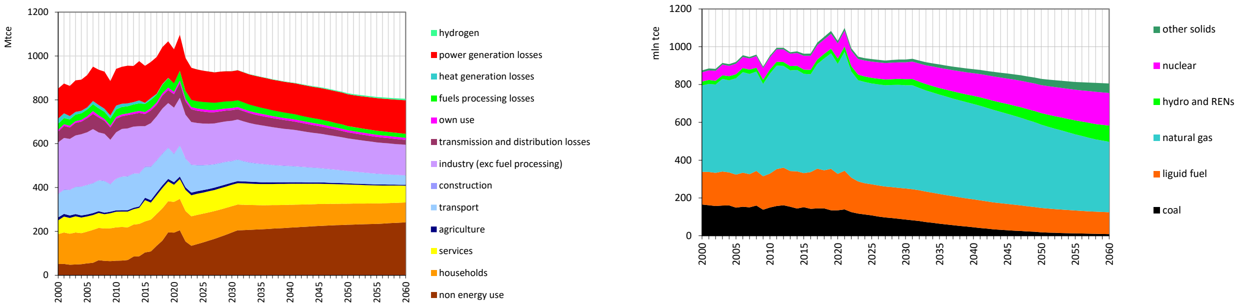
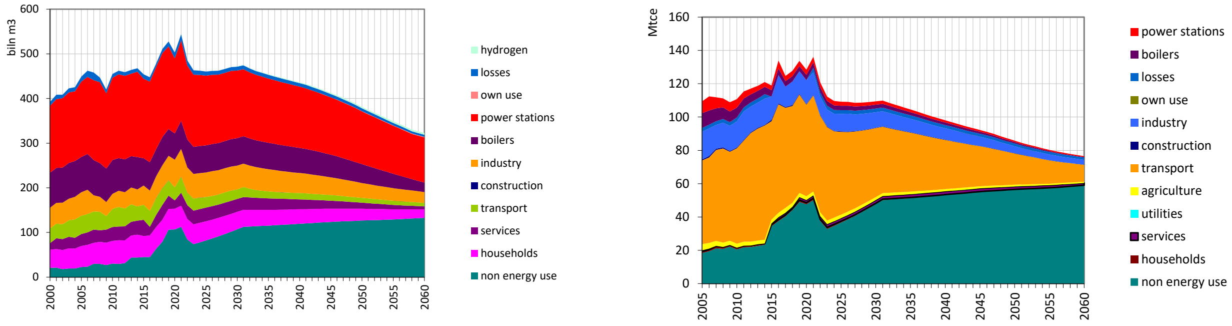
[186] IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector.

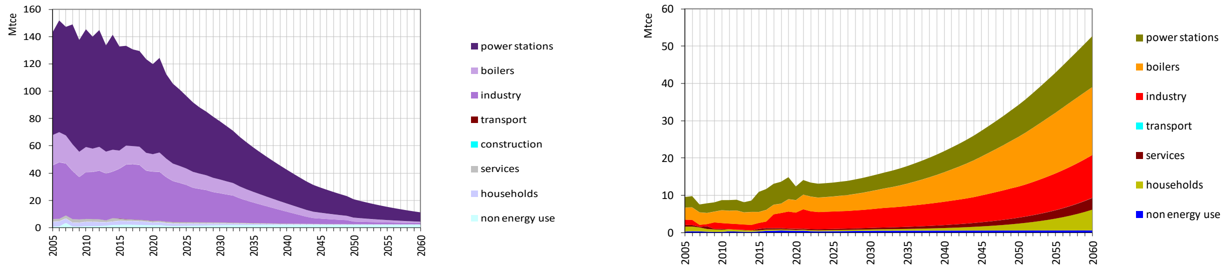
Figure 6.19 Primary energy and fuel use in 4D scenario



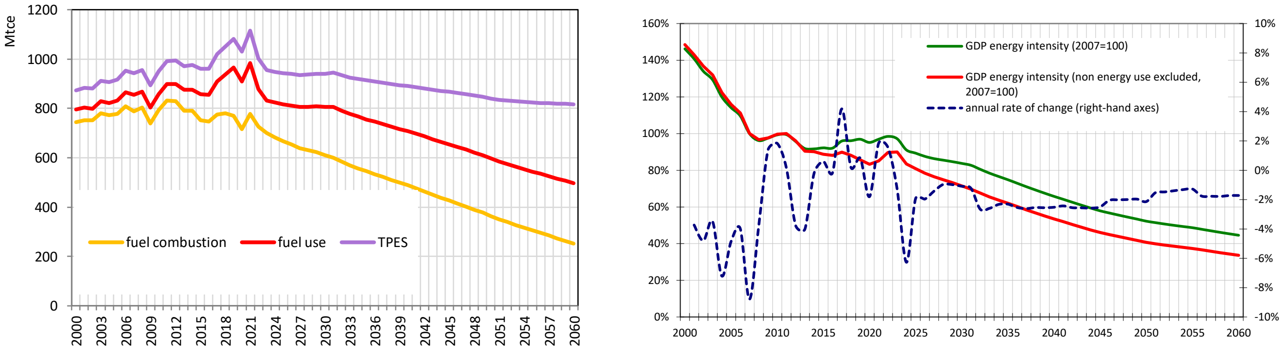
TPES by sectors TPES by energy sources



natural gas liquid fuels



coal other solid fuels



fossil fuels use GDP energy intensity

Source: CENEf-XXI.

Energy efficiency improvements coupled with growing power generation by RENs, hydro, and nuclear make fossil fuel consumption drop by two thirds from 779 to 253 Mtce, or twice as much as in 4S scenario. In the fossil fuels mix, there is a shift towards natural gas. Natural gas consumption will be 42% down from 553 to 323 bcm, and gas combustion volumes will be down to 190 bcm. Cumulative extraction in 2021-2060 will reach 18 trcm, and if added to the resources required to maintain the 2060 production level – 32 trcm, which is below proven resources as reported by BP (37.4[187]) demanding no additions to proven resources. Liquid fuels

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[187] BP Statistical Review of World Energy. July 2021.

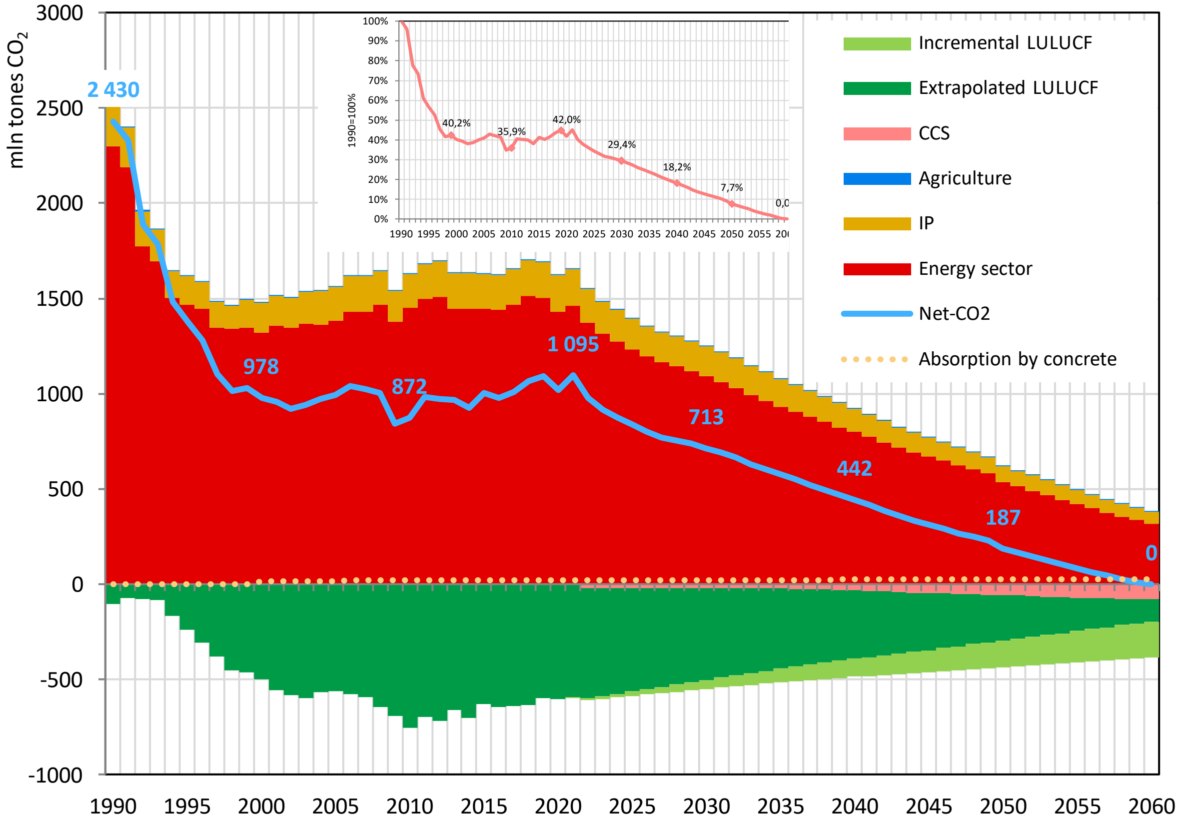
consumption will decline by 44%, and its combustion part by 80%, mostly due to the declined consumption by transport. Cumulative extraction in 2021-2060 will reach 8.8 bln t (versus 13.2 bln t in 4S scenario), and if added to the resources required to maintain the 2060 production level – 10 bln t, which is again below the proven resources as reported by BP (14.8[188]), and thus no additional proven resources are needed.

