Transmission to a Low-carbon Economy and its Implications for Financial Stability in Russia

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Abstract

Energy transition and climate policies associated with it may become one of the major challenges for the Russian economy. We present an approach to assessing consequences of climate policy for Russia and evaluating related transition risks for the country's financial system. This approach relies on a CGE model for the Russian economy and a financial model based on firm-level data. We show that both international and domestic climate policies affect the financial stability of the Russian Federation. The effects of international climate actions summarised in the NGFS Net Zero 2050 scenario are bigger than the effects of the introduction of a domestic emission trading system with a reduction goal of the Intensive scenario of the Russian state strategy of low-carbon development.

Key words: Russia, climate policy, energy transition, transition risk, financial stability, CGE

JEL classification : C68, E51, E62, G10, G21, Q52, Q54, Q58.

Contents

Figures

Tables

1. Introduction

Energy transition and climate policies associated with it may become one of the major challenges for the Russian economy. We assess the effects of a tightening of international and domestic environmental regulation on the Russian financial system. We study the industry-level responses to a more stringent external and domestic environmental regulation with the help of a small open-economy environmental computable general equilibrium (CGE) model and use these estimates in a detailed financial model based on the Russian credit registry.

The domestic policy under review involves the introduction of a CO2 emission trading system. Böhringer et al. (2015) show that cap-and-trade is the preferred way to curb emissions in terms of minimising welfare costs compared to other domestic policies (industry emission standards and energy efficiency standards).

The current Strategy of Socio-Economic Development of Russia with a Low Level of Greenhouse Gas Emissions until 2050,[1] updated in October 2021, does not introduce any CO2 emission trading system. Instead, there is a heavy reliance on energy efficiency and emission standards as the primary way to a low-carbon economy (Strielkowski et al., 2021). Nevertheless, we will show what effects an emission trading system could have on the economy in the case of its implementation.

Our paper is close to three strands of the literature. The first strand represents the literature on CGE modelling of economic effects of climate policies. The second strand of the literature focuses on risks, costs, and benefits of transition to a low-carbon economy for Russia as an energy-intensive and fossil fuel exporting country. There are a few papers dealing with general equilibrium effects of global and domestic climate policies in Russia and we seek to fill this gap in the literature with our study. Additionally, we calibrate and simulate the model with a more detailed sector structure (42 sectors versus 30 sectors in Böhringer et al., 2015), based on the up-to-date Russian input–output table for the year 2016 and more nuanced data on energy consumption in Russia (for details, see Section 4. CGE benchmark dataset).

The third strand of the literature encompasses new but increasingly frequent studies evaluating the transition risks of climate policies for national financial systems and

[1] https://www.iea.org/policies/14859-strategy-of-socio-economic-development-of-russia-with-a-low-level-of-greenhouse-gas-emissions-until-2050

conducted mostly by central banks. Baudino and Svoronos (2021) highlight the growing materiality of climate risk for the banking sector. It implies that the exposure that banks currently face might result in higher losses, which could not be extrapolated from the history of severe events.

As a reference point in our modelling, we use one of the scenarios of the Network of Central Banks and Supervisors for Greening the Financial System (NGFS)[2] – *the Net Zero 2050* scenario, which is the most ambitious one in terms of limiting global warming by 2050.

The NGFS considers that transition risks could affect the economy in different ways: via profitability of businesses, wealth of households, aggregated impacts on the macroeconomy and financial system contagion (NGFS 2021).

We are mostly interested in one particular channel of the influence: effects of international and domestic climate policies on the performance of the banking sector (Battiston, Dafermos, and Monasterolo 2021). To our knowledge, this is the first paper to address issues of Russian corporate debt and financial stability through the lens of a possible structural change induced by climate policies.

We present a "what if" analysis, which should neither be viewed as a forecast, nor be compared to any other forecasts that the Bank of Russia publishes on a regular basis.

2. Literature review

There is a long history of CGE modelling of environmental and climate-related policy problems. The first examples of CGE models designed for an economy-wide analysis of climate policy and, in particular, the introduction of CO2 taxes are rooted in the late 1980s–early 1990s (Peterson 2003). CGE modelling of climate policies substantially accelerated after the adoption of the Kyoto Protocol in 1997 aimed at reducing GHG emissions by industrialised countries and economies in transition according to their agreed individual targets.[3] One of the measures recommended by the

[2] The Network of Central Banks and Supervisors for Greening the Financial System (NGFS) is a group of central banks and financial supervisors established in 2017 with the aim to strengthen the global response to climate change and promote best practices in the financial sector. As of 14 June 2022, the NGFS consisted of 116 members and 19 observers. More information is available at www.ngfs.net.

[3] The Kyoto Protocol sets binding targets for 37 developed and transition economy countries and the European Union under the principle of "common but differentiated responsibility and respective

Kyoto Protocol was international emission trading; thus, a large number of studies used CGE modelling of the global market for GHG emission permits allowing countries to set the carbon price (Springer 2003).

Uncontrolled GHG emissions represent a classic example of an externality when economic agents do not consider social costs of their activities and do not pay for polluting the air during these activities as clean air (or emission) is not priced. The theory predicts that the problem of controlling GHG emissions can be solved by internalising the externality and incentivising economic agents to reduce GHG emissions through setting the right prices for their actions.

There are two theoretically equivalent solutions to correct a socially inefficient outcome in the case of an externality – creating the market for the unpriced good and imposing the so-called Pigovian tax on socially undesirable activities of producers and consumers. As the goal of climate policy is to reduce GHG or just CO2 emissions by a certain percentage, the policy instruments are accordingly designed as cap-and-trade regulation and carbon tax. Under a cap-and-trade scheme (or an emission trading system, ETS), the percentage of emission reductions is set by policy makers, while the market for emission allowances (permits) determines the price of CO2 emissions (the price of carbon). Alternatively, under a carbon tax scheme, authorities specify a tax rate on CO2 emissions (the price of carbon) for producers and consumers, while the emission reduction percentage is determined by the market.

In practice, there are pros and cons for both carbon taxes and cap-and-trade regulation, which implies the functioning of an emission trading system (IMF 2019). Theoretically, under both schemes, the marginal abatement costs of CO2 emissions are equal for all economic agents (assuming that there is a nation-wide carbon tax). However, the ETS as a continuously functioning market for CO2 permits automatically provides corrections of the abatement cost across time in line with changes in technologies, prices of fossil fuels, and other demand and supply side factors. The political viability of both approaches may crucially depend on the specifics of how the collected revenues are supposed to be used (IMF 2019).

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capabilities”, while establishing no obligations in relation to the climate targets for developing countries. Overall, individual targets were supposed to reduce GHG emissions in the countries by approximately 5% compared to the 1990 level over the period of 2008–2012. Under the Kyoto Protocol, Russia agreed that its emissions would not exceed the 1990 level.

In CGE models, climate policies are usually formulated in terms of cap-and-trade regulation: the specified target levels of emissions allow researchers to solve for values of carbon taxes.

As climate risk mitigation efforts are a global issue and constitute a global public good (Böhringer et al., 2021), most CGE models applied in climate policy analysis are global multi-country (or multi-region) models that are built and run by international organisations and large international consortiums of national institutes. Some global models are applied to examine the impacts of external and internal climate policies on Russia's economy, and we briefly discuss the results simulated using these models for Russia below. Nevertheless, there are several recent examples of constructing and applying single-country CGE models to analyse global and national strategies of CO2 or GHG emission reduction, e.g., in Spain (Böhringer, García-Muros, and González-Eguino 2022), Denmark, Ireland, Norway and Switzerland (Braendle 2021), India (Pradhan and Ghosh 2021), and China (Liang et al., 2022).

In a large number of studies that emerged after the Paris Climate Conference held in 2015, there are just a few studies with detailed CGE modelling of the Russian economy. Liu et al. (2020) include Russia in the global G-cube model (McKibbin and Wilcoxen 1999, McKibbin and Wilcoxen 2013) as a separate economy. G-cube is a complex multi-country dynamic CGE model. It comprises both the benefits of CGE models, which are rich in the number of sectors (20 sectors) and the description of the production structure, and such advantages of classical DSGE models as nominal and real rigidities, a mix of forward- and backward-looking economic agents, central bank monetary policy rules, and intertemporal budget constraints for households, governments, and countries.

Liu et al. (2020) analyse economic and environmental outcomes of the Nationally Determined Contributions (NDCs) submitted by the countries under the Paris Climate Agreement for the ten economic regions. The authors assume that all the ten regions (countries) introduce national carbon taxes as policy instruments to achieve their NDCs. The model solves for the time path of CO2 prices for each region assuming that the countries linearly reduce CO2 emissions by the target dates (2025–2030) according to their NDCs. Revenues from the carbon taxes are redistributed to households as lump-sum transfers. The baseline year for the model simulations is 2015.

The authors examine the impact of such a design of climate policies on regions' real GDP, private consumption, and changes in welfare relative to the business-as-usual

(BAU) scenario where countries do not adopt any new measures to fulfil their NDCs. In its NDC, Russia pledged to reduce emissions of all GHGs by 30% relative to the 1990 level by 2030. According to the authors' estimations, this means that, by 2030 compared to 2015, CO2 emissions in Russia increase by 8% in the *«BAU»* scenario and drop by 14% in the carbon tax scenario.

The estimated carbon price in Russia appears to be much lower than in most other regions within the model – only $US5/t (in constant 2015 prices) in 2030, compared to more than $US20/t in China, more than $US30/t in OPEC countries, and $US44/t in India.[4] Liu et al. (2020) explain such a variation in CO2 prices across regions mostly by differences in carbon intensity of fossil fuels used by the regions, the values of various fuels in each region's energy mix, baseline price levels and the relative shares of different fossil fuels in electricity generation.

While Russia is one the regions where a relative reduction in CO2 emissions can be achieved at the lowest CO2 prices, in 2016–2030, the country experiences the largest among all the ten regions declines in real GDP and private consumption (about -4.5% for GDP and -1.8% for private consumption in 2030), relative to the *«BAU»* scenario.

Makarov, Chen, and Paltsev (2020) specifically focus on the impact of the Paris Climate Agreement on the Russian economy and mainly on its energy exports using the MIT Economic Projection and Policy Analysis (EPPA) model. EPPA is a global recursive CGE model with 18 regions and 32 sectors (Chen et al., 2016). One of the strengths of the model is the detailed description of advanced energy technologies (e.g., biofuels, oil shale, synthetic gas from coal, hydrogen, advanced nuclear, wind and solar generation) which are characterised by an endogenous timing of market entry determined by their cost competitiveness with existing technologies (Chen et al., 2016). EPPA includes emissions of six GHGs (CO2, CH4, N2O, HFCs, PFCs, and SF6) and air pollutant emissions (SO2, NOx, black carbon, organic carbon, NH3, CO, and VOC).

Makarov et al. (2020) consider four scenarios for the period of 2015–2050 (the model outcomes are simulated at 5-year intervals) – three climate policy scenarios and the *«Reference»* scenario where the authors assume no changes in the countries' current climate policies, i.e., no new measures are introduced to fulfil the NDC commitments. The

[4] The estimates of a uniform global carbon tax that would produce the same reduction of CO2 emissions as all the NDCs is about $US15/t in 2030.

climate policy scenarios include 1) the «*ParisForever»* scenario, in which the Paris Agreement targets are achieved by 2030 and, afterwards, countries continue to reduce emissions at the same pace; 2) the «*Paris2C_RussiaBAU»* scenario where countries, except Russia, increase their climate mitigation efforts after 2030 aiming to stabilise the temperature at 2°C, while Russia does not impose any emission reductions through the entire simulation period of 2020–2050; and 3) the «*Paris2C_RussiaPolicy»* scenario where Russia joins the global efforts and claims not to increase its emissions above 60% of the 1990 levels after 2030.

Compared to 2015, Russia's GHG emissions increase under all the three climate policy scenarios in 2020–2050. Russia's highest emission level is estimated in the «*Paris2C_RussiaBAU»* scenario due to the so-called carbon leakage effect when energy-intensive productions are relocated from countries with stringent climate regulations to countries with mild emission reduction policies.

In the *«Reference»* scenario, Makarov et al. (2020) set Russia's GDP growth rate exogenously in the range of 0.5–2.5% in 2020–2050, while in the climate policy scenarios, GDP is determined endogenously by the model. In all the climate policy scenarios, Russia's GDP growth and welfare are adversely affected by lower global demand for fossil fuels and lower producer prices of these commodities due to the introduction of carbon taxes in other countries.

Makarov et al. (2020) do not provide estimates of domestic carbon tax in Russia in the «*Paris2C_RussiaPolicy»* scenario, but stress that the impact of domestic carbon tax in Russia on its GDP in the «*Paris2C_RussiaPolicy»* scenario is rather negligible compared to the influence of global climate policies (we obtain similar results in our study as well). The country's GDP growth rates drop by 0.2–0.3 pp in 2020–2030 and by almost 0.5 pp in 2035–2050 under the *«Paris2»* scenarios relative to the *«Reference»* scenario.

Makarov et al. (2020) examine in detail the influence of global and domestic climate policies on Russian energy exports (coal, natural gas, refined and crude oil). In all the climate policy scenarios in 2030–2050, Russia's total exports of fossil fuels (in exajoules) are lower relative to the *«Reference»* scenario where its energy exports are growing. Russian energy exports are expanding in the «*ParisForever»* scenario (but appear to be 25% lower by 2050 than in the *«Reference»* scenario) and declining (by more than 30% relative to the 2010 export level) in the *«Paris2»* scenarios.

As can be expected, the coal sector is most affected by the strengthening of global climate regulations. In the «*ParisForever»* scenario, coal exports in 2050 fall by more than 80% relative to the *«Reference»* scenario and by about 75% relative to the 2010–2015 export levels. In the *«Paris2»* scenarios, by 2050, coal exports plummet to less than 10% of the current levels.

Russia can increase its exports of natural gas during 2020–2050 from the current levels in the «*ParisForever»* scenario, mostly due to growing demand in Asian markets. However, in the *«Paris2»* scenarios, natural gas is widely substituted by renewable resources in the post–2030 period, especially in Europe, and Russia experiences a certain reduction (about 20%) in natural gas exports in 2050 relative to the current levels.

Crude oil exports are rather stable compared to the 2010–2015 levels in the «*ParisForever»* scenario but decline by more than 50% by 2050 in the *«Paris2»* scenarios due to lower world producer prices and decreased demand. Interestingly, the model projects increasing exports of Russia's refined products both in the «*ParisForever»* and *«Paris2»* scenarios due to a growing number of cars in Asia, but according to the authors, significant progress in electric vehicles may put Russia's petroleum products exporters at risk.

The most recent and largest-scale study assessing the impacts of external and internal decarbonisation policies on the Russian economy is Makarov et al. (2021), a report prepared by the World Bank (WB) in collaboration with the Higher School of Economics (HSE). The analysis was performed using the Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model, a global recursive dynamic CGE model (Mensbrugghe 2019). The ENVISAGE Model was designed to analyse the interactions between economies and the global environment related to human-made GHG emissions. Originally, the ENVISAGE Model was developed at the WB. The current version of the model is residing at the Center for Global Trade Analysis (GTAP) and remains a work in progress (Mensbrugghe 2019). Makarov et al. (2021) use the version of the model with 16 regions and 20 sectors.

Makarov et al. (2021) design two sets of scenarios. The first one deals with the EU carbon border adjustment mechanism (CBAM) and a possible future implementation of such a tool by a wider "club" of countries. We focus on the second set of scenarios in Makarov et al. (2021) that the authors jointly label as "long-term decarbonisation" and develop for the period of up to 2050.[5] In all long-term scenarios, including the baseline one, emission reductions are achieved using carbon pricing, which is applied to all agents in the model.[6]

In the long-term reference (baseline) scenario, countries reduce their emissions in line with their NDCs by 2030 and then continue their efforts until 2050. In this scenario, Russia's emissions increase from 2020 to 2050 by approximately 40%. For the policy scenarios, 16 countries and regions in the model are separated into two "clubs": climate policy leaders (CPLs) and fossil fuel-dependent countries (FFDCs), with the latter including Russia.

In the «*Carbon price globally»* scenario with a uniform global carbon tax, both CPLs and FFDCs collaborate to achieve a carbon budget consistent with the goal to limit global warming to 2°C by 2050. The global carbon budget for the period of 2018–2050 is 30% lower relative to the baseline scenario. This scenario implies emission reductions in Russia by about 20% by 2050 relative to the 2020 level.

The «*Carbon price in CPL»* scenario has the same global carbon budget for the period of 2018–2050 as the «*Carbon price globally»* scenario but assumes that only CPLs participate in climate mitigation efforts. There are unilateral carbon taxes in CPLs under the «*Carbon price in CPL»* scenario. Russia's emission trend is close to the baseline scenario.

«High carbon price globally» is a more ambitious cooperative scenario where the carbon budget for the period of 2018–2050 is 10% lower than under the other policy scenarios and consistent with the effort of limiting global warming well below 2°C. In this scenario, Russia reduces emissions by about 40% by 2050 compared to the 2020 level.

As follows from the above description, the two scenarios where Russia joins the common mitigation efforts («*Carbon price globally»* and «*High carbon price globally»*) look somewhat unrealistic. Both scenarios assume a uniform global carbon tax, while

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[5] The current version of our study does not include the CBAM scenario. That is why we now skip the detailed discussion of the CBAM scenarios in the WB/HSE Report. Simulations in the CBAM set of scenarios cover the period of 2014–2035. Besides, we do not consider the long-term scenario where border carbon adjustment taxes are imposed by high-income countries and fuel fossil importers.