Domestic coal consumption will decline 10-fold in 2060 from the 2021 level, and some part of it will be using CCS. Coal is going to face the greatest pressure from carbon pricing and so it will be largely substituted with natural gas, as gasification programs will expand along with biomass energy use. This will help biomass to deeper penetrate centralized and individual heat markets. District heat use will be 44% down. Hydrogen use in this scenario will not exceed 1.3 Mt in 2060 and will be mostly for feedstock.

6.6.2 Emission trajectories towards net-zero carbon in 2060

In 4D scenario, Russia may attain carbon neutrality in 2060 without expanding LULUCF net sink, which can be down from 605 $MtCO_2$ in 2020 to 291 $MtCO_2$ in 2060. In other sectors, emission reductions will amount to 1,291 $MtCO_2$ in 2021-2060. In addition, 93 $MtCO_2$ will be captured by CCS in the power sector and industry. Using the declining net sink trend in LULUCF as a baseline, policies and projects in this sector will be required to ensure additional 176 $MtCO_2$ sinks, which is only a quarter of the 685 $MtCO_2$ needed in 4S scenario, and only one sixth of the 1,085 $MtCO_2$ required to be added in LTS. The remaining net emissions from all sectors (excl. LULUCF) will be down to 383 $MtCO_2$ in 2060 (Figure 6.20).

Figure 6.20 CO2 emission pathway in 4D scenario



Source: CENEf-XXI.

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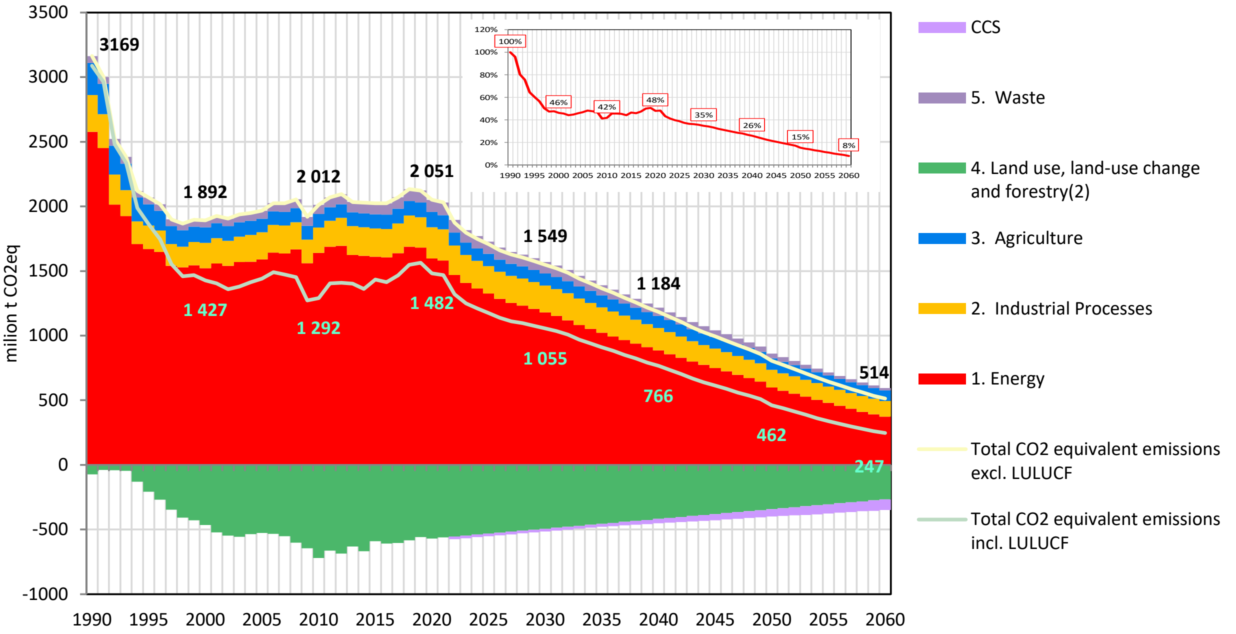
[188] Ibid.

Fit for 65. In 4D scenario, in 2030 Russia will never exceed 35% of 1990 CO_2 emissions and 36% of GHG emissions. Like in 4S, Russia will be ahead of the EU in cutting its CO_2 and GHG emissions by 2030. Expected GHG emission reduction is 64% and CO_2 reduction is nearly 70% (Figures 6.20 and 6.21). In 4D scenario, LTS gets more pillars to attain carbon neutrality in 2060. Faster (compared to 4S) economic growth is no barrier to more dynamic emission reductions, as it is accompanied by dynamic modernization and advanced capacity additions in all sectors. Such upgraded facilities and manufacture of products with low carbon footprint for highly competitive local and international markets are critical for the growth in total factor productivity and non-oil and gas GDP.

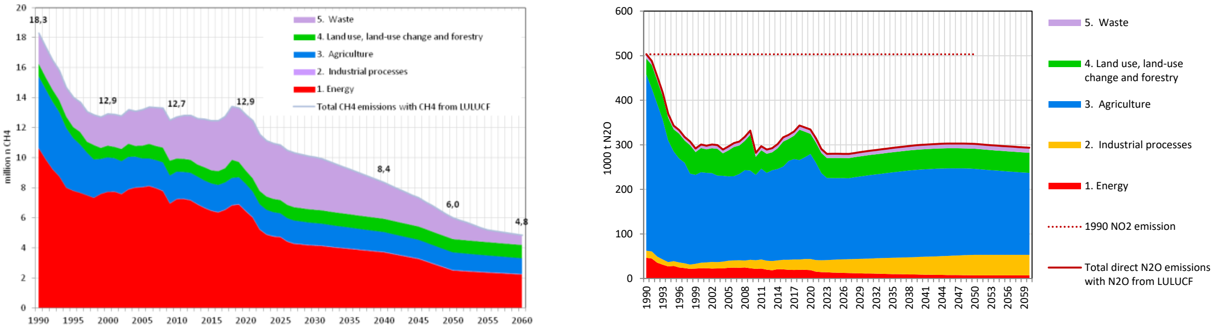
Figure 6.21 GHG emission pathway in 4D scenario



Source: CENEf-XXI.

In 4D scenario, Russia will not attain GHG neutrality in 2060, yet will come quite close with the remaining net GHG emission equal to 8% of the 1990 level. GHG emission reduction will reach 92% of the 1990 level. CO_2 emissions will get to net zero. CH_4 emissions will be 62% down in 2060, while N_2O emissions will be nearly stable over 2020-2060 (Figure 6.22). More research is required to identify N_2O emissions in agriculture. If 243 Mt CO_2 additional LULUCF sinks are available in 2060, Russia may become GHG-neutral.

Figure 6.22 CH_4 and N_2O emissions in 4D scenario



CH_4 emissions

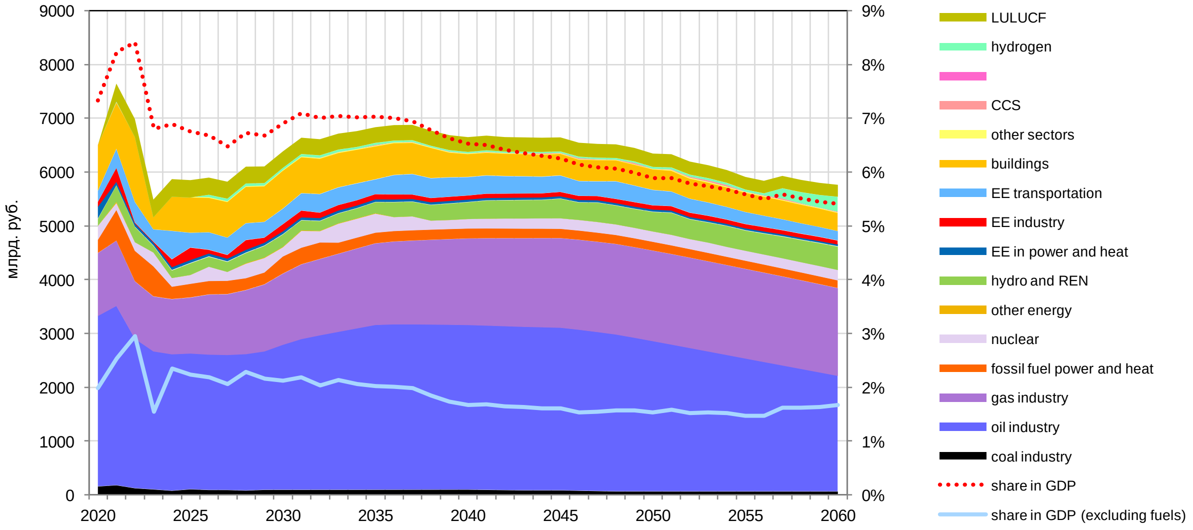
N_2O emissions

Source: CENEf-XXI.

6.6.3 Mitigation costs

Total capital expenses in 2022-2060 will amount to 197 (versus 247 in 4S) trillion rubles in 2021 prices. Energy and GHG mitigation investments in 4D scenario are lower, than in 4S – 50 trillion rubles, – due to a much lower investment demand from the oil and gas sector. In 4D scenario, investments in low carbon projects amount to 92 trillion rubles (versus 78 trillion in 4S). This is about as high as investments in fuels supply – 105 trillion rubles (versus 169 trillion in 4S). Total investment demand from the energy sector is 204 trillion rubles (Figure 6.23). Total costs of low carbon technologies in the power industry amount to 25 trillion rubles. Incremental capital investment in energy efficiency is 53 trillion rubles. Investments in the LULUCF sector are close to 3.4 trillion rubles.

Figure 6.23 Investments in 4D scenario



Source: CENEf-XXI.

No additional investment demand is associated with 4D scenario. The share of investment in low-carbon transformation (total investment less investment in fuel supply) of GDP will be gradually declining from 2.2-2.7% in 2021-2030 to 1.5-1.7% in 2050-2060. This decline is associated with cost reductions for many low carbon technologies, while the uptake will be increasing. The share of investment in fossil fuel supply will be steadily declining from 5.7% in 2021 to 1.4% in 2060, and in 2050 this investment will have lost its dominance releasing financial resources for other sectors.

Carbon price in 4S scenario will be introduced in 2031 at 3 \$US/tCO_2 to grow by 3 \$US/tCO_2 annually to 108 \$US/tCO_2 in 2060. Carbon price collections will be reaching 5.2 trillion rubles, or 1.3% of GDP. Carbon pricing mechanisms might be introduced as offsets by lowering taxes on incomes; then the tax pressure on businesses will not increase. The proceeds from these mechanisms (25 trillion rubles before 2060) can be used to finance 92 trillion rubles-worth mitigation options with the leverage ratio below 1:4.

Energy affordability (the share of energy cost in incomes) will be staying close or below the thresholds and ranges registered in 2000-2021. Carbon prices growth schedule was developed to avoid exceeding the upper affordability thresholds.[189] Driven by carbon prices, energy price growth will be offset by energy efficiency improvements and prosumers' investments in on-site RENs generation, thus reducing the costs of purchased fuels, electricity, and heat. A carbon

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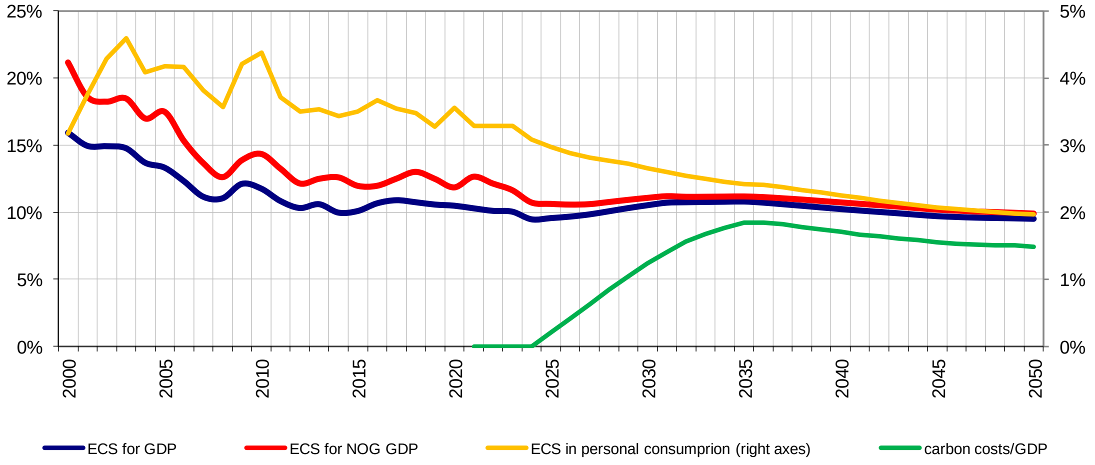
[189] For more detail see Bashmakov I., Myshak A. (2018). 'Minus 1' and energy costs constants: Sectorial implications. Journal of Energy, Vol. 2018, Article ID 8962437 https://doi.org/10.1155/2018/8962437; Bashmakov I. (2017). The First Law of Energy Transitions and Carbon Pricing. International journal of energy, environment, and economics. Volume 25, Number 1, 2017. Pp. 1-42.

pricing scheme was developed looking to avoid impacts on fuel use in the residential sector. Alternatively, the ECS for residential sector in 2060 will be 0.3% higher, which is twice as low as the 2003 value. If this is the goal, then large-scale support to energy efficiency improvements and RE development is not to be confined to the pricing mechanisms alone, but rather include a wide and costly package of energy efficiency policies.

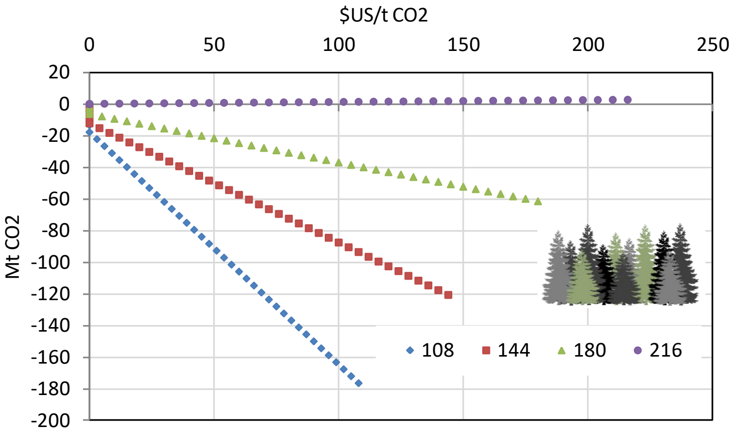
Figure 6.24 Energy cost shares (ECSs) in 4D scenario



Source: CENEf-XXI.