[6] In addition, it is assumed that emission reductions are facilitated by exogenous technological changes (e.g., declining costs of renewables, improvements in energy efficiency) and non-price related changes in preferences towards renewables.

numerous studies (e.g., Lui et al., 2020, IMF/OECD 2021) show substantial heterogeneity in terms of carbon prices across countries. In addition, it is not quite clear how the resulting national emission trends are determined in the policy scenarios given the global carbon budgets.

The values of uniform global carbon prices in cooperative scenarios specified in Makarov et al. (2021) appear to be rather high, rising from US$44–50/tCO2 in 2025 to US$130–265/tCO2 in 2050.

Makarov et al. (2021) estimate the impacts of global and domestic climate mitigation efforts on Russia's GDP, welfare, and energy exports in the policy scenarios relative to the baseline scenario. The baseline scenario in Makarov et al. (2021) differs from that one in the other studies discussed above, which precludes direct comparisons of the simulation results. Probably, due to ambitious global targets and the introduction of a high global uniform carbon tax in Russia, assumed by Makarov et al. (2021), negative effects on the country's economy in cooperative policy scenarios are rather significant relative to the baseline scenario. Russia' GDP is lower by almost 4% in the «*Carbon price globally»* scenario and by more than by 6% in the «*High carbon price globally»* scenario in 2050, relative to the baseline scenario (about -1% in the «*Carbon price in CPL»* scenario).

As in Makarov et al. (2020), coal exports decline most severely across energy sectors in all long-term scenarios relative to the baseline scenario (minus 30–60% in 2050). The next most affected sector is natural gas due to a substantial decrease in global demand under all policy scenarios: Russia's natural gas exports fall by about 25% in the «*Carbon price in CPL»* scenario and by more than by 70% in the «*High carbon price globally»* scenario relative to the baseline scenario in 2050. Sectors that slightly benefit from changes in relative prices and experience a moderate increase in output under certain policy scenarios, relative to the baseline, in 2050 are agriculture and other (light) manufacturing. Substantial increases in output relative to the baseline scenario (131% and 219%) in 2050 are reported for the sector “Other power and heat generation” which includes renewables substituting coal and gas generation in cooperative policy scenarios.

There are some alternatives to CGE models used by researchers in energy and climate policy analysis. Partial equilibrium models are widely applied in sector-specific policy studies. Bottom-up (BU) partial equilibrium models are employed to conduct in-depth energy system approximation with a high degree of technological detail (in contrast to top-down (TD) models, e.g., CGE models, which focus on the macroeconomic impact of a given climate policy scenario).[7]

The Integrated MARKAL-EFOM System (TIMES),[8] a technology-diverse BU model with many applications in European countries, uses linear programming to produce a least-cost energy system.[9] A particular interest is the RU-TIMES model applied for the Russian economy. A brief overview of the RU-TIMES model is provided by Korppoo, Safonov, and Lugovoy (2010). Laitner, Lugovoy, and Potashnikov (2020) used the RU-TIMES model to estimate the Russian decarbonisation pathway for the Deep Decarbonization Pathways Project (IDDRI 2014). Laitner, Lugovoy, and Potashnikov (2020) present an updated version of this research and exploit a two-step methodology. First, quantitative, and structural changes in investment and output of the Russian energy industry are estimated using the RU-TIMES model. Second, these changes are expressed in terms of changes in GDP using the country's stochastically extrapolated input-output tables.

According to Laitner, Lugovoy, and Potashnikov (2020), the transition to a low-carbon economy brings more possible benefits to Russia than is commonly supposed. The overall positive effect on GDP consists of two components. Increased investment in new technologies will benefit construction, manufacturing, and other industries, which will become possible owing to lower power bills. The second effect is the growth of total factor productivity (TFP) in manufacturing, driven by demand for carbon-free technologies, which is assumed three times higher in the deep decarbonisation scenario than in the *«BAU»* scenario. As a result, Laitner, Lugovoy, and Potashnikov (2020) assert that Russia's average annual GDP growth might speed up to 2.5% in 2030–2050 under the deep decarbonisation scenario, compared to 1.3% in the *«BAU»* scenario.

Due to an explicitly structural description of the economy, CGE models appear to be very appealing to central banks in financial system stress testing, given various

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[7] A comprehensive review of key features and conventional BU models' description are documented by Herbst et al. 2012.

[8] The model was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program); https://iea-etsap.org/index.php/etsap-tools/model-generators/times.

[9] Another example is the Asia-Pacific Integrated model (AIM). The AIM family integrates top-down (TD) and bottom-up (BU) models and helps analyze policies related to greenhouse gas emissions, climate change, and its impact. A recent application example for the development of Japan's energy system under the country's strategy to reduce GHG emissions is presented by Oshiro et al. (2020).

exposures of financial institutions to sectors that are vulnerable to transition risks. Moreover, CGE models take into account sectors' interactions and "second-round" effects of changes in policy instruments. Chen et al. (2022) summarise the scenarios and the simulation results obtained with the use of the MIT–EPPA model (Chen et al., 2016) as part of the project launched by the Bank of Canada. The results of the CGE model are linked to two macroeconomic models of the Bank of Canada, and then sectoral outputs are applied to assess climate-related credit and market risks of Canadian financial institutions (for details, see Hosseini et al., 2022). We apply a similar approach in our study projecting changes in Russian industries' output estimated in our CGE model onto industries' debt service payments and equity valuations, which allows us to trace the effects of climate policies on the country's financial institutions in different scenarios (see Section 6).

CGE models certainly have their limitations in general and in the analysis of climate policies' economic effects. The simulation results of CGE modelling in alternative scenarios should be interpreted as "what if" explanations and cannot be viewed as forecasts. With a few exceptions, CGE models ignore monetary and financial aspects of the economy (e.g., inflation). As regards climate policies, most CGE models focus on analysing economic costs caused by mitigation efforts and are not well suited for evaluating economic and, especially, social benefits associated with GHG emission reductions.

3. CGE model description

We apply a static version of the model designed by Böhringer et al. (2015). The model is based on optimizing behaviour of all economic agents and suggests that supply and demand are balanced across all markets for goods, services, and factors. Budgets are balanced for all agents.

Economic agents

We distinguish producers, a representative economic agent, the government, and a savings-investment bank. The representative economic agent (RA) maximises utility subject to the budget constraint. The RA owns all factors of production in the economy; thus, the RA receives a wage, a capital rent, and payments for specific capital in extraction industries.

The government collects taxes, including CO2 tax, in relevant scenarios. In all scenarios, we fix government consumption at the level of the base (benchmark) year (2016) in real terms. A budget surplus, i.e., tax revenues less costs for government purchases, is transferred to the budget of the RA. The reverse is also true: if there is a budget deficit, it is financed from the budget of the RA.

The savings-investment bank purchases investment goods in the final market. The structure of investment demand is fixed at the base year (2016) level in real terms and is financed from the budget of the RA, i.e., we assume investment-driven savings (Lofgren et al., 2002).

Producers

There are 42 CRTS industries (see Table 4) producing goods and services. Cost-minimising firms operate in free-entry markets, which leads to zero profit, i.e., marginal returns for an individual firm equal to marginal costs.

Following Böhringer et al. (2015), we distinguish three types of production processes: production of fossil fuels, electricity, and all other goods and services. Each of the processes uses factors, energy, and intermediate goods for production.

Factors

There are three types of factors in the model: labour, capital, and specific capital. Labour and capital are moving freely across industries; thus, there are economy-wide markets for these factors. These settings result in a single wage and a single capital rent for all sectors. Specific capital is used only in extraction industries and is fixed at the level of the base year (2016) for each of these industries. Thus, there is a specific capital rent in each extraction industry.

Energy and emissions

There are two different types of energy carriers in the model: electricity and fossil fuels. The use of fossil fuels (coal, refined oil, natural gas, and coke) produces CO2e emissions according to fixed industry-specific emission factors.

4. CGE benchmark dataset

The dataset for the model consists of economic indicators describing the Russian economy for the base year (2016) (see Section 4.1) and emissions data (see Section 4.2).

Economic data for calibration

The main sources of economic data for model calibration are Russian input–output (IO) tables for 2016, and the National Accounts for 2016. The input–output tables consist of a resource table, use tables in buyers' prices and basic prices, use tables of domestic and imported products, tables with transport and trade margins, and a table of net taxes. Sectoral and commodity details of the original tables were aggregated into 42 industries and 59 commodity groups (Table 4 and 5). Development of a dataset for a CGE model from an IO table is a well-documented process (Rutherford and Paltsev 1999).

Emissions

Our model uses information about the amount of greenhouse gas emissions generated in the production of goods and services by burning different fuels. The most accurate information on emissions is available in the National Inventory Report on anthropogenic emissions from sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol (hereinafter, the National Inventory Report, or the Inventory) (Romanovskaya et al., 2022).[10] Inventory data are available for the period from 1990 to 2019. Their main advantages are completeness, comparability with data from other countries, and a common methodology for collecting data and estimates over the entire period. The Inventory relies on detailed information from federal executive authorities, large enterprises, and research institutes.

Unfortunately, it is impossible to directly use the information from the National Inventory Report for the purposes of our model since the structure of data provided in the Inventory does not correspond to the structure of other data we use (with the economic activity type specified).

The most acceptable source of information for our research in terms of data structure is Form No. 4-TER of federal statistical observation "Information on the use of fuel and energy resources" (hereinafter, Form No. 4-TER). This form contains information

[10] The National inventory Report on anthropogenic emissions from sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol is published annually in accordance with the obligations of the Russian Federation under the UN Framework Convention on Climate Change and the Kyoto Protocol to the UN Framework Convention on Climate Change.

The compilation of the report is organised by the Federal Service for Hydrometeorology and Environmental Monitoring (Rosgidromet). Estimates of emissions and removals of greenhouse gases, methodological guidance, the preparation and editing of the report are carried out by the Federal State Budgetary Institution Yu. A. Izrael Institute of Global Climate and Ecology.

on the actual annual consumption of fuel and energy resources to produce certain types of products and works (services) by type of fuel and type of economic activity. The form is compiled annually based on enterprises' reports in accordance with the requirements for statistical reporting by Rosstat, grouped by type of economic activity, and is comparable with other reporting forms.

To determine the amount of anthropogenic gas emissions from fuel combustion, we estimated separately emissions from stationary combustion and emissions from internal combustion engines. The emission estimates were made based on the simple calculation methods described in the IPCC Guidelines for National Greenhouse Gas Inventories and the National Inventory Report.

Stationary combustion

To calculate greenhouse gas emissions from stationary combustion of fuel, we used information from Form No. 4-TER on the actual consumption of boiler and furnace fuel for all manufactured products (work performed), expressed in tons of standard fuel (i.e., tons of coal equivalent, tce). For the purposes of this study, we focused on the emissions of three main greenhouse gases: carbon dioxide CO2, methane CH4, and nitrous oxide N2O. For this, the data were converted into the International System of Units (SI system, from tce into TJ using a conversion factor equal to 0.0293076 TJ/tce) and multiplied by the emission factors of respective gases by fuel type, as shown in formula 1.

Equation 1

$$Q_i = AD_i \cdot E \cdot C_i,$$

where

i –type of fuel,

$\boldsymbol{Q_i}$ – emissions of a particular greenhouse gas, by type of fuel (CO2, CH4, N2O) [kg]

$\boldsymbol{AD_i}$ – amount of fuel combusted [tce]

E – conversion factor equal to 0.0293076 [TJ/tce]

$\boldsymbol{C_i}$ – default or country-specific emission factor of a particular greenhouse gas, by type of fuel [kg gas / TJ].

Table 6 and 7 summarise the CO2, CH4 and N2O emission factors that we used to estimate greenhouse gas emissions by fuel type (for the 2016 data structure). Since Form No. 4-TER lists fuels by their names that do not correspond to the names of fuels in the Inventory, it is not always possible to determine the exact correspondence between emission factors and fuels. We used the closest values.[11]

Considering a large difference in production in terms of the potential to emit methane and nitrous oxide in the process of stationary combustion, as shown in Source: NIR data (Romanovskaya et al. 2022)

Table 7, we conditionally grouped economic activities as follows. Energy industries include mining and electricity, gas and water supply. Manufacturing industries and construction comprise manufacturing, mining of metal ores, construction, transport via pipelines, and water collection, treatment, and supply. The remaining economic activities were included in the commercial/institutional, residential, and agriculture/forestry/fishing/fishing farms categories.

Mobile combustion

A feature of mobile combustion is that fuel is burned in various engines with significantly different efficiency. We have information on the type of motor fuel used in physical units and the volume of fuel consumed by type of economic activity from Form No. 4-TER. However, information about the mileage of vehicles, the quality of roads, and the technical characteristics of engines is unavailable.

Since data on consumed mobile fuel are presented in physical units (tons and m^3), we first convert them into energy units (tce) using the conversion factors presented in Table 8, and then apply eq. (1) with the carbon dioxide emission factors from Table 6 and the methane and nitrous oxide emission factors for mobile combustion from Table 9.

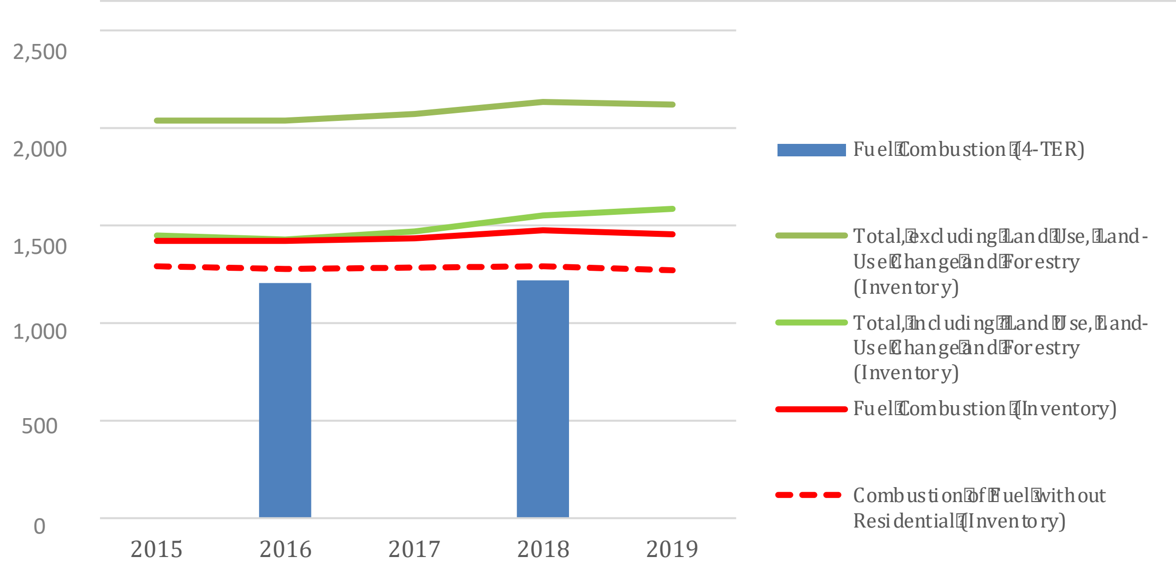
Cumulative greenhouse gas emissions are presented in Table 10 as a CO2 equivalent obtained by summing the calculated volumes of gases using global warming potential factors (‘1’ for CO2, ‘25’ for methane, and ‘298’ for nitrous oxide).

The obtained estimates of greenhouse gas emissions for 2016 and 2018 using Form No. 4-TER were compared with the information of the National Inventory Report (Romanovskaya et al., 2022). As shown in Figure 1, greenhouse gas emissions are

[11] The emission factors were taken from Table 3.8 of the National Inventory Report (Romanovskaya et al. 2022). To determine emission factors for fuels not listed in the Inventory, we additionally used Table 1.2. The recommended values for the conversion factors into energy units and emission factors for carbon dioxide (tCO2/TJ), methane (kg CH4/TJ) and dinitrogen oxide (kg N2O /TJ) for stationary fuel combustion of the Methodological Recommendations for Conducting a Voluntary Inventory of Greenhouse Gas Emissions in the Constituent Territories of the Russian Federation, approved by Order of the Ministry of Natural Resources of Russia No. 15-p, dated 16 April 2015.

generally well above our estimates. This is because we consider only emissions from fuel combustion by enterprises and organisations. Therefore, our calculations should be compared with the Inventory sector "Energy" without the final fuel consumption by the population. The discrepancy is about 6%, which is mainly due to the limited data available to us.

Figure 1. Comparison of information from the National Inventory Report with the emission estimates in Form No. 4-TER (million tons of CO2 equivalent)



Sources: NIR data (Romanovskaya et al. 2022), authors' calculations.

Benchmark emissions in the model

Benchmark emissions are presented in Table 11 and Figure 44. Industrial emissions are calculated based on data from Form No. 4-TER, emissions from combustion associated with final demand are estimated based on emission factors. Emission factors are ratios between total industry emissions by type of fuel and fuel costs for intermediate consumption (Table 12).