If carbon price doubles in 2060 from 108 to 216 \$US/t CO_2, carbon neutrality may be attained without any incremental LULUCF sink (Figure 6.25). The declining LULUCF sink trend can be compensated by more substantial CO_2 emission reductions in other sectors. Every additional 1 \$US/tCO_2 allows it to reduce incremental LULUCF sink demand by 1.7 Mt. However, when the carbon price reaches 216 \$US/tCO_2, ECSs will exceed the threshold levels. ECS in GDP will reach 12-13% beyond 2030, which is prohibitive for economic growth, and the share of carbon payments in GDP will reach 3.6% in 2035 to further decline to 2.7% in 2060. Such high carbon price doesn’t give consumers enough time to adjust. Therefore, a reasonable amount of forestry projects, if successful in storing carbon for a long time and less costly, than other mitigation options elsewhere, might help to attain carbon neutrality in 2060 with a moderate and affordable carbon price.

Figure 6.25 Incremental (versus baseline) LULUCF sink as a function of emission reductions in other sectors driven by carbon price



* The legend shows carbon prices in 2060.

Source: CENEf-XXI.

7 4F – Fossil Fuels For Feedstock

4F scenario builds on the same economic assumptions as 4D. It builds upon 4D in all sectors and was developed to see, to what degree Russian fossil fuel resources, including oil and gas, can be additionally used as feedstock for chemicals production, including plastics, ammonia, and hydrogen, and how GHG emissions will be evolving then. There are a few differences though. Oil and gas production is larger, than in 4D, affecting economic growth and investments in the oil and gas sector. In addition, 4F assumes hydrogen and ammonia exports, which bring additional export revenues and so impact the macroeconomic parameters.

In its *Net Zero by 2050* report IEA specifies the following reasons preventing fossil fuel use from falling down to zero in 2050:[190]

- Fossil fuels use for non-energy purposes in applications where the fuels are not combusted and so do not result in direct CO_2 emissions, such as chemical feedstocks, lubricants, paraffin waxes and asphalt;
- Fossil fuels use at installations equipped with CCUS. Around half of fossil fuel use in 2050 is in plants equipped with CCUS, including natural gas conversion to blue ammonia or hydrogen with CCUS.

Globally, the IEA Net Zero scenario expects non-energy use of 700 Mtoe of oil, 180 Mtoe of natural gas, and nearly 50 Mtoe of coal in 2050.[191]

In 4F, the assumption is that Russia will expand its plastics, ammonia, hydrogen and other chemicals supply to the international markets. There are good prospects for increased global consumption of these chemicals by mid-century. As Russian oil and gas exports will be shrinking, growing chemicals production and exports might be able to substantially mitigate some of the lost export revenues and budget income. However, only low carbon chemicals will be welcomed by these markets and encouraged by CBAM-like mechanisms.

7.1 International chemicals and hydrogen markets

According to the available projections, global plastics production could more than double from almost 400 Mt in 2019 to 985 Mt in 2050. In low-carbon scenarios, it rises to 600-659 Mt (Figure 7.1). In the IEA projection, expected growth is 28-40% in 2019-2050 with a peak in 2050 followed by a 10% reduction from this peak towards 2060. In their Planned Energy Scenario (PES), Saygin and Gielen (2021) expect virgin plastics market to grow to 800 Mt (Figure 7.2).

Only impressive progress in plastics waste management can limit virgin plastics demand growth. If some of the exported plastics were combusted after the end of life of products in which they are embedded, say, as fuel for clinker production at facilities with CCS, they would generate no emission.

Global ammonia production is expected to grow 2.5-fold from 175-183 Mt in recent years to 441 Mt in 2050. Ammonia and methanol production are expected to grow significantly, as new market segments emerge for chemical building blocks, hydrogen, shipping, fuels and power generation (Figure 7.2). According to some estimates, ammonia market could reach 1,000 Mt.[192] Ammonia synthesis using renewable energy is a carbon-free process with a century-long

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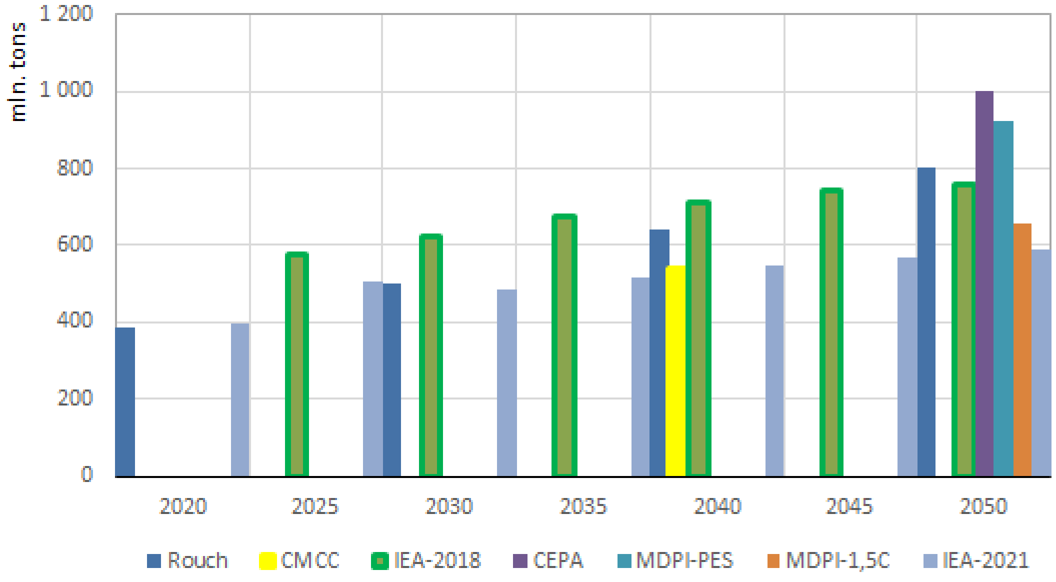
[190] IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector.

[191] Ibid.

[192] Valentini A. 2020. Green shift to create 1 billion tonne ‘green ammonia’ market? Argus Media group. June 2020.

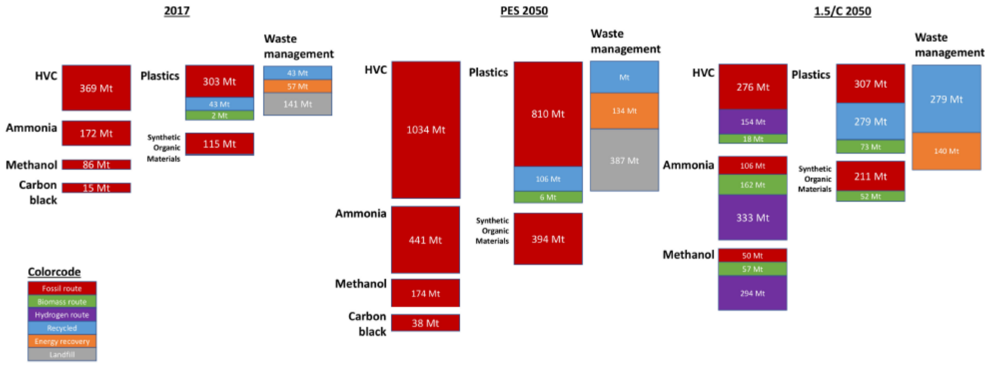
history[193] and a peak in 1960-1970. Ammonia can be produced from fossil fuels using CCS, if it is cost-competitive.

Figure 7.1 Projections of global plastics production



Sources: Plastics future: How to reduce the increasing environmental footprint of plastic packaging, January 2021; https://www.climateforesight.eu/global-policy/the-future-of-plastics-is-uncertain/; The Future of Petrochemicals, IEA, Technological report, 2018; Estimation of carbon dioxide reduction by utilization biomass bioplastic in Malaysia using carbon emission pinch analysis (CEPA), Research Paper, 2020; MDPI, Zero-Emissions Pathway for the Global Chemical and Petrochemical Sector, Deger Saygin and Dolf Gielen; https://www.iea.org/t_c/termsandconditions/.

Figure 7.2 Estimated production volumes of the key chemicals in 2050



Source: Saygin, D., and D. Gielen, 2021: Zero-emission pathway for the global chemical and petrochemical sector. *Energies*, 14(13), 3772, doi:10.3390/en14133772.

Ammonia has a higher volumetric energy density, than liquefied hydrogen, and so does not require such large tanks for storage.[194] Ammonia is an effective transport (Figure 7.2) and storage medium, it is easily stored in large quantities as a liquid at moderate pressures (10-15 bar) or refrigerated to -33°C. In this form, its energy density is around 40% of that for petroleum. As a zero-carbon fuel, ammonia can be either used in fuel cells, or combusted in ICEs, industrial burners and gas turbines. The maritime industry is likely to be an early adopter of ammonia as a

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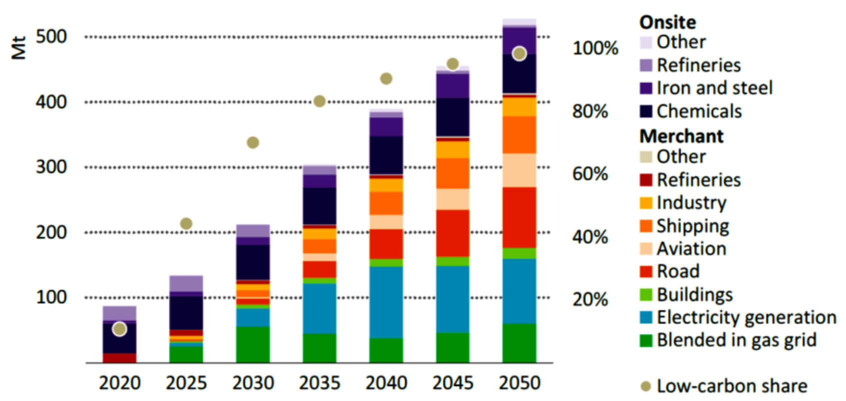
[193] Rouwenhorst, K.H.R., Travis, A.S., Lefferts, L. 1921–2021: A Century of Renewable Ammonia Synthesis. Sustain. Chem. 2022, 3, 149–171. https://doi.org/10.3390/ suschem3020011.

[194] American Bureau of Shipping. 2020. SUSTAINABILITY WHITEPAPER. AMMONIA AS MARINE FUEL. OCTOBER 2020.

fuel. Ammonia has the potential to decarbonize rail, heavy road transport, and aviation. Ammonia is an effective energy carrier for international supply chains. It has lower cost and is much easier to store and transport, than hydrogen. The international infrastructure is already in place.[195] Closer to the consumption point, ammonia can be decomposed, or ‘cracked’, into nitrogen and hydrogen, when needed. Ammonia can also be used for heat storage.

Global hydrogen production is expected to grow from 87 Mt in 2020 to 528 Mt in 2050 (Figure 7.3). Hydrogen use for chemicals production is expected to grow slightly – from 46 to 60 Mt, in iron and steel from 5 to 40 Mt. The major growth is expected for energy use, including 60 Mt to be blended in gas grids. Global hydrogen market may reach $US 650-850 billion in 2030[196] and $US 2,500 billion in 2050,[197] up from present $US 12 billion.[198]

Figure 7.3 Global hydrogen and hydrogen-based fuel use in the NZE



Source: IEA. 2021. Net Zero by 2050. A Roadmap for the Global Energy Sector.

7.2 Chemicals, ammonia, and hydrogen production perspectives in Russia

The international restrictions have substantially limited access to the potential global markets for Russian chemicals, ammonia, and hydrogen. The Hydrogen Energy Development Concept of the Russian Federation (approved by the RF Government Decree No. 2162-r of August 5, 2021) specifies the following potential global hydrogen exports: 0.2 Mt in 2024y, 2-12 Mt in 2035, and 15-50 Mt in 2050, depending on the global low carbon economic development rates and global hydrogen demand evolution. The RF Ministry of Industry and Trade has developed a Map of Russian projects to produce low and zero carbon ammonia and hydrogen, which shows the locations of 33 scheduled projects (Figure 7.4). These projects include Rosatom’s four pilot projects to produce hydrogen in 2024–2025 in Kaliningradskaya, Murmanskaya, and Sakhalinskaya Oblasts, of which the first two were supposed to supply hydrogen to the European markets. According to the RF Ministry of Energy, the investment demand from the hydrogen industry is $US 33 billion, and 3.9–5.6 trillion rubles in tax revenues were expected with a potential to contribute 0.2-0.5% to GDP in 2025-2030.

In 4F, and assumption is made that low carbon hydrogen exports will grow up to 15 Mt in 2060 (versus 0.7 Mt in 4D scenario), and low carbon ammonia exports will reach 15 Mt in 2060 (versus 6.5 Mt in 4D scenario). In addition, non-energy use for chemicals will

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[195] Ammonia: zero-carbon fertilizer, fuel and energy store. Issued: February 2020.

[196] McKinsey & Company. 2022. Playing offense to create value in the net-zero transition. McKinsey Quarterly. April 2022.

[197] Bashmakov I.A., Bashmakov V.I., Borisov K.B., Carvalho P., Drummond P., Dzedzichek M.G., Lunin A.A., Lebedev O.V. (2020). Monitoring low carbon technologies deployment in Russia. *Ekologicheskiy Vestnik Rossii*, No. 4, pp. 6–11. (In Russian); The global hydrogen market is expected to reach $2.5 trillion by 2050 | Edmonton Journal.

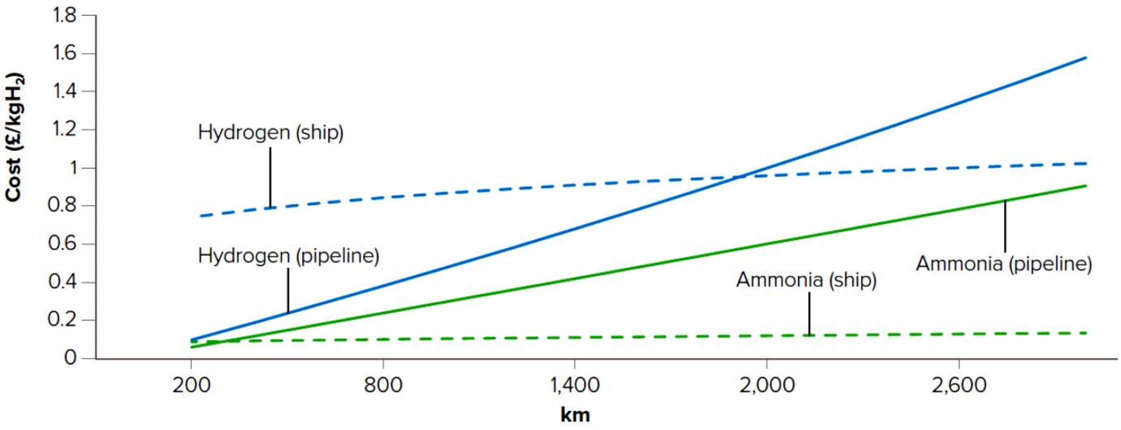
[198] Hydrogen Market Analysis, Size and Trends Global Forecast to 2022-2030 (thebusinessresearchcompany.com).

accelerate to maintain industrial production growth rates to 2060. The sanctions have restricted access to many of the global hydrogen markets, and the distance to the remaining potential markets makes exports economically impractical for the high transport costs. Therefore, for the years to come, the focus will be put on the domestic hydrogen market. For example, Rosatom's project "Sakhalin hydrogen belt" targets exactly the domestic market: 7 trains powered by this new fuel and 2 hydrogen stations for 30 thousand tons of hydrogen per year.

Figure 7.4 A map of Russian projects to produce low and zero carbon ammonia and hydrogen

Source: RF Ministry of Industry and Trade.