5. CGE results: energy transition in Russia

Scenario design

We turned to the NGFS set of scenarios for the initial framework in elaborating our own scenarios. The NGFS suggests six scenarios which are split into three groups (NGFS

2021).[12] The first group, “orderly”, assumes that climate policies in countries are introduced early, in a concerted and orderly manner across all countries. The second, “disorderly”, group considers the state of the world where policies are divergent across sectors and countries, but climate goals are nevertheless achieved. Finally, the third group, “hot house world”, assumes that, although some countries introduce climate policies, global efforts are not sufficient to slow down global warming. As a reference scenario, we chose the Net Zero 2050 scenario from the orderly group. This is one of the scenarios with the most ambitious climate goal (limiting global warming to 1.5°C), just as the Divergent Net Zero scenario from the disorderly group. We selected Net Zero 2050 as, despite its ambitiousness, it allows a comparative analysis of the effect of climate policy measures in Russia on a “pure” basis, without interfering with the effects of varying policies in sectors and countries. We use the version of the scenarios published in June 2021.[13]

In terms of climate policy instruments, our paper heavily builds on Böhringer et al. (2015) where, in addition to the introduction of cap-and-trade regulation in Russia, two alternative environmental policy tools are considered – emission intensity standards and energy efficiency standards. Böhringer et al. (2015) examine the impacts of these policy instruments on the structure of the economy separately and in the context of Russia’s accession to the WTO. Böhringer et al. (2015) show that cap-and-trade is the preferred way to curb emissions in terms of minimising welfare costs.

In our study, we combine cap-and-trade regulation with changes in global climate policy that aims to stabilise the world GHG emissions at levels mostly consistent with the Net Zero 2050 scenario over the period of 2022–2050.

Our CGE model is a small open-economy model, and we thus treat world prices as exogenous parameters. By world prices, we mean prices of Russian export goods as perceived by Russian exporters.

Export price projections cover the following 11 commodities: aluminium (alu), copper (cop), precious metals (pmt), metal ores (ore), crude oil (cru), natural gas (gas), fertilisers (frt), coal (col), coking coal (cke), steel (stl), and ferrous metals (fmp) (Table

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[12] For details, see https://www.ngfs.net/ngfs-scenarios-portal/explore/.

[13] It was updated in June 2022 when our work was already in progress.

13). All other export prices and exogenous parameters of the model are held fixed in all scenarios.

We use two sets of forecasts of the world prices for the period of 2022–2050: *«BAU»* and climate sets (for details, see Figure 14–Figure 24 and Table 13[14] in Appendix II). We use the *«BAU»* set of prices for the *«BAU»* scenario and the climate set for our climate policy scenarios.

We simulate scenarios as independent model runs; thus, our set of scenario estimations is not recursive. The exogenous parameters of the model that are changed are export prices and domestic climate policy parameters in the relevant scenarios. By specifying different years for the model runs, we mean that we use the respective sets of export prices and domestic climate policy parameters where applicable.

Business-as-usual scenario

The *business-as-usual (BAU)* scenario suggests no changes in climate policy at the global or domestic level. Thus, the *«BAU»* scenario depicts a possible trajectory of world prices faced by major Russian export industries at the time of the research (the end of 2021). There is a commonality in projections across different export goods, namely a decline in prices in 2022–2024. This comes from the authors' shared view that the 2021 rally in world commodity markets might give way to price corrections, ceteris paribus (for details, see Table 13).

Climate scenarios

Climate scenarios assume lower global demand for fossil fuels and, accordingly, lower price levels that Russian exporters face, compared to the *«BAU»* scenario.

We consider the following climate policy scenarios:

- *«Climate reference» («Reference»* scenario, cli) – climate actions are taken by other countries, not Russia. There is no domestic climate policy in this scenario. All major countries, except Russia, act decisively according to the ambitious goals of the GHG emission reduction by 2050, mostly in line with the Net Zero 2050 scenario. We do not model how global climate actions

[14] We give two different representations of changes in world prices for Russian exports: % year-on-year changes are demonstrated in Figure 14–Figure 24, and a % difference relative to the 2016 benchmark level of world prices (2016 is the base year of our model) is presented in Table 13. Please note that most export prices in 2016 were much lower than in 2021; hence, there is a sizable increase in export prices in 2021, compared to 2016, in all scenarios.

affect world demand and prices for Russian exports but rely on the authors' view and expert judgment in this respect. In terms of model simulations, this assumption means that the only changes in external parameters of the model are changes in export prices according to the world price projections under the climate scenario.

- *«Domestic carbon tax»* (*«Domestic»* scenario, ctc) – this is our central climate policy scenario. We imagine that Russia introduces a carbon trading system right away (in 2023) to meet the goals of the intensive scenario of the Strategy of socio-economic development of Russia with a low level of greenhouse gas emissions until 2050.[15]
- *«Intensive domestic climate policy»* (*«Intensive»* scenario, ctc75) – this climate scenario states a more ambitious reduction in carbon emissions from fuel combustion than the central scenario, with carbon trading starting in 2023.
- *«Delayed domestic climate policy»* (*«Delayed»* scenario, ctc75_30) – we assume that climate policy is delayed until 2030, but the final goal for emission reduction is the same as in the (*«Intensive»* scenario.

We assume that, in all these climate scenarios, the rest of the world acts in line with the Net Zero NGFS scenario. These actions affect world commodity prices, as well as prices for Russian exports. The forecast for selected commodity prices is the same as in the *«Reference»* scenario (without domestic policy).

Domestic climate policy in our model is determined by the intensive scenario of the Strategy of socio-economic development of Russia with a low level of greenhouse gas emissions until 2050 (hereinafter, the Strategy). The emission reduction goals stated in the Strategy, as well as the emission levels for 2016, and the benchmark year of our model are presented in the table below (Table 1).

In the data section of the paper, we explain that our model's coverage of emission sources is limited to fuel combustion. The Strategy does not provide any details on the distribution of reduction goals across emission sources. Therefore, we assume that the

[15] https://www.iea.org/policies/14859-strategy-of-socio-economic-development-of-russia-with-a-low-level-of-greenhouse-gas-emissions-until-2050.

reduction in emissions from fuel combustion is proportionate to the reduction in net emissions. Given that the base year of our model is 2016, we formulate climate policy goals in reference to the 2016 net emissions as published in Russia's National Inventory Report (Romanovskaya et al. 2022). Thus, the emission reduction goal in our «*Domestic»* scenario is a 55.5% reduction in 2050 from the 2016 emission level.

Table 1. Emission levels in 2016 and 2019, and emission reduction goals in the Strategy of socio-economic development of Russia with a low level of greenhouse gas emissions until 2050

	2016 (UN FCCC)	2019 (Strategy)	Goal 2030 (Strategy)	Goal 2050 (Strategy)	Change 2050 vs 2016, %
		«Baseline» scenario			
GHG emissions	2,023.4	2,119.0	2,253.0	2,521.0	
Absorption	-608.9	-535.0	-535.0	-535.0	
Net emissions	1,414.5	1,584.0	1,718.0	1,986.0	40%
		«Intensive» scenario			
GHG emissions	2,023.4	2,119.0	2,212.0	1,830.0	
Absorption	-608.9	-535.0	-539.0	-1,200.0	
Net emissions	1,414.5	1,584.0	1,673.0	630.0	-55.5%

Sources: 2020 Russian National Inventory Report (NIR) (Romanovskaya et al. 2022), Strategy of socio-economic development of Russia with a low level of greenhouse gas emissions until 2050.

We assume that a cap-and-trade mechanism is in place starting from 2023 and the emission limit decreases each year at a constant pace. All industries and households pay a uniform CO2 tax. The CO2 tax rate is endogenous in all domestic climate policy scenarios and increases as the emission level is cut.

In addition to our central scenario, we also consider two alternative scenarios with domestic carbon tax: «*Intensive»* and «*Delayed».* The reduction in net emissions under the Strategy largely depends on the improvement of the sink capacity of the land use, land-use change and forestry (LULUCF) sector. In our alternative scenarios, we assume that an increase in the sink capacity is less than stated in the «*Intensive»* scenario of the Strategy and there is a need to raise emission cuts in all other sectors. Thus, we assume a 75% decrease in emissions from fuel combustion relative to the 2016 benchmark level. The «*Intensive»* scenario assumes that carbon tax is imposed in 2023.

The «*Delayed»* scenario assumes that intensive domestic climate policy starts in 2030, but the level of the final emission reduction goal is the same: a 75% reduction by 2050 from the 2016 level. Given that the period to achieve the goal is shorter, the pace of reduction goes up. All emission goals in our climate policy scenarios are presented in the Appendix (see Table 14).

Simulation results

Macro parameters and sectoral output

In all the scenarios for all years, we hold fixed factor endowments, and external closure of the model, i.e., the trade balance, government procurements, and the savings-investment bank's purchases in real terms. Thus, a change in private consumption is the main driver of a GDP change.

We present two different views of simulation results: year-on-year changes (see Figure 25–Figure 41) and a percentage difference relative to the 2016 benchmark level (Table 2).

Lower global demand for fossil fuels in the *«Reference»* scenario induces a decrease in real GDP and household consumption compared to the *«BAU»* scenario (Table 2).

The scenarios with domestic climate policy give anticipated results for the modelling settings we choose:[16] the bigger is the emission cut, the higher is the price of carbon and, thus, the larger is the decline in real GDP. The difference between the results in the *«Reference»* and «*Domestic»* scenarios highlights the effect of domestic climate policy.

In our central case scenario «*Domestic»*, a GDP decline in 2030 resulting from the combined influence of changes in export prices and domestic climate policy is -4.3%, of which -4.0% is due to changes in export prices – this constitutes 93.5% of the decline in GDP. The remaining 6.5% is due to the introduction of a cap-and-trade policy with a 55.5% emission reduction goal by 2050 (relative to the model's 2016 benchmark level).

[16] The prerequisites for "green growth", i.e., economic growth with climate policy, including emissions trading and carbon taxes, is a highly debated topic. Most researchers agree that green investments, as well as breakthrough innovations are essential elements for green growth (Haberl et al. 2020). Our model experiments take a more conservative approach: there are no new technologies in the model; all available technologies are described in the Russian input–output table for 2016; and investments and factor endowments are fixed in real terms. These assumptions mean that investment is just enough to cover amortisation; economically active labour force is fixed in terms of efficiency units, i.e., all changes in demographics are offset by changes in labour productivity. Please note that this paper does not address issues of acute physical risks of climate change or climate change adaptation.

In our alternative scenarios «*Intensive*» and «*Delayed*», the trajectories are different, although the final equilibrium points in 2050 are the same. With delayed climate actions starting in 2030, the pace of the adjustment is higher compared to the «*Intensive*» scenario with a cap-and-trade mechanism introduced in 2023.

Table 2. Macro variables by scenario for 2030 and 2050 and changes vs 2016 benchmark level

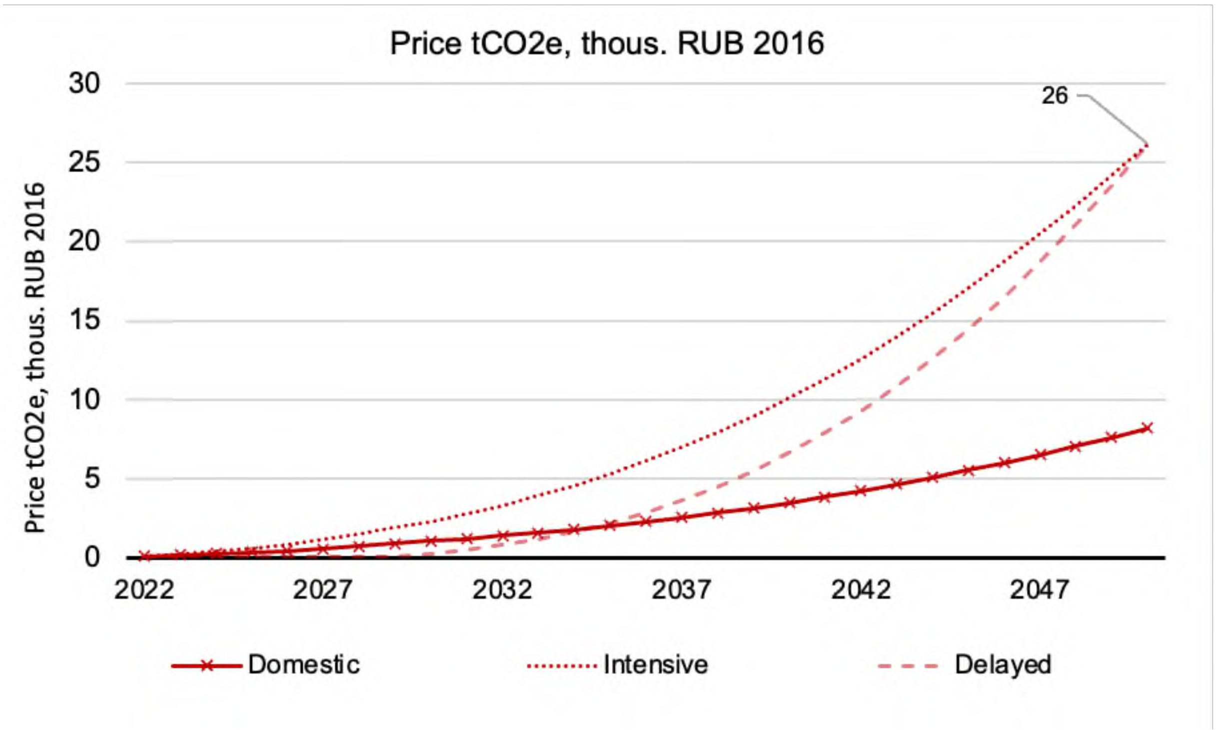
	BAU		Reference		Domestic		Intensive		Delayed	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
	Changes to benchmark (2016), %									
Real GDP, %	-2.6	-1.3	-4.0	-5.4	-4.3	-8.4	-4.7	-14.6	-4.0	-14.6
Real HH consumption, %	-5.0	-2.5	-7.7	-10.4	-8.3	-16.3	-9.2	-28.3	-7.8	-28.3
CO2e emissions, %	8.4	30.4	4.5	1.9	-20.7	-55.5	-32.7	-75.0	-6.4	-75.0
Real price of tCO2e , 1,000Rub/tCO2e	-	-	-	-	1.1	8.2	2.3	26.2	0.3	26.2

Source: authors' calculations.

On the supply (production) side of the economy, we witness changes in the volume and prices of industries' output, changes in distribution between domestic and export markets, as well as changes in factor prices. On the demand side of the economy, adjustments are transmitted through prices and supply of domestic goods produced for the domestic market, affecting demand for imports and supply for intermediate and final consumption. Since government procurements and the savings-investment bank's demand are fixed in real terms at the benchmark level, all adjustments take place through the RA's budget. The resulting changes of the RA's budget and prices for final goods determine the level of the household's consumption in the new equilibrium under each of the scenarios. Simulation results are presented in the Appendix (see Figure 25–43).

A decrease in world energy prices (*«Reference»* scenario), without domestic climate policy in place, would entail a decline in domestic fuel prices and an increase in CO2e emissions (by 4.5% in 2030 and 1.9% in 2050). The carbon price under the «*Domestic*» scenario in 2030 equals RUB 1,100/tCO2e (or $US16/tCO2e in constant 2016 prices) (Figure 2). In the «*Domestic*» scenario, a reduction in CO2e emissions equals 55.5% in 2050 with the carbon price at RUB 8,200/tCO2.

Figure 2. Price of tCO2e, ths RUB 2016



Source: authors' calculations.

We estimate the possible costs for achieving the goals set under the «*Intensive»* scenario of the Russian low-carbon strategy to be 0.3% in 2030 and 3.0% in 2050 of the decrease in real GDP relative to the benchmark level, provided that a cap-and-trade mechanism is introduced promptly (in 2023). If the emission reduction target is raised, as modelled in our alternative scenarios («*Intensive»* and «*Delayed»* scenarios), the economic burden of climate actions may increase significantly as we approach 2050. If the goal is to reduce emissions from fuel combustion by 75% from the 2016 level, without an additional influence of changes in export prices, it might cost 9.2% of the benchmark level of GDP in 2050. We need to draw readers' attention to the fact that we are holding fixed the stock of factors in all our simulations and we do not model an introduction of new technologies or new products in our research.

Economic costs of an intensive reduction in emissions are significant because of using only one policy measure – a cap-and-trade mechanism. Our analysis highlights the importance of diversifying climate policy tools, including by improving the sink capacity of lands and forests, curbing technological emissions and leaks.

Changes in sectoral output under the climate scenarios with and without domestic climate policy in 2050, relative to the *«BAU»* scenario, are shown in Figure 45. In all climate scenarios, fossil fuel extraction industries are affected negatively. The sectors hardest hit by domestic climate policy also include electricity generation, railway and other land transport, metal ore mining, and pipelines. Industries that benefit from changes in relative prices and increase their output in the climate scenarios, relative to the *«BAU»* scenario, are wood processing, forestry, light and machinery manufacturing.

6. Transition risk and financial stability in Russia

This satellite exercise is done to evaluate banks' overall exposure and exposure-at-risk to the industries most sensitive to transition risk. In addition, we estimate the impact of climate regulations on sectors' equity valuation. To ensure a smooth and adequate transition, banks need to be very resilient. The complex nature of transition risk involves additional challenges for estimation, which implies several assumptions.

Another feature is a longer time horizon and deferred realisation of risk. In practice, this means that the maturity structure of current exposure, shorter-term financial needs, and growing pressure to refinance debt might complement each other. The cumulative effect might be notably delayed. The forward-looking nature of transition risk and firms' general flexibility in choosing sources of financing might affect the timing and the magnitude of the actual realisation of exposure-at-risk. Nevertheless, the assessment of the sectoral distribution of exposure-at-risk is required to better understand banks' resilience in terms of their current exposure.

The challenge is twofold. First, firms are heterogeneous in terms of their operating exposure to transition risk. The extent of firms' operating exposure and its translation into their economic results are analysed during the CGE modelling exercise. Second, firms significantly vary in terms of their sources of available financing and particularly their financial needs covered by bank loans. This translates into multiple possible combinations of operating exposure and financial exposure.

6.1. Financial model methodology

Use of DSR concept

We focus on the potential of non-financial companies (NFCs) to service their debt obligations depending on the adjustment path (from the CGE model output). We measure each company's debt service burden using the concept of the debt service ratio (DSR)[17]. This is the ratio of interest payments and the amortised amount of debt to the earnings flow generated by each borrower at any time. By its structure, the DSR captures the non-linearity of changes in interest rates and the remaining maturity:

Equation 2

$$\boldsymbol{DSR_{j,t}} = \frac{\boldsymbol{i_{j,t}}}{\left(\mathbf{1} - \left(\mathbf{1} + \boldsymbol{i_{j,t}}\right)^{-s_{j,t}}\right)} * \frac{\boldsymbol{D_{j,t}}}{\boldsymbol{Y_{j,t}}}$$

where remaining maturity ($\boldsymbol{S}$), lending rate ($\boldsymbol{i}$), and amount of outstanding debt ($\boldsymbol{D}$) for entity $\boldsymbol{j}$ at time point $\boldsymbol{t}$ are normalised by the amount of income ($\boldsymbol{Y}$). It is assumed that the principal debt is amortised over the remaining maturity.[18] On the one hand, this assumption is conservative as it implies that firms should be able to generate earnings sufficient not only to service their interest payments, but also to repay roughly the 1/nth of the amount of outstanding debt (where n is the remaining time to maturity in years). On the other hand, this assumption is precautionary as it reveals insufficient levels of earnings in advance and not at the moment when the principal amount is due. If the insufficient amount of earnings is revealed at the time of scheduled debt repayment, there could only be two options for a borrower – a default or debt rollover (the latter should be assumed continuously).

We calculate the amount of expected interest payments and the amortised amount of the principal debt (collectively referred to as the amount of debt service burden) for the next year based on the information as of 1 January 2020. We relate the amount of debt service burden to the amount of earnings before interest and taxes (EBIT) for each borrower for the 2019 financial year and refer to this ratio as the DSR in the Status Quo.

Implementation of the CGE model output

We assume that a change in the level of earnings before interest and taxes (EBIT) of each borrower would reflect the overall change in the sector that a particular borrower belongs to based on the NACE rev 1.1 industrial classification (actually, we assume that

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[17] The concept of the DSR was introduced by Drehmann and Juselius (2013). It was applied to the micro level database by Burova (2020). For a comprehensive discussion of the DSR and its usefulness as an EWI, refer to Drehmann and Juselius (2013).

[18] Assumptions behind the concept of the DSR are discussed by Drehmann et al. (2015).

firms are representative of the industries they operate in). We take the percentage change in accounting profit from the CGE model for each sector and use it as an input to the DSR denominator from Equation 2. We calculate the debt service burden as of 1 January 2020 and relate it to estimated EBIT in 2030 and 2050 for each scenario (specifically, *«BAU» 2030*, *«BAU» 2050*, *«Reference» 2030*, etc.). Thus, we estimate the impact of different scenarios on firms' ability to service their debt obligations. At the current stage of the research, we do not assume any changes in the debt level, the maturity structure, or interest rates, i.e., we assume a static balance of firms' debt obligations. At the next stage of the research, we are going to relax this assumption and simulate a changing path of debt parameters (shorter or longer maturity, yield curve, etc.).

6.2 Financial model data

We use a loan-level credit registry database.[19] The database contains information on outstanding debt under each credit agreement, initial and remaining maturity (in days), information on interest rates, collaterals, and relevant data on repayment schedules (including interest expenses and amortisation of the principal debt). The information on borrowers include their tax identification numbers and industry classification codes. The granular exposure at the sectoral level was calculated based on the information from the credit registry on each firm: the amounts of each firm's outstanding loans were summed up, firms were then marked based on their industry classification, and the overall exposure was calculated.

We use borrowers' annual financial statements obtained from the SPARK[20] database. We match the information from the credit registry with the information from financial statements to relate the amount of debt service burden to the amount of EBIT for each borrower. For this exercise, we use the amount of outstanding debt as of 1 January 2020 and match it with the information on EBIT for the financial year 2019, i.e.,

[19] Referred to as the credit registry; it is Reporting Form No. 0409303 "Information on Loans Granted to Legal Entities" submitted by Russian credit institutions to the Bank of Russia monthly. The description of the form is available at https://www.cbr.ru/eng/statistics/pdko/sors/summary_methodology/#highlight=0409303.

The detailed description of the database is also available in the working papers prepared using the same data sources, for example, Goncharenko et al. (2021).

[20] The SPARK database provided by the Interfax Group is available at https://spark-interfax.ru/.

the total amount of EBIT for each borrower from 1 January 2019 through 31 December 2019.

6.3. Financial model results

We group all firms into sectors of the economy based on their NACE industrial classification (for the detailed structure of the sectors, refer to the Appendix) and show the evolution of DSRs in the sectors under each of the scenarios.

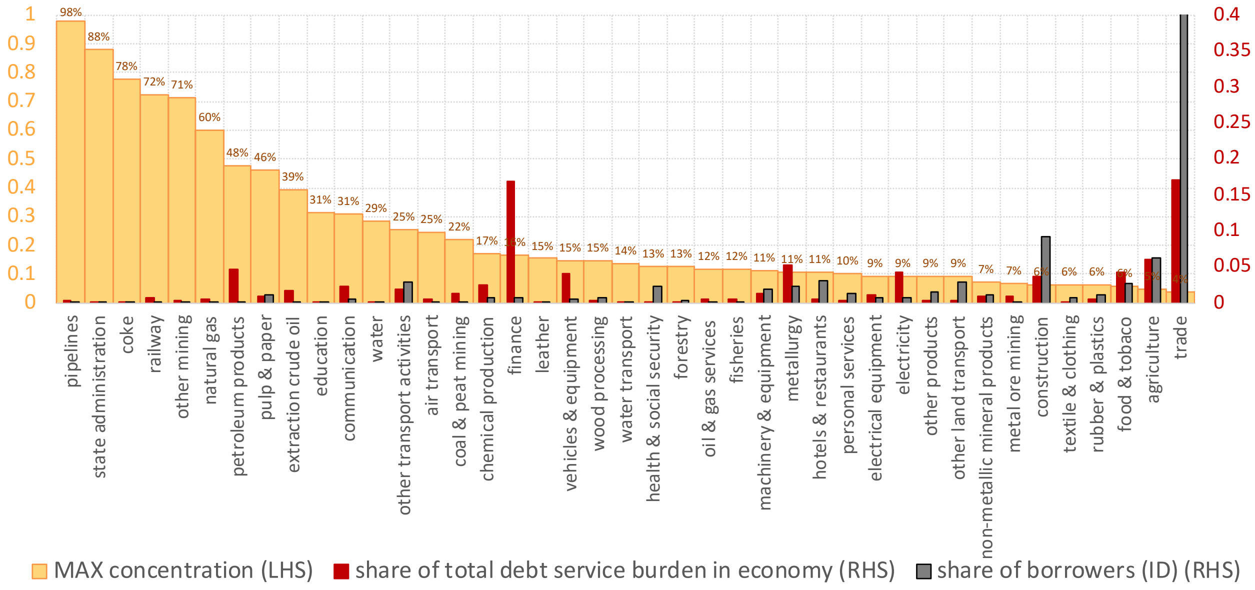
Status Quo

We first describe the characteristics of the DSR distribution based on the actual characteristics of EBIT as of 1 January 2020. We describe the heterogeneity of DSRs in 42 sectors of the economy using the following categories:

- The amount of debt service burden concentrated per one firm-ID in each sector.
- The share of debt service burden (total exposure) attributable to borrowers with negative earnings.
- The share of sectoral exposure (the total amount of debt service burden in each sector) which falls within the range of a DSR greater than 0 and less than or equal to 100%, i.e., (0%, 100%]. We consider this range of the DSR levels to be the safest as the amount of debt service burden in this case (the numerator in Equation 2) is not greater than the amount of a firm's earnings (the denominator in Equation 2).

For visual representation, see Figure 3–Figure 5.

Figure 3. Share of debt service burden, number of firms, and maximum concentration per one firm-ID for 42 sectors of the economy



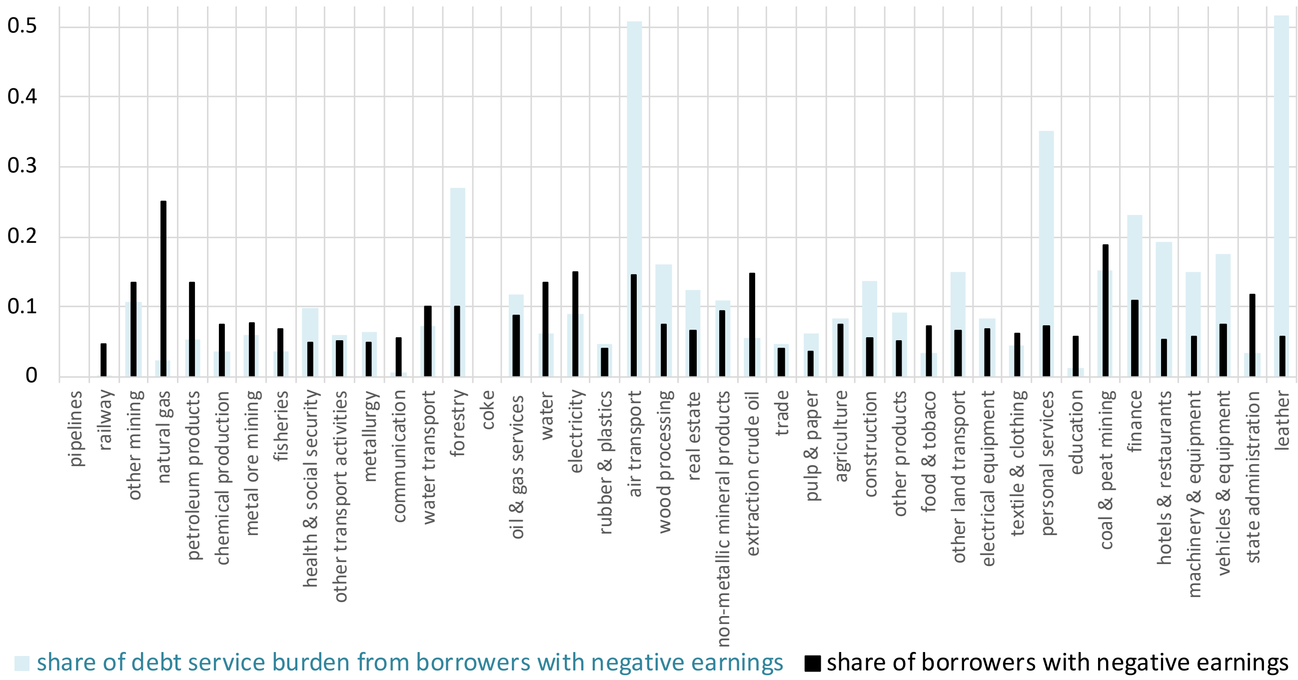
Note: red bars add up to 100%; grey bars add up to 100%.

Sources: Bank of Russia, authors' calculations.

The amount of debt service burden is concentrated in a few sectors of the economy (Figure 3, red bars), namely Wholesale and retail trade (sG) – 17%, Financial intermediation (sJ) – 17%, and Real estate (sK) – 12% with the shares of borrowers (Figure 3, grey bars) equalling 41%, 1%, and 12%, respectively.

A high concentration (more than 50%) of sectoral exposure per one-firm-ID (Figure 3, yellow bars) is observed in the Transportation sector: pipelines (s603) – 98% and railways (s601) – 72%; Manufacture of coke oven products (s231) – 78%, Extraction of natural gas (sgas) – 60%, Other mining and quarrying (s14) – 71%, and Public administration and defence (sL) – 88% sectors.

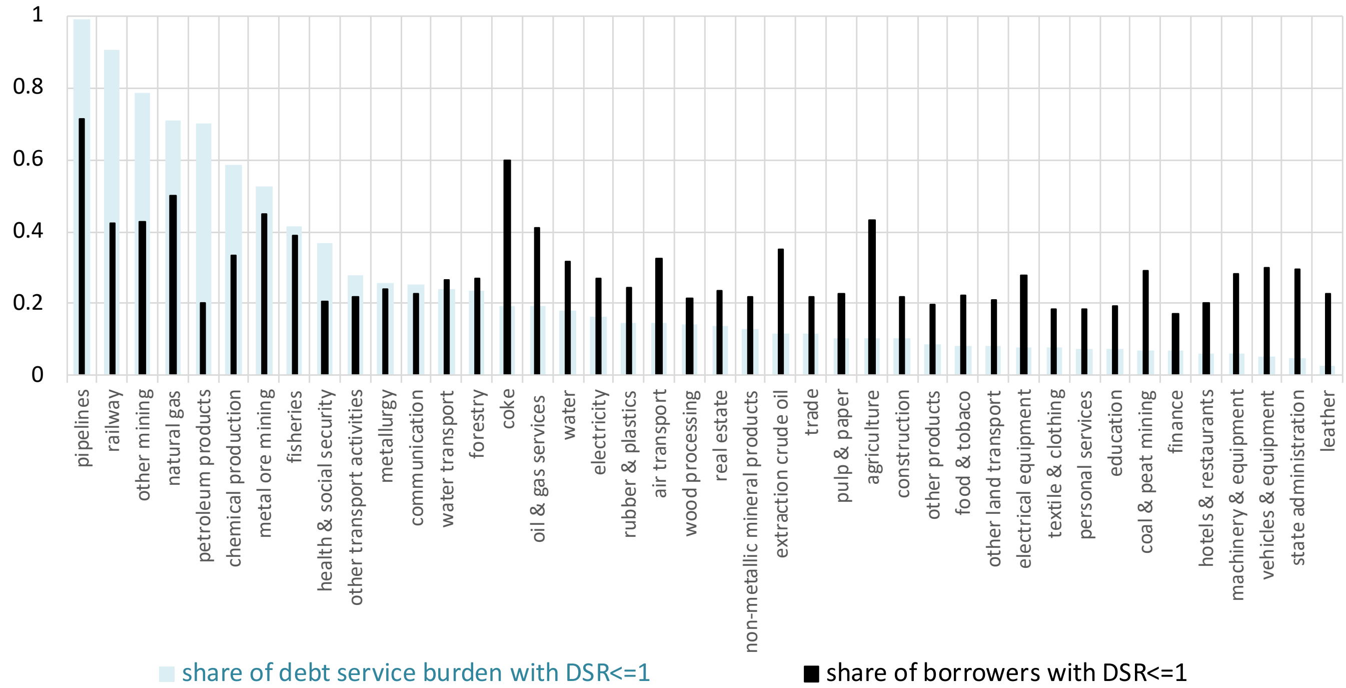
Figure 4. Share of debt service burden of borrowers with negative earnings in total sectoral exposure (Status Quo)



Sources: Bank of Russia, authors' calculations.

The share of exposure attributable to borrowers with negative earnings (Figure 4, blue bars) is the highest in the following sectors: Manufacture of leather products (sDC) – 52%, Air transportation (s62) – 51%, Other community, social and personal service activities (sO) – 35%, Forestry (s02) – 27%, and Financial intermediation (sJ) – 23%. However, the share of firm-ID with negative earnings in these sectors (Figure 4, black bars) does not reflect the share of their exposures equalling 6%, 15%, 7%, 10%, and 11%, respectively. Thus, it is possible to notice that firms with negative earnings account for a disproportionately large amount of sectoral exposure in some sectors of the economy.

Figure 5. Share of debt burden of borrowers with DSR below or equal to 100% of earnings in total sectoral exposure (Status Quo)



Sources: Bank of Russia, authors' calculations.

We consider the levels of DSRs falling within the range of (0, 100%] to be safe for the financial stability purpose (with a level close to 100% to be warning as this means that the potential cash outflow to service the debt is higher than earnings from operating activities).