Figure 7.5 Cost estimates for the transport of energy as hydrogen or ammonia by ship and pipeline



Source: International Energy Agency. The Future of Hydrogen, June 2019. https://webstore.iea.org/the-future-of-hydrogen (accessed 24 October 2019).

The distance from the potential markets also brings ammonia projects to the agenda, for ammonia is cheaper to transport for long distances (Figure 7.5). NOVATEK had plans to become the first Russian producer of low carbon ‘blue’ ammonia (Obsky Gas Chemical Facility – 2.2 million tons of low carbon ‘blue’ ammonia; two ammonia synthesis lines with 1.1 million tons per year each, and 130 tons of hydrogen with 4.4 million tCO_2 yearly storage). In 2021, a contract was signed between PAO NOVATEK and the German company Uniper SE for the supply of 1.2 million tons of low-carbon “blue” ammonia from the Obsky GCC project. Thus, already at the preliminary design stage, PAO NOVATEK ensured the industrial supply of up to 50% of produced low-carbon ammonia as a carrier for hydrogen.

The sanctions forced Uniper SE to leave the Obsky GCC project. At the same time, it suspended any investments in the project. The future of the low carbon “blue” ammonia agreement is unclear. The sanctions formally do not apply to the production of low-carbon “blue” ammonia, which is related to the gas chemical industry. However, it is not clear yet, under which conditions the Ob GCC project will be possible to get European equipment.

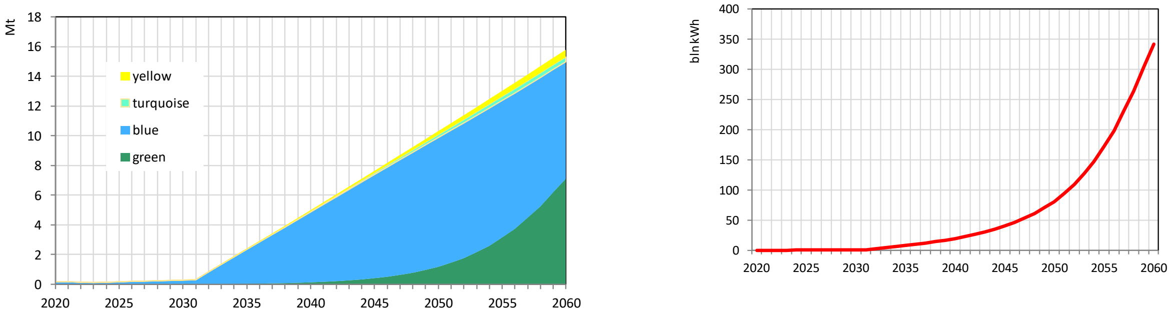
To keep the project going, NOVATEK has requested the Government to extend the economic incentives, which are used to support LNG production in the Arctic (zero mineral extraction tax – MET), to the “blue” ammonia and hydrogen production. According to some estimates, zero MET would save NOVATEK about 1 billion rubles a year and improve the project IRR by 1-3 percentage points (with an account of 2.2-2.5 billion m3 of gas for ammonia production). NOVATEK further requested the RF Government to entitle the Russian regional governments to setting lower profit tax rates, if they wish.

ENERGIA Foundation was planning to produce 2.2 million tons of “blue” ammonia in Yamalo-Nenetsky Autonomous District in 2025.

7.3 Hydrogen

Even if half of the 2060 Russian hydrogen production (15.8 Mt) is “blue”, still additional electricity demand to produce it will be 350 billion kWh, which is one third of today’s power generation in Russia (Figure 7.6). Additional power demand originates not only from water electrolysis, but also from steam methane reforming (SMR) and from CCS installations. The SMR would also require 3 MGcal of steam. IEA expects, that CAPEX for water electrolysis will decline to 450 $\$US/kgH_2$, while not much decline is expected for SMR. Driven by the carbon price, gas prices will be growing. This will make hydrogen from electrolysis competitive, and so the share of “green” hydrogen will grow. The structure of hydrogen production seriously affects the energy balance parameters, the dynamics of power capacities, and the deployment of CCS.

Figure 7.6 Hydrogen production by technology and additional power demand



(a) hydrogen production (b) additional power demand

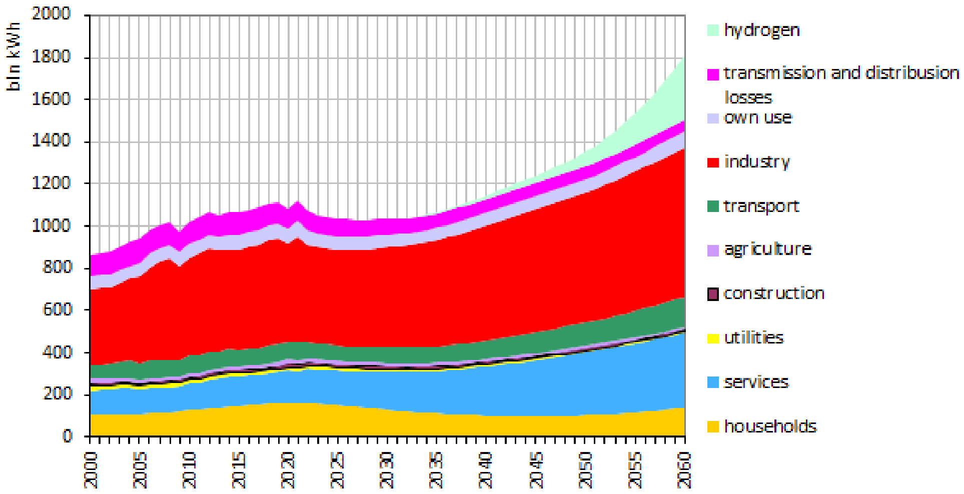
Source: CENEf-XXI.

If the availability of zero carbon generation is limited, the high level of “green” hydrogen production may generate significant additional GHG emission. This situation is highly likely. In 4F scenario, water electrolysis hydrogen production requires nuclear power generation to scale up 2.5-fold to 553 bln kWh, hydro power generation scale up 1.3-fold to 267 bln kWh, and other centralized variable RENs scale up 95-fold to 541 bln kWh, or two orders of magnitude. If nuclear and renewable resources in this scenario are scarce, then fossil fuel-based generation will be called upon with additional capital costs and emissions (if not equipped with CCUS). 4F is the scenario with 50% “blue” hydrogen. If the goal is to achieve 100% electrolysis-based hydrogen production, or to increase the hydrogen exports, it becomes even more problematic and hardly attainable.

3.4 Power and heat sector

For 4F scenario, the green power revolution or the green electrification program is required. After two decades-long stagnation electricity generation will skyrocket to 1,825 bln kWh in 2060 driven by demand for low carbon hydrogen production (Figure 7.7). In 2040-2060, incremental electricity demand will be nearly three times the 2000-2021 level.

Figure 7.7 Electricity consumption in 4F scenario



Source: CENEf-XXI.

To meet the demand from 4F scenario, overall power capacity has to be expanded to 418 GW in 2060, of which 102 GW will be wind, 86 GW solar, and 77 GW nuclear (Figure 7.8). For wind, it will only amount to one third of the 2021 Chinese wind capacity[199] (329 GW) and to about one fourth of the 2021 Chinese solar capacity (307 GW). Therefore, it is manageable. Hydro and geothermal capacities will be added to reach 62 and 0.2 GW respectively. Total thermal power plant capacity will be 59 GW down for gas and to 22 GW for coal. After 2035, over 95% of annually phased in capacity will be low carbon.