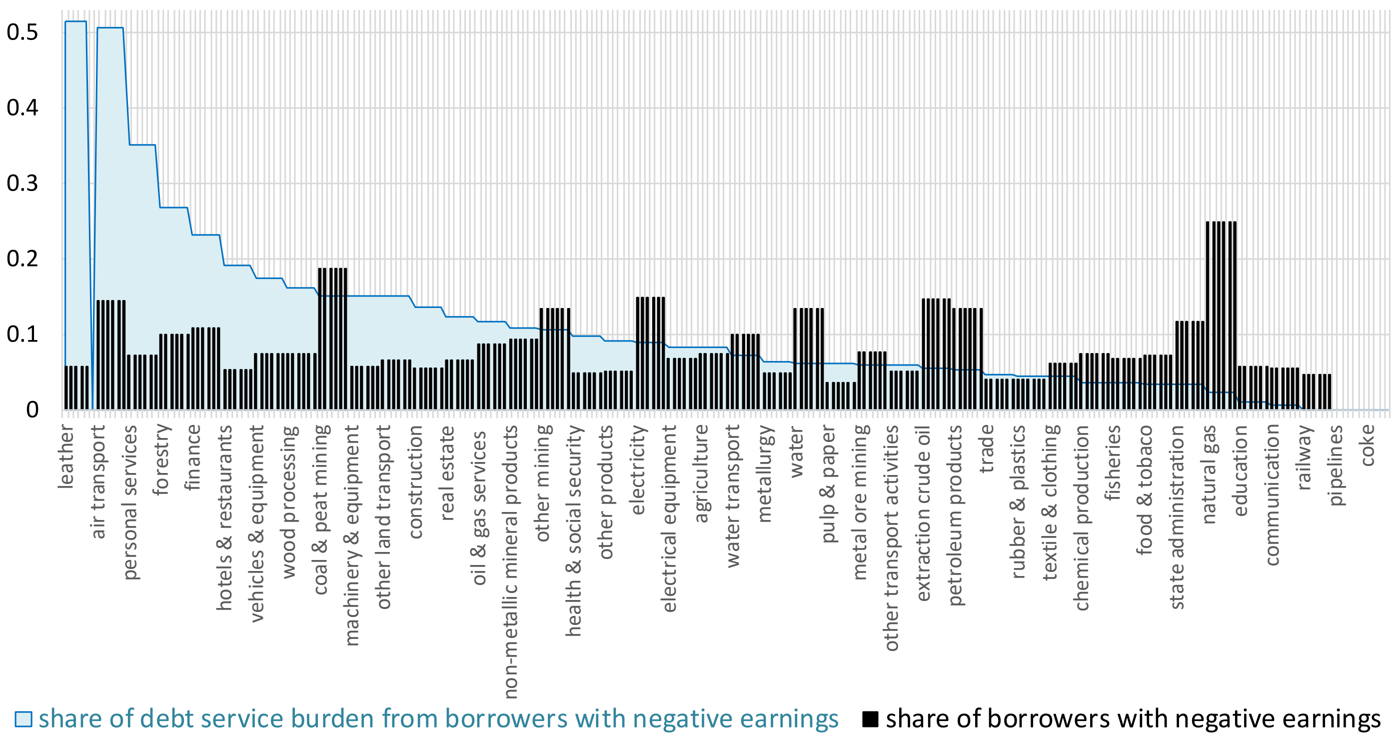
The lowest share of exposure within the safest range (Figure 5, blue bars) is in Manufacture of leather products (sDC) – 3%, Manufacturing of machinery and equipment (sDK) – 6%, Mining of coal and lignite; extraction of peat (s10) – 7%, Hotels and restaurants (sH) – 7%, Education (sM) – 7%, Manufacture of textiles and textile products (sDB) – 8%, and Manufacture of food products, beverages and tobacco (sDA) – 8%. The share of firms-ID (Figure 5, black bars) with DSRs in the safest range is 19–30% in these sectors. This means that financially sound firms have a disproportionately low share of exposure in some sectors of the economy.

Scenarios

We apply the results of an accounting profit change from the base year to 2030 and 2050 in our central scenario («*Domestic», ctc*) obtained from the CGE model. We translate the percentage change in accounting profit into the corresponding change in EBIT for firms in each sector, assuming that firms are representative of their sectors.

Next, we discuss the changes in the DSR distribution, particularly the change in the share of exposure attributable to firms with negative earnings (Figure 6), the share of exposure falling within the range of (0, 100%], and the resulting change in the ruble value of exposure-at-risk under each of the scenarios (Table 3).

Figure 6. Share of debt service burden of borrowers with negative earnings (all Scenarios)



Note: each bar corresponds to a different scenario.
Sources: Bank of Russia, authors' calculations.

The share of exposure attributable to borrowers with negative earnings remains the same under all scenarios (Figure 6), except for Manufacture of leather products (sDC) in the scenario «*Domestic»2050* (from 52% of exposure and 6% of firms-ID to 0%).

For each of the scenarios, we calculate the share of firms-ID and the amount of corresponding exposure, for which:

- the level of the DSR changes from (0,100%] to above 100% (and call it "adverse change");
- the level of the DSR changes from above 100% to (0,100%] (and call it "favourable change").

For changes in billions of rubles, refer to Table 3. For a detailed analysis of a percentage change disaggregated by firm and exposure, refer to Figure 7–Figure 12.

Table 3. Changes in exposure-at-risk (RUB bln) and total scenario effects for sectors of the economy

Sector	BAU 2030			cli 2030			ctc 2030			BAU 2050			cli 2050			ctc 2050		
	adverse change	favourable change	Total effect	adverse change	favourable change	Total effect	adverse change	favourable change	Total effect	adverse change	favourable change	Total effect	adverse change	favourable change	Total effect	adverse change	favourable change	Total effect
s01	(2)		(2)	(0)		(0)		0	0	(2)		(2)		3	3		1	1
s02					0	0		0	0	(0)		(0)		0	0		0	0
s10				(9)		(9)	(10)		(10)				(9)		(9)	(15)		(15)
s112		0	0		1	1		0	0		0	0		1	1	(2)		(2)
s13							(0)		(0)	(4)		(4)	(9)		(9)	(22)		(22)
s14																		
s231		6	6				(1)		(1)		6	6				(1)		(1)
s232		7	7		63	63		63	63		7	7		63	63		6	6
s40	(3)		(3)	(3)		(3)	(6)		(6)	(3)		(3)	(4)		(4)	(24)		(24)
s41	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(1)		(1)
s601		0	0	(0)		(0)	(0)		(0)		0	0	(0)		(0)	(5)		(5)
s602	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(1)		(1)
s603																		
s61		3	3		3	3		3	3		3	3		4	4		3	3
s62		4	4		4	4		4	4					4	4			
s63		3	3		4	4		4	4		3	3		6	6	(1)		(1)
s64	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)
sB		0	0		4	4		4	4					4	4		3	3
sDA	(2)		(2)	(3)		(3)	(3)		(3)	(2)		(2)	(2)		(2)	(3)		(3)
sDB					1	1		1	1	(0)		(0)		1	1		1	1
sDC					0	0		0	0	(0)		(0)		0	0		1	1
sDD		0	0		10	10		10	10	(0)		(0)		12	12		15	15
sDE	(0)		(0)		0	0		0	0	(0)		(0)		0	0			
sDG	(68)		(68)	(68)		(68)	(68)		(68)	(197)		(197)	(197)		(197)	(197)		(197)
sDH	(0)		(0)		0	0		0	0	(1)		(1)		0	0		0	0
sDI					0	0		0	0	(0)		(0)		0	0		0	0
sDJ	(4)		(4)		10	10		1	1	(5)		(5)	(0)		(0)	(5)		(5)
sDK		0	0		2	2		2	2		0	0		3	3		3	3
sDL		3	3		3	3		3	3					3	3		5	5
sDM		17	17		19	19		19	19		11	11		20	20		23	23
sDN	(0)		(0)		0	0		0	0	(2)		(2)		0	0			
sF		0	0		0	0								0	0	(12)		(12)
sG	(7)		(7)	(19)		(19)	(20)		(20)	(4)		(4)	(26)		(26)	(64)		(64)
sH	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(1)		(1)
sJ														0	0	(9)		(9)
sK	(1)		(1)	(1)		(1)	(2)		(2)	(2)		(2)	(0)		(0)	(35)		(35)
sL																		
sM	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)
sN	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)
sO	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(0)		(0)	(2)		(2)
scru							(2)		(2)				(2)		(2)	(12)		(12)
sgas																(52)		(52)
Total	**(89)**	**42**	**(46)**	**(104)**	**124**	**20**	**(113)**	**114**	**1**	**(223)**	**30**	**(193)**	**(251)**	**124**	**(127)**	**(464)**	**62**	**(402)**

Note: "cli 2030", "ctc 2030", "cli 2050" and "ctc 2050" are related to the «Reference» 2030, «Domestic»2030, «Reference» 2050 and «Domestic» 2050 scenarios, respectively.

Sources: Bank of Russia, authors' calculations.

The most notable favourable change (Table 3, green slots) is observed for Manufacture of refined petroleum products (s232) in the scenarios *«Reference» 2030*, *«Reference» 2050*, and *«Domestic» 2030*, amounting to RUB 63 bln.

Favourable changes in the sector Manufacture of transport equipment (sDM) are observed in all scenarios, but the amounts vary from RUB 11 bln in the scenario *«BAU» 2050* to RUB 23 bln in the scenario *«Domestic» 2050*.

Favourable changes in the sector of Manufacture of wood and wood products (sDD) are only observed under the scenarios *«Reference»* and *«Domestic»* and range from RUB 10 bln under *«Reference» 2030* to RUB 15 bln under *«Domestic» 2050*.

Overall, the maximum favourable change for the economy is observed in the scenarios *«Reference» 2030* and *«Reference» 2050* totalling RUB 124 bln. However, this is offset by the adverse changes of RUB 104 bln (*«Reference» 2030*) and RUB 251 bln (*«Reference» 2050*). Thus, the scenario *«Reference» 2030* is the most favourable one with the total favourable change of RUB 20 bln for the economy (this may also be interpreted as an overall decrease in exposure-at-risk of RUB 20 bln).

The most severe adverse effect (Table 3, red slots) is observed in the scenario «*Domestic»2050* with an additional amount of exposure-at-risk reaching RUB 402 bln (total for the economy). This mainly comes from the sector Manufacture of chemicals, chemical products and man-made fibres (sDG) accounting for an increase in exposure-at-risk equalling RUB 197 bln, Wholesale and retail trade (sG) – RUB 64 bln, and Extraction of natural gas (sgas) – RUB 52 bln.

Next, we move to the disaggregate analysis of favourable and adverse changes in the number of firms and their debt burden under different scenarios (Figure 7–Figure 12).

Scenario *«BAU»*

Please refer to Figure 7 for the year 2030 and Figure 8 for the year 2050. Manufacture of coke oven products (s231) demonstrated a significant increase (40%) in the number of firms, with the level of DSRs moving from above 100% to the safest range of within (0,100%]. The corresponding level of sectoral exposure is 81%. The sector Water transport (s61) demonstrated an increase in the number of firms (4%) and related exposure (12%) within the safest range. Thus, the scenario results in a *favourable* change for borrowers with a higher level of debt burden in these sectors.

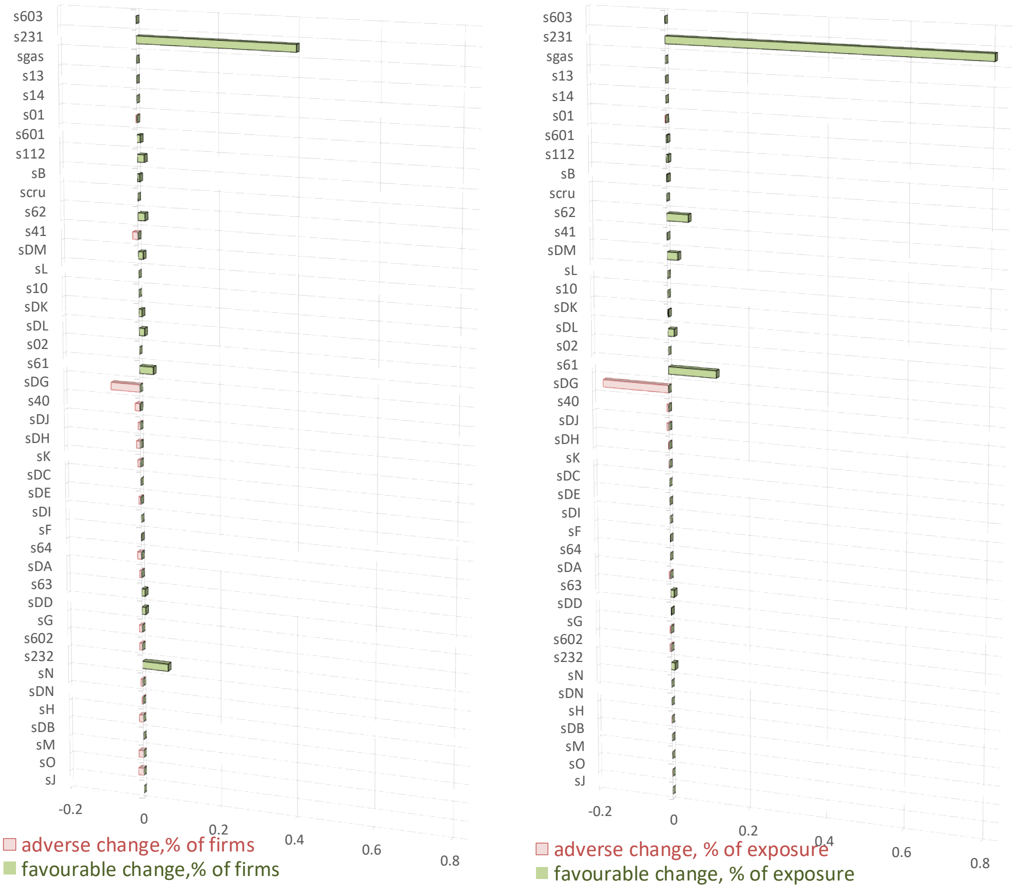
The sector Manufacture of chemicals, chemical products and man-made fibres (sDG) shows an *adverse* move (i.e., from the levels of DSRs within the range of (0,100%] to the levels above 100%) in the number of firms and related exposure as follows:

- by 2030: 8% of firms and 17% of sectoral exposure;
- by 2050: 11% of firms and 50% of sectoral exposure.

Thus, firms characterised by higher sectoral exposure experience adverse changes closer to 2050.

Figure 7. Changes in sectoral exposure, «*BAU*» 2030

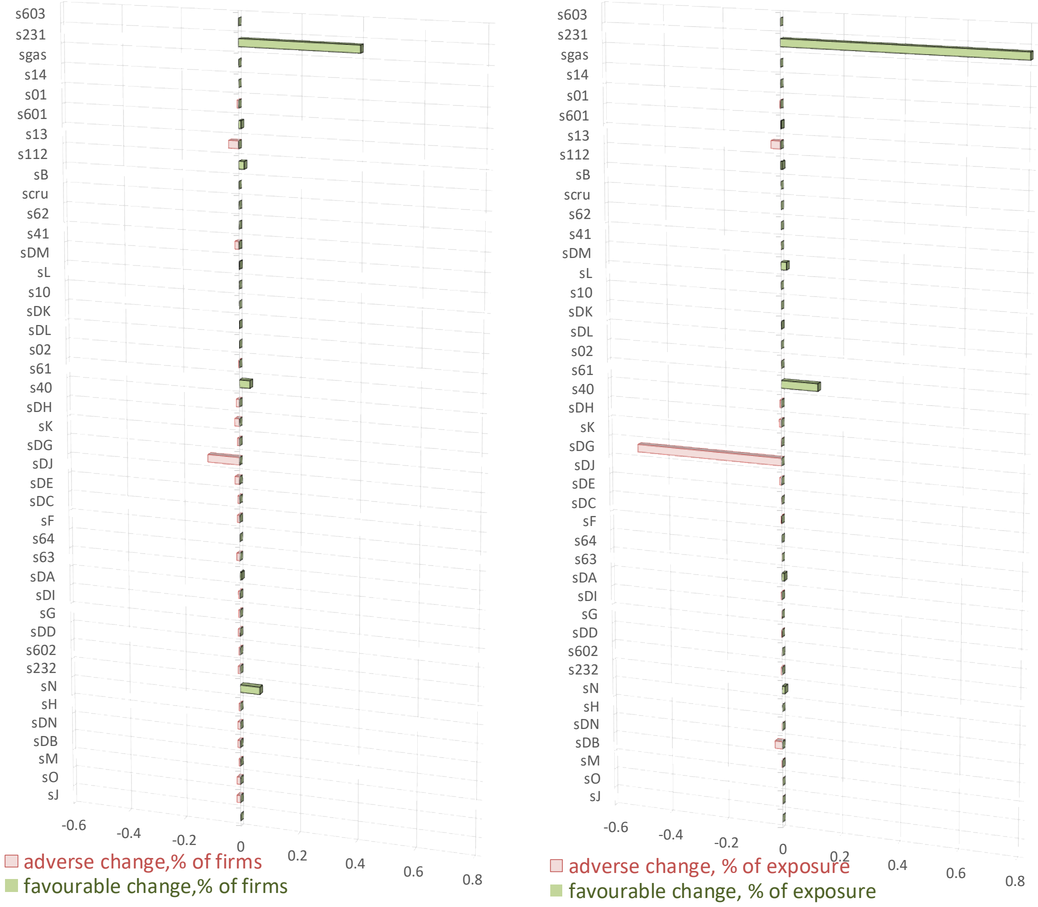
A) Share of firms (firm-ID), % B) Share of sectoral exposure, %



Sources: Bank of Russia, authors' calculations.

Figure 8. Changes in sectoral exposure, *«BAU»* 2050

A) Share of firms (firm-ID), % B) Share of sectoral exposure, %



Sources: Bank of Russia, authors' calculations.

Scenario «*Reference*»

Please refer to Figure 9 for the year 2030 and Figure 10 for the year 2050. The sector Manufacture of wood and wood products (sDD) demonstrated a significant increase (19% in 2030 and 24% in 2050) in exposure falling within the safest range, i.e., the level of DSRs moved from above 100% to within (0,100%]. The number of firms increased by 3% and 5%, respectively. Thus, a smaller number of firms accounting for a greater share in overall sectoral exposure moved into the safest range.

Manufacture of refined petroleum products (s232) shows *favourable* changes in the number of firms by 2030 and 2050: 14% and 15%, respectively. The related share of sectoral exposure is 9% for both time horizons. Thus, favourable changes are observed for firms with a smaller share of sectoral exposure.

The sector Water transport (s61) demonstrated an increase in the number of firms (7% by 2030 and 14% by 2050) and related exposure (14% by 2030 and 16% by 2050) within the safest range. Thus, *favourable* changes in 2030 are demonstrated by firms with a greater share of sectoral exposure, whereas in 2050, firms with a smaller share of debt burden also show a favourable move.

The sector Manufacture of chemicals, chemical products and man-made fibres (sDG) shows an *adverse* move (i.e., from the levels of DSRs within the range of (0,100%] to the levels above 100%) in the number of firms and related exposure:

- by 2030: 8% of firms and 17% of sectoral exposure;
- by 2050: 11% of firms and 50% of sectoral exposure.

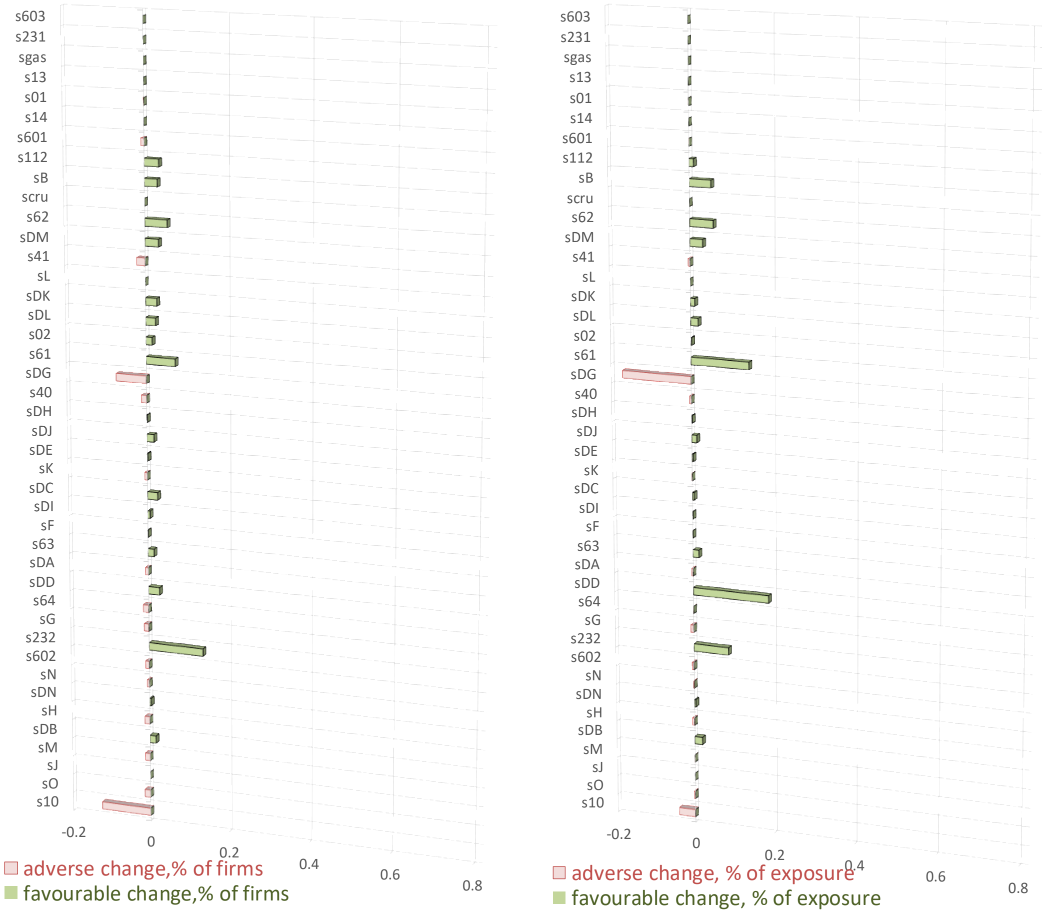
Thus, a more severe effect is observed closer to 2050.

The sector Mining of coal and lignite; extraction of peat (s10) shows an *adverse* move for both time horizons: 13% of firms and 4% of sectoral exposure.

The sector Mining of metal ores (s13) shows a notable *adverse* move only in the scenario by 2050: an 8% increase in the number of firms with the exposure of 7%.

Figure 9. Changes in sectoral exposure, *«Reference»* 2030

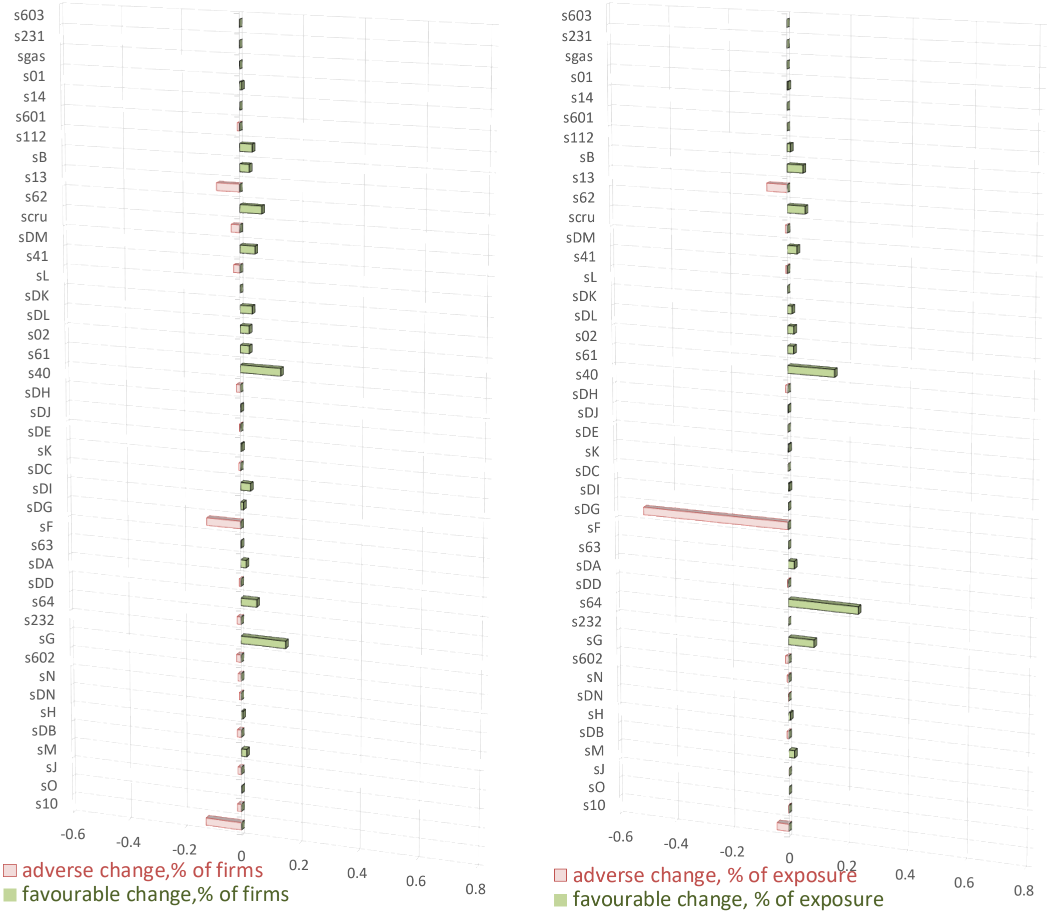
A) Share of firms (firm-ID), % B) Share of sectoral exposure, %



Sources: Bank of Russia, authors' calculations.

Figure 10. Changes in sectoral exposure, *«Reference»* 2050

A) Share of firms (firm-ID), % B) Share of sectoral exposure, %



Source: Bank of Russia, authors' calculations.

Scenario «*Domestic*»

Please refer to Figure 11 for the year 2030 and Figure 12 for the year 2050. The following sectors demonstrated a significant *favourable* change (when the levels of DSRs above 100% moved within the range of (0,100%] as a result of the scenario assumptions by 2030 and 2050, respectively:

- Manufacture of wood and wood products (sDD) – an increase by 3% and 10% in the number of firms, and 19% and 30% in exposure;
- Manufacture of refined petroleum products (s232) – an increase by 12% and 3% in the number of firms, and 9% and 1% in exposure;
- Water transport (s61) – an increase by 7% and 6% in the number of firms, and 14% in exposure; and

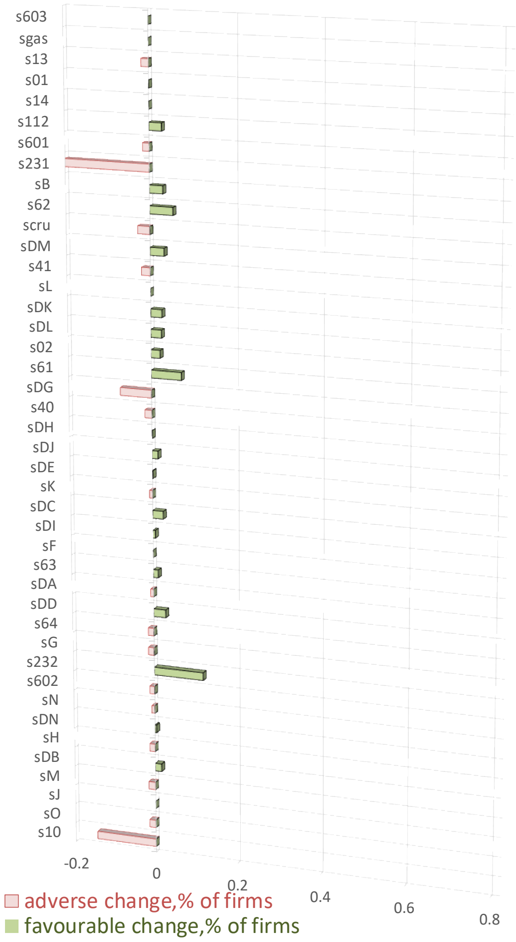
– Manufacture of leather products (sDC) – an increase by 19% in the number of firms, and 16% in exposure, but only in the 2050 scenario.

The following sectors demonstrated a notable *adverse* change (when the levels of DSRs within the range of (0,100%] moved to the levels above 100% because of the scenario assumptions):

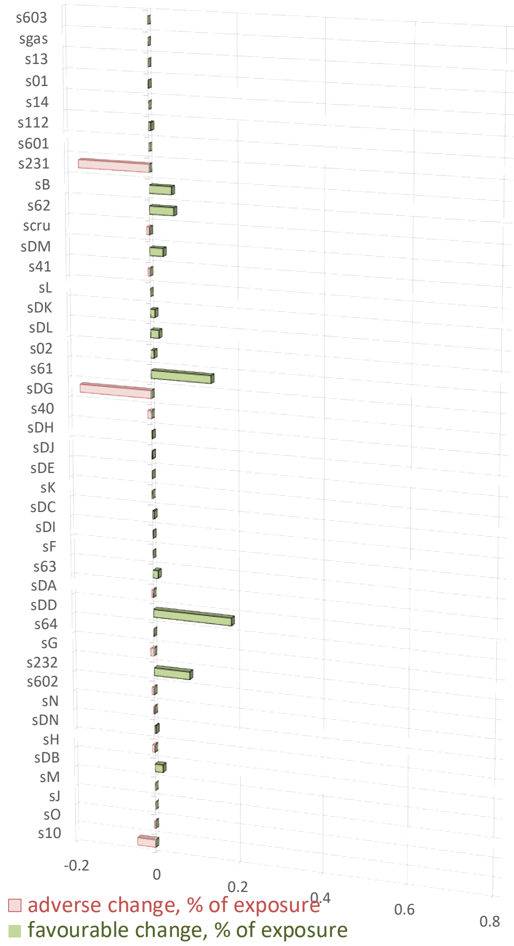
– Manufacture of coke oven products (s231) – an increase by 20% and 60% in the number of firms, and 16% and 19% in exposure;
– Mining of coal and lignite; extraction of peat (s10) – an increase by 15% and 19% in the number of firms, and 5% and 7% in exposure;
– Manufacture of chemicals, chemical products and man-made fibres (sDG) – an increase by 8% and 11% in the number of firms, and 17% and 50% in exposure;
– Extraction of crude petroleum (scru) – an increase by 3% and 15% in the number of firms, and 1% and 4% in exposure by 2030 and 2050;
– Extraction of natural gas (sgas) – an increase by 38% in the number of firms, and 71% in exposure (in the 2050 scenario only); and
– Mining of metal ores (s13) – an increase by 15% in the number of firms, and 16% in exposure (in the 2050 scenario only).

Figure 11. Changes in sectoral exposure, «*Domestic*»2030

A) Share of firms (firm-ID), %



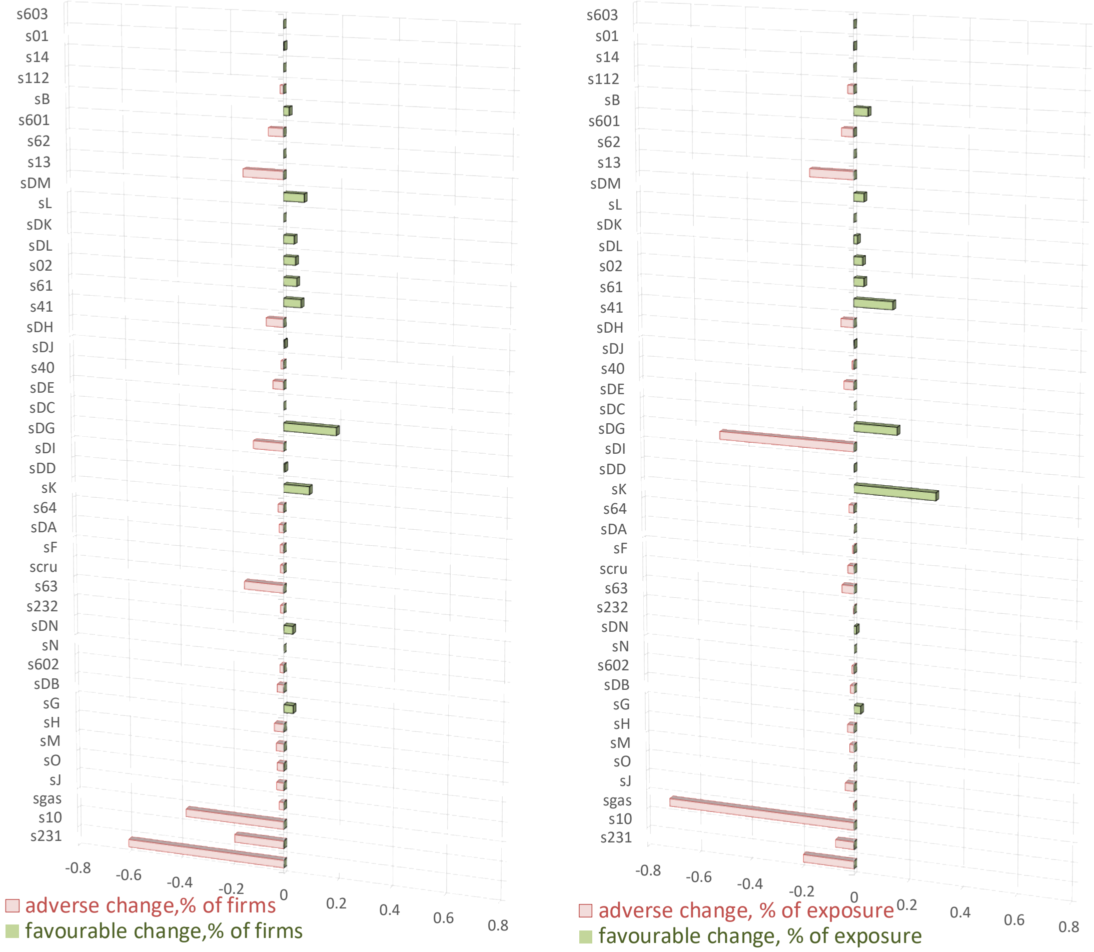
B) Share of sectoral exposure, %



Sources: Bank of Russia, authors' calculations.

Figure 12. Changes in sectoral exposure, «*Domestic*» 2050

A) Share of firms (firm-ID), % B) Share of sectoral exposure, %



Sources: Bank of Russia, authors' calculations.

Implications

The granularity of data makes it possible to measure the concentration of sectoral exposure (debt burden) within each sector and across sectors of the economy. Considering the uncertainty of a future transition path, exposure-at-risk is reported for aggregate sectors only (Table 3; overall, 42 sectors of the economy).

In terms of their comparability with stress tests conducted by other central banks, the results could be useful to compare different metrics of banks' sectoral exposure, e.g., DSR vs ICR.

This satellite exercise could serve as a reference point in assessing sectoral exposure during transition. The results could also help evaluate a possible impact of different scenarios on sectoral exposures. The current understanding of the existing credit exposure and a better understanding of exposure-at-risk can improve the awareness about additional burden on banks' equity. It is worth mentioning though that the set of scenarios is not exhaustive. Nevertheless, the results could serve to set the basis for a further discussion in this area.

Disaggregated results might be used to estimate potential losses in a stand-alone assessment. The main challenge is to measure the evolution of exposure over a long-term horizon. A rise in risks could adversely affect firms, particularly their ability to service bank loans. Developing new insights might be helpful in testing the resilience of the banking system facing transition risk.