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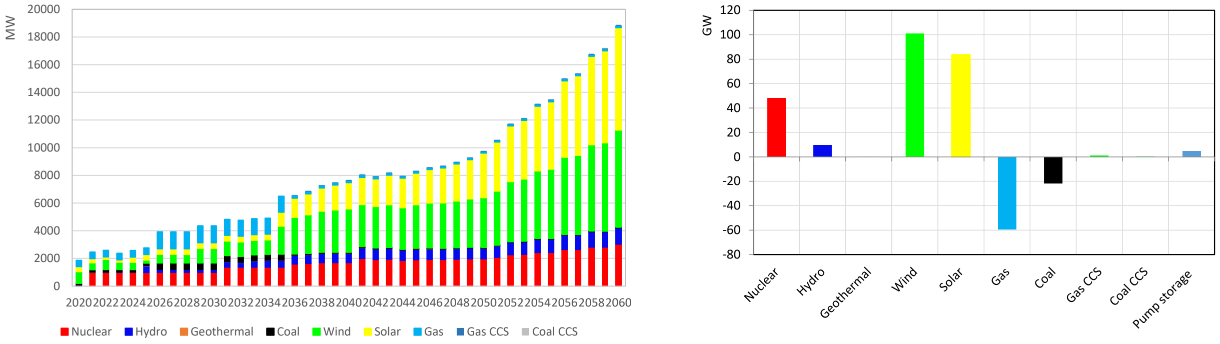
[199] Renewable Capacity Statistics 2022. IRENA, 2022.

Figure 7.8 Power capacity additions in 4F scenario



a) power plant additions b) installed capacity change in 2021-2060

* Capacity additions are shown as annual increments, since in reality they are commissioned proportional to block unit capacities.

Source: CENEf-XXI.

Annual capacity additions reach 18 GW in 2060 versus maximum 7.7 GW capacity commissioned in 2014. If compared with China, it is only 13% of average capacity increments in 2012-2021. Annual capacity additions for wind will approach 7 GW in 2060 and for solar 7.4 GW. In China, wind capacities in 2020 and 2021 were 73 GW and 47 GW up, for solar 49 GW and 53 GW up. Therefore, capacity additions projected in 4F scenario in 2060 are huge by the current Russian scale, but small if compared to China.

Non-fossil fuel-based power generation will reach 78% in 2060. Wind generation will reach 352 billion kWh (versus 118 billion kWh in Germany[200] in 2021) and solar generation will be 192 billion kWh (versus 49 billion kWh in Germany in 2021). Together, these intermitted power sources contribute manageable 30% to the total generation. To improve capacity credits, pump storage capacity will scale up to 6 GW, and battery storage capacity to 1 GW. Nuclear generation will reach 533 billion kWh in 2060.

7.4 Energy and fuels use

In 4F scenario, after a 16% drop by 2027 total primary energy consumption (TPES) will be nearly stable – 932-944 Mtce – until 2050 and then will grow up to 1,013 Mtce in 2060. On the whole time span, it will never exceed the 2021 level (Figure 7.9). Primary energy consumption decline in other sectors will be compensated by growing non-energy use for chemicals production and energy use for hydrogen and ammonia production.

Growing "blue" hydrogen and ammonia production, along with additional feedstock demand, will stabilize domestic natural gas consumption at a level close to 470-480 bcm till 2045 with a subsequent decline to 400 bcm, as "blue" hydrogen is substituted by "green" hydrogen (Figure 7.9). On the whole 2060 time horizon, domestic gas demand will stay below 533 bcm as reported for 2021. In 2021-2060, cumulative gas extraction will reach 22.2 bcm versus 20.8 trcm in 4D scenario. Together with the resources needed to maintain the 2060 production level cumulative resources demand will reach 38.8 trcm, which is just a little over the proven resources as estimated by BP – 37.4[201] – demanding very little additions to proven resources.

Additional liquid fuels demand for non-energy use in 4F scenario doesn't help avoid domestic liquid fuels demand reduction, but the decline will not be as deep as in 4D scenario (Figure 7.9). Liquid fuels consumption will be 36% down in 2021-2060 versus 44% in

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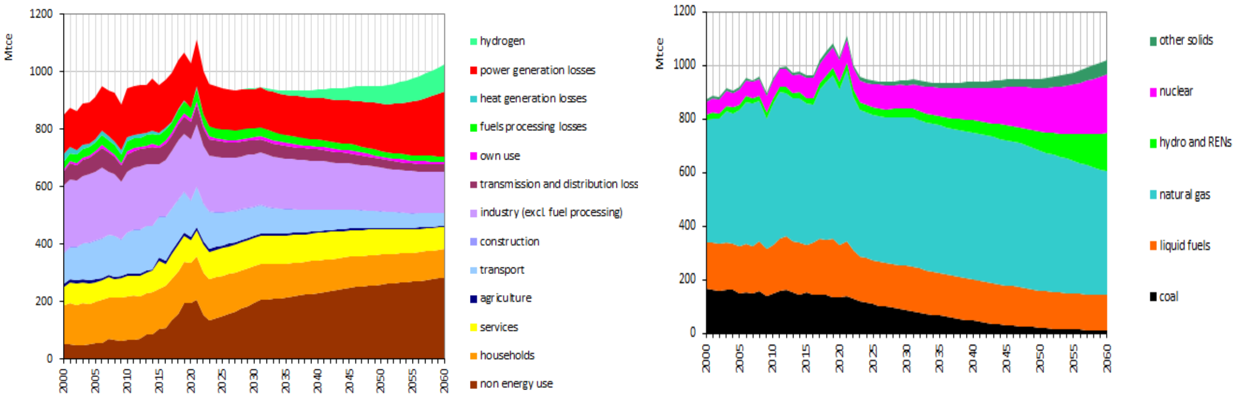
[200] Fraunhofer Energy-Charts (https://energy-charts.info).

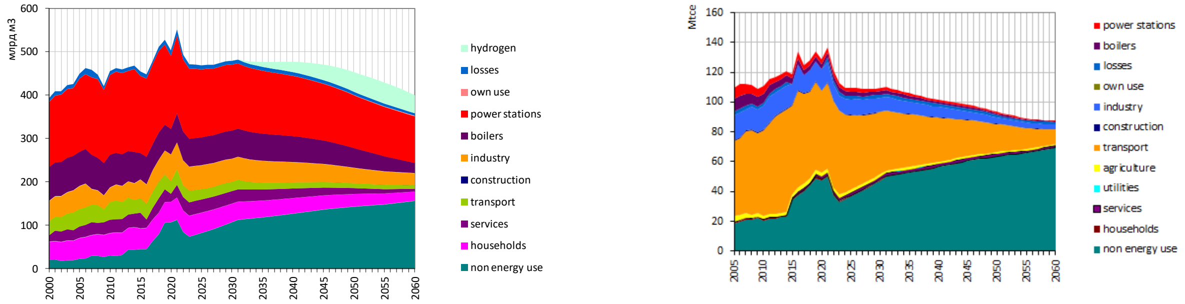
[201] BP Statistical Review of World Energy, July 2021.

4D scenario. In 2060, the remaining liquid fuels energy use will only be 21%, while the rest will be for feedstock in chemicals production. Cumulative oil extraction in 2021-2060 will reach 9.1 billion t (versus 8.8 billion t in 4D scenario), and the resource demand to maintain the 2060 production level will be 10.3 billion t, which is below the proven resources as reported by BP – 14.8[202] – and so no additional proven resources will be required.

Figure 7.9 Primary energy and fuel use in 4F scenario



TPES by sectors TPES by energy sources



natural gas liquid fuels

Source: CENEf-XXI.

7.5 Emission trajectories towards net zero carbon by 2060

CO_2 emissions trajectory in 4F scenario is quite close to that in 4D, as additional ammonia and “blue” hydrogen production will use CCS and additional non-energy use for chemicals production will store carbon in plastics and resins until they are incinerated in the importing countries (Figure 7.10). If they are incinerated at installations with CCS, no carbon will be released to the atmosphere. In this scenario, net additionally needed sink in LULUCF is 122 Mt CO_2, which is below the level required to ensure carbon neutrality in 4D scenario (176 MtCO_2) and less than one fifth of 685 MtCO_2 needed in 4S scenario. The deployment of CCS in 4F pathway is up to 182 MtCO_2 versus 70 MtCO_2 in 4D scenario.