6.4. Approach to assessing market risk

The estimates of industries' outputs simulated by the CGE model in various climate scenarios can be used to assess transition-related market risks of financial institutions. The most straightforward way to estimate the impacts of changes in climate policy on sectors' equity valuation is to use the Dividend Discount Model (DDM, see ECB/ESRB 2021; Hosseini et al., 2022). According to the discount dividend model, equity value ($\boldsymbol{P_{i,t}}$) for sector ***i*** at time ***t*** is a linear function of future dividend flows ($\boldsymbol{Div_{i,t+s}}$):

Equation 3

$$P_{i,t} = \sum_{s}^{T} \frac{Div_{i,t+s}}{(1+r)^s}$$

While sectoral dividend flows are not usually generated by the CGE model, they can be viewed as proportional to sectoral value added (VA) for the year under review. ***r*** is a risk-free rate.

Given that changes in global climate policy are credible, economic agents incorporate them immediately into their equity valuations. As an assumption about the foresight of economic agents, one can suggest, for example, that economic agents might foresee the impact of climate policy on dividend flows over a 10-year horizon.

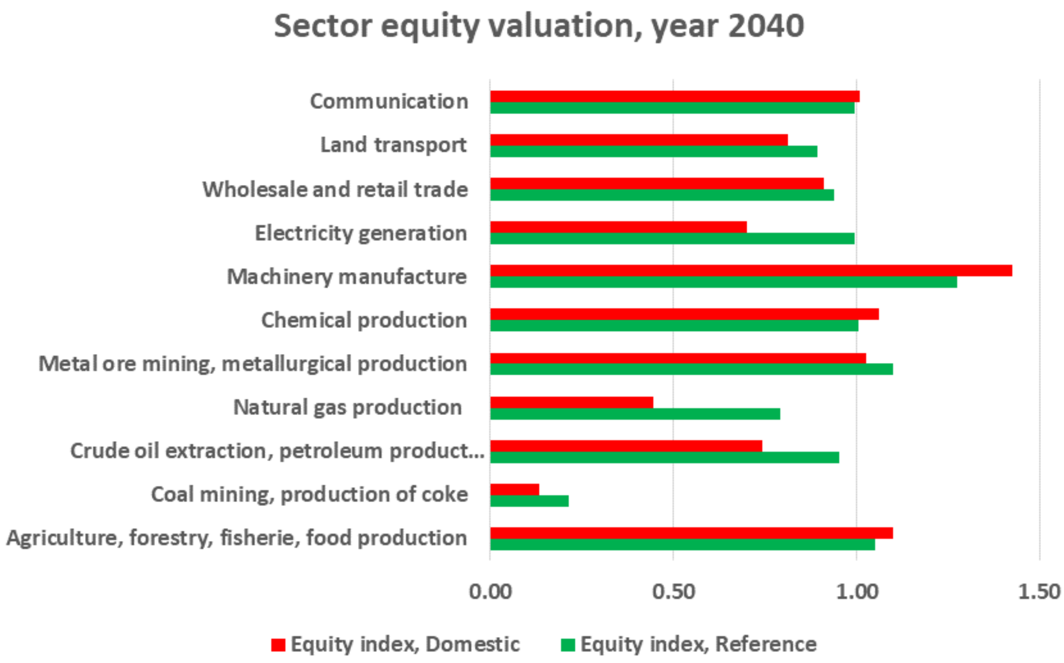
We apply the above approach to estimate equity values for 11 main large sectors of the Russian economy under two scenarios, namely *«Reference»* and *«Domestic»*. As we are interested in the effects of changes in climate policies on valuations, we calculate the ratios of equity valuations in the climate policy scenarios relative to that one in the *«BAU»* scenario (*Equity index*$_{i,t}$):

Equation 4

$$Equity\ Index^{reference}{}_{i,t} = \frac{P_{i,t}^{reference}}{P_{i,t}^{BAU}},\ Equity\ Index^{domestic}{}_{i,t} = \frac{P_{i,t}^{domestic}}{P_{i,t}^{BAU}}$$

Figure 13 shows equity valuations for the year 2040. The most negative effects are likely to be observed for the coal, crude oil, and natural gas sectors. Machinery manufacturing experiences a certain increase in equity valuation.

Figure 13. Equity indices for 2040



Sources: Bank of Russia, authors' calculations.

7. Conclusions

In this paper, we presented an approach to assessing consequences of climate policy in Russia and evaluating the associated transition risks for the country's financial system. To do this, we used a CGE model for the Russian economy and a financial model based on firm-level data. We show that both international and domestic climate policies affect financial stability of the Russian Federation. The effects of international climate actions, summarised in the NGFS's Net Zero 2050, are greater than the effects of the introduction of a domestic emission trading system with a reduction goal set under the «*Intensive»* scenario of the Russian state strategy of low-carbon development.

We estimate the possible costs for achieving the goals provided for in the «*Intensive»* scenario of the Russian low-carbon strategy to be 0.3% in 2030 and 3.0% in 2050 of the decrease in real GDP to the benchmark level, given that a cap-and-trade mechanism is introduced promptly (in 2023). If the emission reduction target is raised, as modelled in our alternative scenarios of intensive and delayed domestic climate policy, the economic burden of climate actions may increase significantly as we approach 2050. If the goal is to reduce emissions from fuel combustion by 75% from the 2016 level, without any additional influence of changes in export prices, it might cost 9.2% of the benchmark level of GDP in 2050. We need to draw readers' attention to the fact that we are holding fixed the stock of factors in all our simulations and we do not model the introduction of new technologies or new products in this research.

In addition, all our domestic climate policy scenarios are based on the assumption that the government revenues from carbon tax are transferred to households, while investment is fixed at its benchmark year level. Alternatively, we may consider a steady-state model where the mobile capital stock and investment demand are endogenously determined, while the price of capital is constant. In the steady-state model, we may assume that the government revenues from carbon tax payments fully translate into an investment increase. Modelling this scenario can be one of the directions for future research.

Moreover, directions for future research may include climate policy scenarios with carbon border adjustment taxes levied by groups of Russia's trade partners on carbon content of imports from the country.

The granularity of data in the financial model makes it possible to evaluate the concentration of sectoral exposure (debt burden) within each sector and across sectors of the economy. Comparing the results of the «*Reference»* and «*Domestic»* scenarios, we can see that firms' and industries' financial positions may be rather sensitive to the introduction of climate policy. Adverse effects are likely to be concentrated in the extraction and fuel sectors and in chemical production. Industries that might gain the most from changes in relative prices and experience favourable changes in sectoral exposure are wood processing, forestry, light and machinery manufacturing. The results of the financial model are corroborated by the market risk evaluation model, stating that the most negative effects for equity valuations are observed in the coal, crude oil and natural gas sectors, while machinery manufacturing experiences sizeable gains in equity valuation.

Significant economic costs of an intensive reduction in emissions arise when only one policy measure is implemented, namely a cap-and-trade mechanism. Our analysis highlights the importance of diversifying climate policy tools, including by increasing the sink capacity of lands and forests through innovative and active forest management and introducing carbon farming, curbing technological emissions and leaks.

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Appendix I. Data and parametrisation

Industry list

Table 4. List of industries

No.	Model code	Industry name
1	s01	agriculture, hunting and related service activities
2	s02	forestry, logging and related service activities
3	sB	fishing
4	s10	mining of coal and lignite; extraction of peat
5	scru	extraction of crude petroleum
6	sgas	extraction of natural gas
7	s112	service activities incidental to oil and gas extraction, excluding surveying
8	s13	mining of metal ores
9	s14	other mining and quarrying
10	sDA	manufacture of food products, beverages and tobacco
11	sDB	manufacture of textiles and textile products
12	sDC	manufacture of leather and leather products
13	sDD	manufacture of wood and wood products
14	sDE	manufacture of pulp, paper and paper products; publishing and printing
15	s231	manufacture of coke oven products
16	s232	manufacture of refined petroleum products
17	sDG	manufacture of chemicals, chemical products and man-made fibres
18	sDH	manufacture of rubber and plastic products
19	sDI	manufacture of other non-metallic mineral products
20	sDJ	manufacture of basic metals and fabricated metal
21	sDK	manufacture of machinery and equipment n.e.c.
22	sDL	manufacture of electrical and optical equipment
23	sDM	manufacture of transport equipment
24	sDN	manufacturing n.e.c.
25	s40	electricity, gas, steam and hot water supply
26	s41	collection, purification and distribution of water
27	sF	construction
28	sG	wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
29	sH	hotels and restaurants
30	s601	transport via railways
31	s602	other land transport
32	s603	transport via pipelines
33	s61	water transport
34	s62	air transport
35	s63	supporting and auxiliary transport activities
36	s64	post and telecommunications
37	sJ	financial intermediation
38	sK	real estate, renting and business activities

No.	Model code	Industry name
39	sL	public administration and defence; compulsory social security
40	sM	education
41	sN	health and social work
42	sO	other community, social and personal service activities

Source: authors.

Table 5. List of commodities

No.	Code	Commodity group
1	g01	agriculture, hunting and these services
2	g02	forestry and provision of services in the field
3	woo	wood
4	gB	fisheries, fish farming and the provision of services in these areas
5	col	coal, brown coal and peat
6	cru	crude oil and oil (associated) gas; extraction of fractions from oil (associated) gas 11.10.1
7	gas	production of natural gas and gas condensate 11.10.2 + 11.10.3
8	g112	provision of oil and gas production services 11.2
9	g12	mining of uranium and thorium ore
10	ore	metal ore mining
11	g14	mining of other minerals
12	gDA	food production including beverages and tobacco
13	gDB	textile and clothing production
14	gDC	leather, leather goods and shoes
15	gDD	wood processing and production from wood
16	pap	paper
17	gDE	pulp and paper production; publishing and printing
18	cke	coke
19	oil	petroleum products
20	gDG	chemical production
21	ior	other chemical inorganic basic substances
22	org	other basic organic chemical substances
23	frt	fertilisers and nitrogen compounds
24	gDH	production of rubber and plastic products
25	gDI	manufacturing of other non-metallic mineral products
26	cmn	cement, lime and gypsum
27	stl	iron, cast iron, steel and ferroalloys
28	pps	pipes and pipeline connecting elements
29	fmp	other products of primary processing of ferrous metals
30	pmt	precious metals
31	alu	aluminium and aluminium products
32	lzt	lead, zinc, tin and products thereof
33	cop	copper products
34	nfe	products from other non-ferrous metals
35	gDJ	metallurgical production and production of finished metal products
36	gDK	manufacture of machinery and equipment
37	gDL	manufacture of electrical, electronic and optical equipment
38	gDM	manufacture of vehicles and equipment
39	gDN	other products
40	ele	electricity

No.	Code	Commodity group
41	cag	combustible artificial gases
42	g40	generation, transmission and distribution of electricity, gas, steam and hot water
43	g41	collection, cleaning and distribution of water
44	gF	building
45	gG	wholesale and retail trade; repair of vehicles, motorcycles, household and personal items
46	gH	hotels and restaurants
47	g601	railway transport activities
48	g602	activities of other land transport
49	g603	transportation through pipelines
50	g61	water transport activities
51	g62	air transport activities
52	g63	support and additional transport activities
53	g64	communication
54	gJ	financial intermediation
55	gK	real estate operations, rentals and services
56	gL	state administration and military security; mandatory social security
57	gM	education
58	gN	health and social service provision
59	gO	provision of other public, social and personal services

Source: authors.

Table 6. CO2 emission factors used to calculate emissions from combustion of different fuels accounted for in Form No. 4-TER (kg CO2/TJ)

Fuel type in Form No. 4-TER	Fuel type in the National Inventory Report	CO2 emission factors [kg CO2 /TJ]
Coal	Hard coal (other types of bituminous coal)	94,600
Brown coal	Lignite	101,000
Peat	Peat	106,000
Briquettes and semi-briquettes peat	Peat briquettes*	106,000
Fuel wood	Firewood for heating	112,000
Metallurgical coke from coal obtained by carbonisation at high temperature, dry coke nuts, dry coke fines	Metallurgical coke*	107,000
Oil produced, including gas condensate	Oil, including field gas condensate	73,300
Aviation gasoline for aircraft piston engines	Aviation gasoline	70,000
Motor Gasoline	Motor gasoline	69,300
Diesel fuel	Diesel fuel	74,100
Motor fuel for marine diesel engines	Other motor fuels	71,900
Domestic stove fuel	Domestic stove fuel	77,400
Gas turbine fuel	Other petroleum products	73,300
Fuel oil	Fuel oil	77,400
Navy fuel oil	Navy fuel oil	77,400
Fuel oil, not included in other groups, other	Other petroleum products	73,300
Other liquefied propane and butane, hydrocarbon gases and mixtures thereof, liquefied, not included in other groups	Liquefied petroleum gases	63,100
Gas refineries	Gas refineries	57,600
Combustible natural gas (natural gas)	Natural gas	54,400
Associated petroleum gas (combustible natural gas of oil fields)	Natural gas condensate*	64,200
Combustible artificial blast-furnace gas and other waste gases	Combustible artificial blast-furnace gas	260,000
Combustible artificial coke oven gas	Combustible artificial coke oven gas	44,400
Other solid fuels	Industrial waste	143,000
Other types of petroleum products	Oil waste*	73,300

Source: NIR data (Romanovskaya et al. 2022)

Table 7. CH4 and N2O emission factors used to calculate emissions from stationary combustion of different fuels accounted for in Form No. 4-TER (kg CH4/TJ, kg N2O /TJ)

	Fuel type in Form No. 4-TER	**CH4 emission factors [kg CH4/TJ]**				**N2O emission factors [kg N2O/TJ]**			
		Energy industries	Manufacturing and construction	Commercial/ institutional	Residential and agriculture / forestry/fishing	Energy industries	Manufacturing industries and construction	Commercial/ institutional	Residential and agriculture/ forestry/fishing
1	Coal	1	10	10	300	1.5	1.5	1.5	1.5
2	Brown coal	1	10	10	300	1.5	1.5	1.5	1.5
3	Peat	1	2	10	300	1.5	1.5	1.4	1.4
4	Briquettes and semi-briquettes peat	1	2	10	300	1.5	1.5	1.4	1.4
5	Fuel wood	30	30	300	300	4	4	4	4
6	Metallurgical coke from coal obtained by carbonisation at high temperature, dry coke nuts, dry coke fines	1	10	10	300	1.5	1.5	1.5	1.5
7	Oil produced, including gas condensate	3	3	10	10	0.6	0.6	0.6	0.6
8	Aviation gasoline for aircraft piston engines	3	3	10	10	0.6	0.6	0.6	0.6
9	Automobile gasoline	3	3	10	10	0.6	0.6	0.6	0.6
10	Diesel fuel	3	3	10	10	0.6	0.6	0.6	0.6
11	Motor fuel for marine diesel engines	5	5	5	5	0.6	0.6	0.6	0.6
12	Domestic stove fuel	3	3	10	10	0.6	0.6	0.6	0.6
13	Gas turbine fuel	3	3	10	10	0.6	0.6	0.6	0.6
14	Fuel oil	3	3	10	10	0.6	0.6	0.6	0.6
15	Navy fuel oil	3	3	10	10	0.6	0.6	0.6	0.6
16	Fuel oil, not included in other groups, other	3	3	10	10	0.6	0.6	0.6	0.6
17	Other liquefied propane and butane, hydrocarbon gases and mixtures thereof, liquefied, not included in other groups	1	1	5	5	0.1	0.1	0.1	0.1
18	Gas refineries	3	3	10	10	0.6	0.6	0.6	0.6
19	Combustible natural gas (natural gas)	1	1	5	5	0.1	0.1	0.1	0.1
20	Associated petroleum gas (combustible natural gas of oil fields)	3	3	10	10	0.6	0.6	0.6	0.6
21	Combustible artificial blast-furnace gas and other waste gases	1	1	5	5	0.1	0.1	0.1	0.1
22	Combustible artificial coke oven gas	1	1	5	5	0.1	0.1	0.1	0.1
23	Other solid fuels	30	30	300	300	4	4	4	4
24	Other types of petroleum products	30	30	300	300	4	4	4	4

Source: NIR data (Romanovskaya et al. 2022)

Table 8. Conversion factors of natural units into energy units by type of fuel (thsd tce/unit)

	Fuel type in Form No. 4-TER	Units	Conversion factors of natural units into tce [thousand tce/unit]
1	Aviation gasoline for aircraft piston engines	thousand tons	1.49
2	Automobile gasoline	thousand tons	1.49
3	Kerosene, including kerosene jet	thousand tons	1.47
4	Diesel fuel	thousand tons	1.45
5	Motor fuel for marine diesel engines	thousand tons	1.43
6	Domestic stove fuel	thousand tons	1.45
7	Gas turbine fuel	thousand tons	1.47
8	Fuel oil	thousand tons	1.37
9	Navy fuel oil	thousand tons	1.43
10	Fuel oil, not included in other groups, other	thousand tons	1.43
11	Combustible natural gas (natural gas)	million m^3	1.15
12	Associated petroleum gas (combustible natural gas of oil fields)	million m^4	1.15
13	Other liquefied propane and butane, hydrocarbon gases and mixtures thereof, liquefied, not included in other groups	million m^5	1.57
14	Other types of petroleum products	thousand tons	1

Source: Ministry of Natural Resources of Russia.