Fit for 65. In 4F scenario, beyond 2030 Russia will never exceed 31% of 1990 CO_2 emissions and 35% of 1990 GHG emissions. In all of the scenarios (4S, 4D, and 4F) Russia is ahead of the EU in cutting CO_2 and GHG emissions by 2030 (Figure 7.10). In both 4D and 4F, Russian LTS gets more reliable pillars for not only attaining the carbon neutrality in 2060, but also for getting out of the 2020s crisis and accelerating the economic growth thereafter, as it is accompanied by dynamic modernization and penetration to the new global markets. Such upgraded facilities and manufacture of products with low carbon footprint should be welcomed at highly competitive local and international low carbon markets.

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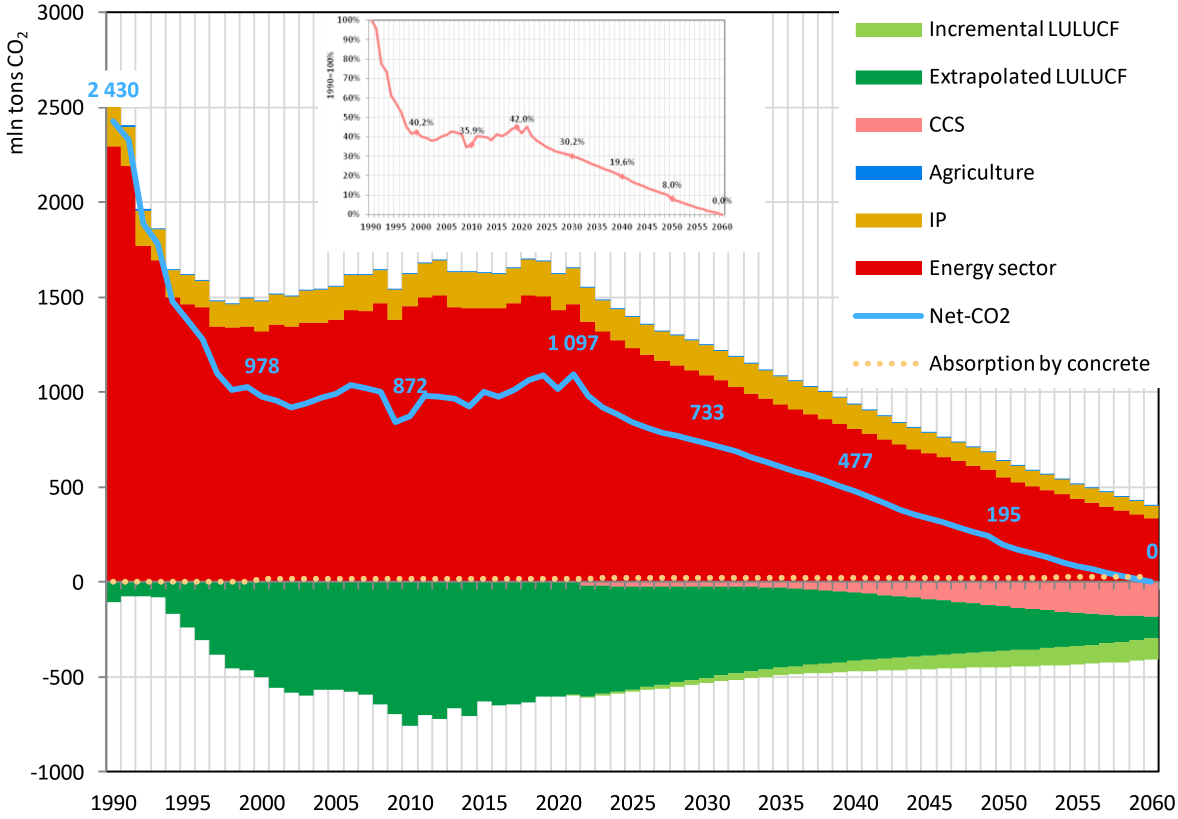
[202] Ibid.

Figure 7.10 CO2 emission pathway in 4F scenario



Source: CENEf-XXI.

4D and 4F scenarios are consistent with global pathways to limit the global warming to 1.5-2°C. Cumulative net CO_2 emissions in 2021-2060 will be 21.7 $GtCO_2$, or 4% of the current central estimate of the remaining carbon budget from 2020 onwards to limit the warming to 1.5°C with a 50% probability (500 Gt CO_2). It is 2% of the estimated remaining 1,150 Gt CO_2 carbon budget with a 67% probability to limit the warming to 2°C.[203]

In 2060, cumulative reduction in GHG emissions from the 1990 level will reach 140 Gt CO2eq. This figure might be used as a new form of national commitment. It amounts to 12-28% of the remaining carbon budget and is 2.4 times the global 2019 GHG emission.

7.6 Investments

Limiting the global warming in 4F scenario necessitates a shift in energy investments away from fossil fuels towards low carbon technologies. Cumulative 2022-2060 GHG mitigation investments (119 trillion rubles) overweigh investments in fossil fuels supply or generation (112 trillion rubles) (Figire 7.11). In this scenario, total capital expenses in 2022-2060 will amount to 231 trillion rubles (versus 197 trillion in 4D and 247 trillion in 4S scenarios). The 4F investments are higher, than in 4D, for two reasons: first, larger production of oil and gas due to additional fuel production for feedstock use; second, substantial additional investments are needed for hydrogen and ammonia production. Total investments in low carbon technologies in

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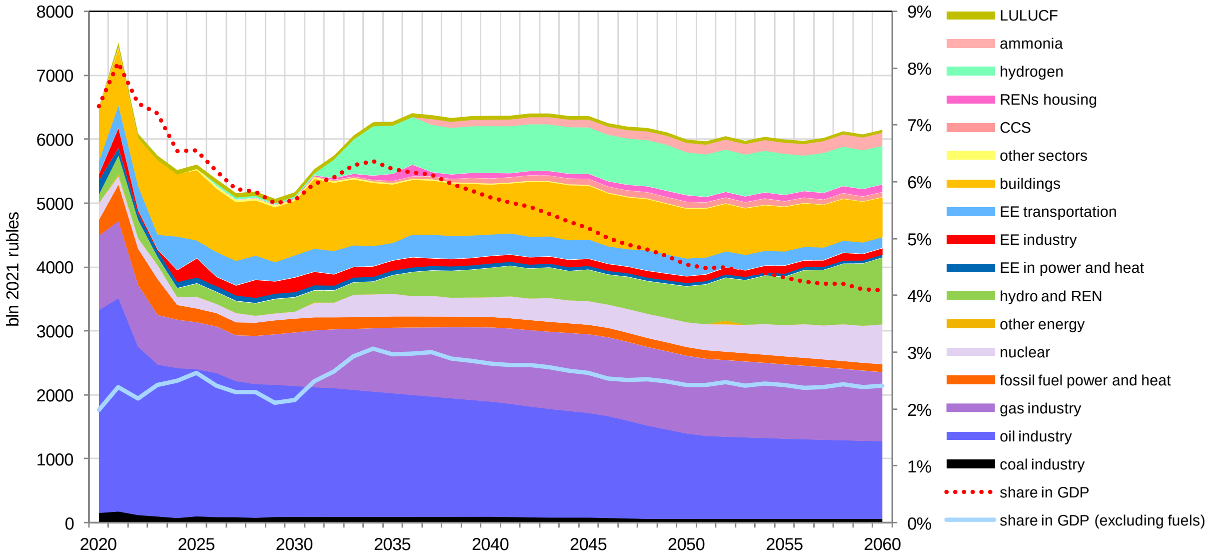
[203] IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

the power industry total to 31 trillion rubles, and in hydrogen and ammonia production to 24 trillion rubles.

Figure 7.11 Investments in 4F scenario



Source: CENEf-XXI.

Even in 4F scenario, no additional investment demand is anticipated compared to the 2021 level. The share of investment demand in low-carbon transformation (total investment demand less investment in fuel supply and generation) of GDP will be first recovering from the 2022-2030 drop to reach 3.2% of GDP and then will be steadily declining to 2.4% in 2060. The share of investment in fossil fuels supply will be down from 5.7% in 2021 to 1.7% in 2060. This decline will drive overall energy and mitigation investment on the 4F pathway down from 8% in 2021 to 4% in 2060.