Table 9. CH4 and N2O emission factors used to calculate emissions from mobile combustion of different fuels accounted for in Form No. 4-TER (kg CH4/TJ, kg N2O /TJ)

	Petrol	Diesel fuel	Fuel oil	Natural gas	Liquefied petroleum gas	Coal	Other liquid motor fuel
CH4 Emission Factors [kg CH4/TJ]							
Agriculture, hunting & forestry	110	4.15		92	62		10
Navigation		7	7				
Railway transport		4.15					
Aviation	0.5						
Pipeline transport				1	1		3
Road transportation	13.4	4.99			62		
Cars & light duty trucks	11.4	0.8			62.0		5.0
N2O Emission Factors [kg N2O/TJ]							
Agriculture, hunting & forestry	1.2	29		3	0.2		0.6
Navigation		2	2				
Railway transport		28.6				1.5	
Aviation	2						
Pipeline transport				0.1	0.1		0.6
Road transportation	1.87	1.79			2.89		
Cars & light duty trucks	2.6	2.4			1.8		0.6

Source: Ministry of Natural Resources of Russia.

Table 10. Aggregate estimate of greenhouse gas emissions from stationary and mobile combustion in 2016 using Form No. 4-TER (million tons of CO2 equivalent)

Stationary combustion	
Estimated CO2 emissions	1,031.5
Estimated CO2-eq emissions (from CH_4)	1.3
Estimated CO2-eq emissions (from N_2O)	2.3
Mobile combustion	
Estimated CO2 emissions	166.8
Estimated CO2-eq emissions (from CH_4)	0.6
Estimated CO2-eq emissions (from N_2O)	3.3
Total CO2 – equivalent	***1,205.8***

Sources: Ministry of Natural Resources of Russia, authors' calculations.

Table 11. Benchmark emissions from combustion by fuel type in 2016, mln tCO2e

	Industry	**Coal**	**Natural gas**	**Coking coal**	**Petroleum products**	**Distributed gas**	***Industry's total***
s01	agriculture	0.86			14.67	5.22	*20.76*
s02	forestry	0.44			1.75	0.04	*2.23*
sB	fisheries	0.02			3.33	0.00	*3.35*
s10	coal & peat mining	2.82			4.93	0.10	*7.85*
scru	extraction of crude petroleum	0.00	10.64		3.43	7.28	*21.35*
sgas	natural gas		5.81		0.29	7.45	*13.55*
s112	oil & gas services		0.14		3.17	4.34	*7.65*
s13	mining of metal ores	1.53		0.80	5.88	3.26	*11.47*
s14	other mining				2.48	0.29	*2.76*
sDA	food & tobacco	2.00		0.02	3.37	9.11	*14.49*
sDB	textile products	0.02			0.06	0.41	*0.50*
sDC	leather products	0.00			0.01	0.07	*0.08*
sDD	wood products	5.64			0.74	1.19	*7.58*
sDE	pulp & paper	18.00			1.88	6.72	*26.60*
s231	coke oven products				0.01	1.23	*1.24*
s232	petroleum products	2.47	5.30	0.04	28.93	2.31	*39.06*
sDG	chemicals	0.59		0.01	1.44	22.39	*24.43*
sDH	rubber & plastics	0.00			0.14	0.71	*0.85*
sDI	non-metallic mineral products	3.60			2.75	15.18	*21.53*
sDJ	metallurgy	11.05		75.50	2.39	70.67	*159.62*
sDK	machinery & equipment	5.07		0.00	1.00	5.98	*12.04*
sDL	electrical equipment	0.05		0.00	0.35	1.52	*1.92*
sDM	vehicles & equipment	1.12		0.01	1.26	3.62	*6.01*
sDN	other products	0.24		0.00	0.25	0.12	*0.61*
s40	electricity	213.80	221.55		20.00	143.81	*599.18*
s41	water	0.39			1.00	0.99	*2.38*
sF	construction	0.43			26.99	0.86	*28.29*
sG	trade	0.08	0.12		4.29	0.10	*4.59*
sH	hotels & restaurants	0.14			0.68	0.11	*0.92*
s601	railway	0.31			8.23	0.29	*8.83*
s602	other land transport	0.21			15.43	0.58	*16.21*
s603	pipelines		14.13		1.06	69.78	*84.97*
s61	water transport	0.02			2.50	0.02	*2.54*
s62	air transport	0.01			17.30	0.06	*17.37*
s63	other transport activities	0.48	0.03	0.00	6.84	0.90	*8.25*
s64	communication	0.10			0.58	0.08	*0.76*

	Industry	Coal	Natural gas	Coking coal	Petroleum products	Distributed gas	*Industry's total*
sJ	finance				0.68	0.00	*0.68*
sK	real estate	0.35		0.00	4.28	3.24	*7.87*
sL	public administration	2.31		0.00	5.83	2.13	*10.27*
sM	education	0.41			1.00	0.48	*1.89*
sN	health & social security	0.49			1.72	0.86	*3.07*
sO	personal services	0.50			1.48	0.36	*2.35*
c	households	4.90			46.02	69.11	*120.03*
i	investment	2.05			8.12		*10.17*
g	government	0.00			0.00	12.85	*12.86*
	Total by fuel type	***282.52***	***257.74***	***76.38***	***258.54***	***475.83***	***1,351.00***

Source: authors' calculations.

Table 12. Emission factors by fuel type, kgCO2/RUB

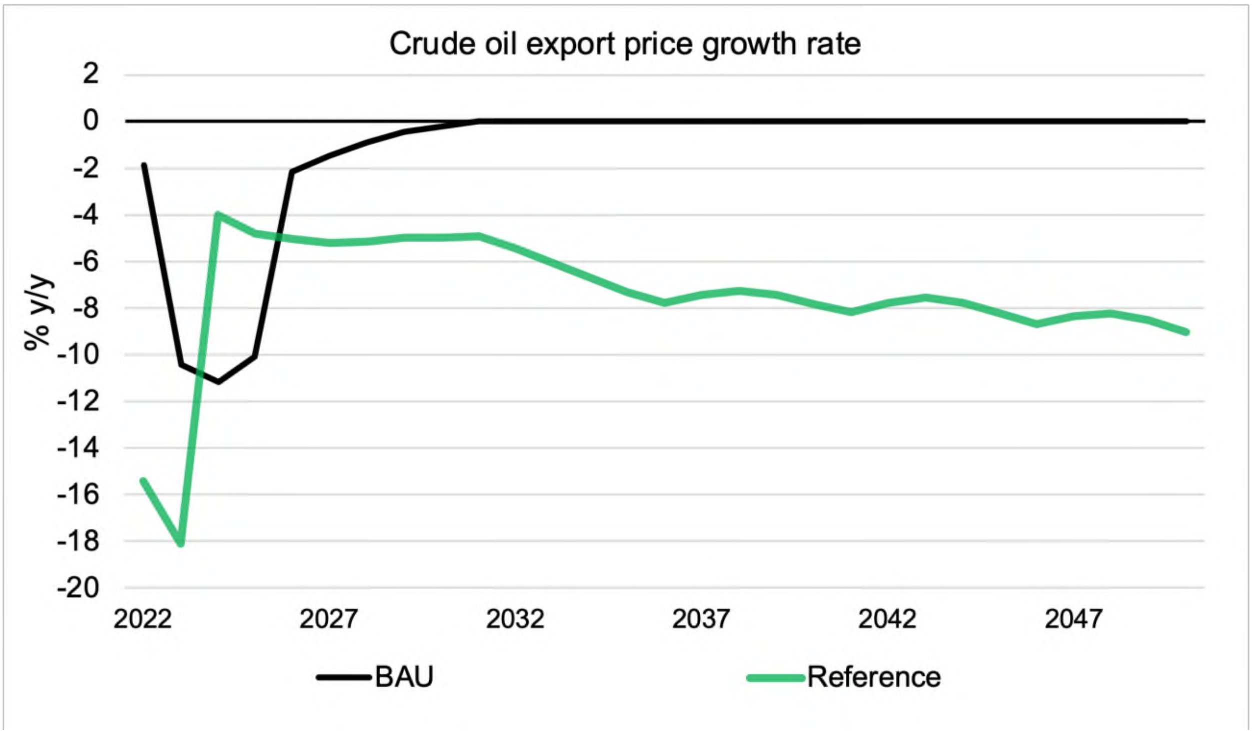
	Industrial emissions from combustion, mln tCO2e	Intermediate consumption, bln RUB	Emission factor, kg CO2e/RUB
Coal	275.56	505.05	0.55
Natural gas	257.74	844.49	0.31
Coking coal	76.38	96.69	0.79
Petroleum products	204.39	3,464.09	0.06
Manufactured and distributed gas	393.87	1,220.87	0.32

Source: authors' calculations.

Appendix II. Simulations design

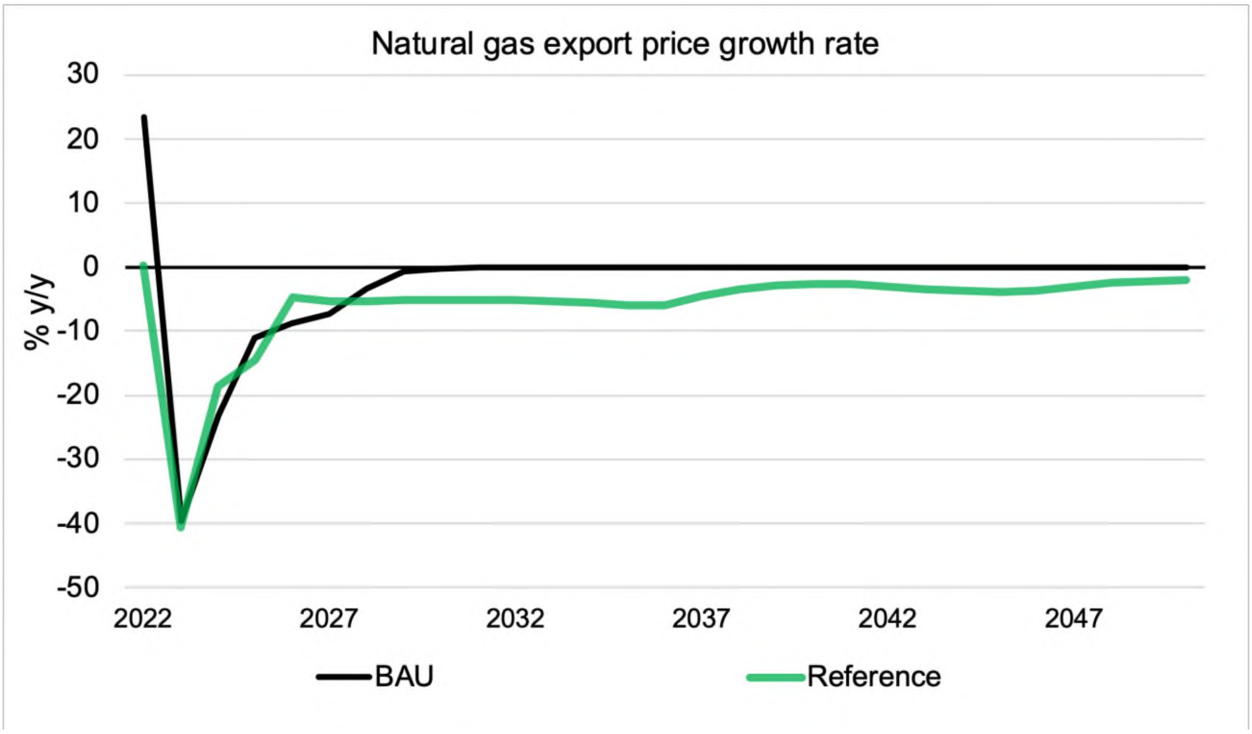
Changes in export prices under *«BAU»* and climate scenarios

Figure 14. Crude oil export price growth rate, % YoY



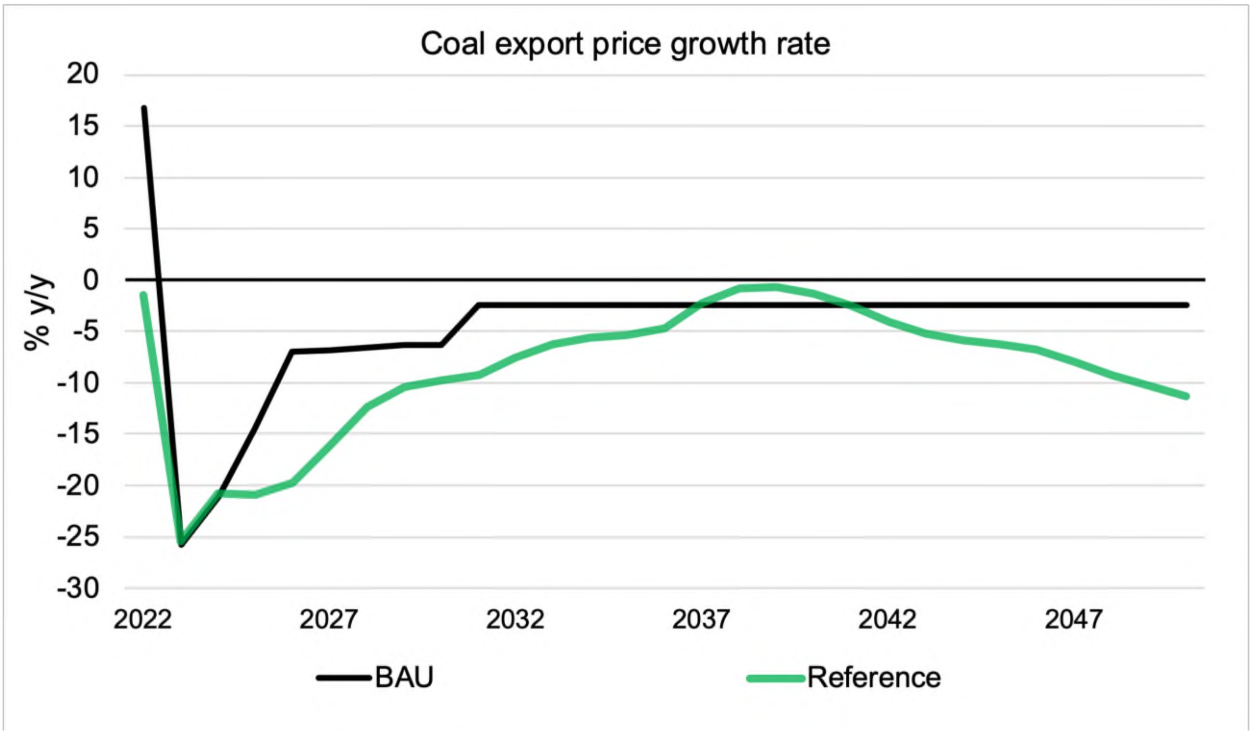
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 15. Natural gas export price growth rate, % YoY



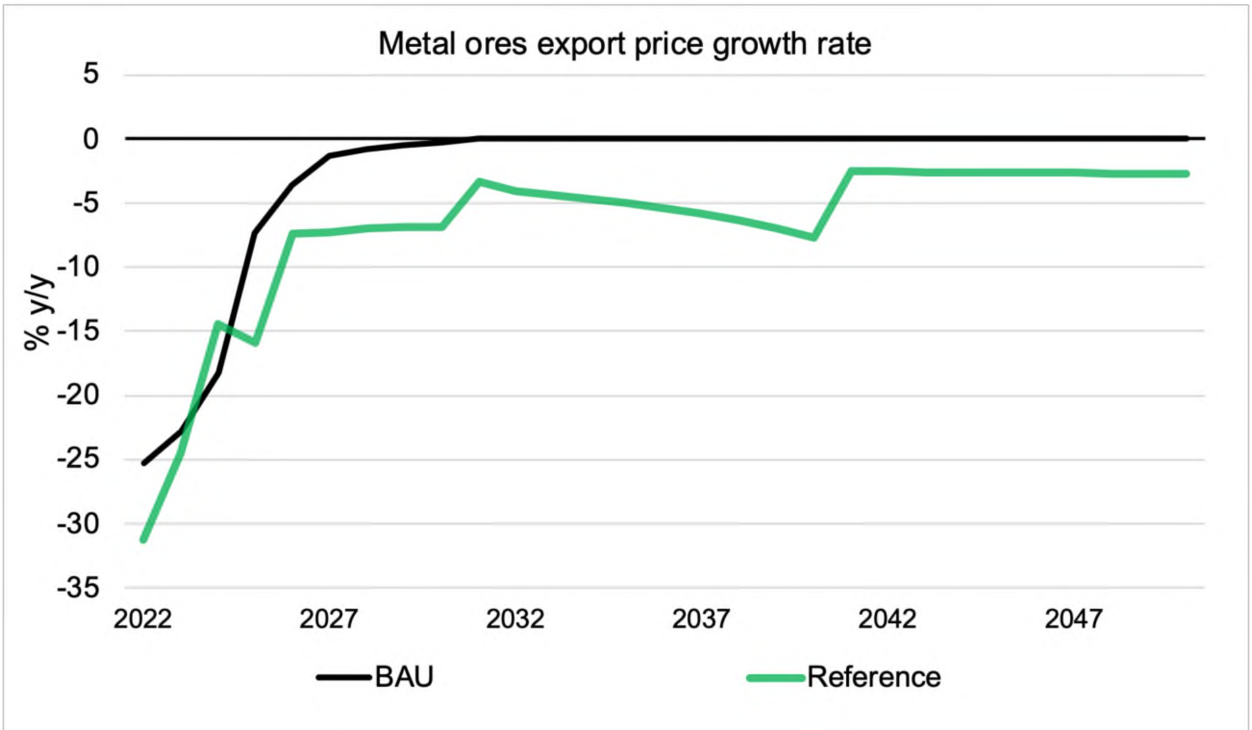
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 16. Coal export price growth rate, % YoY



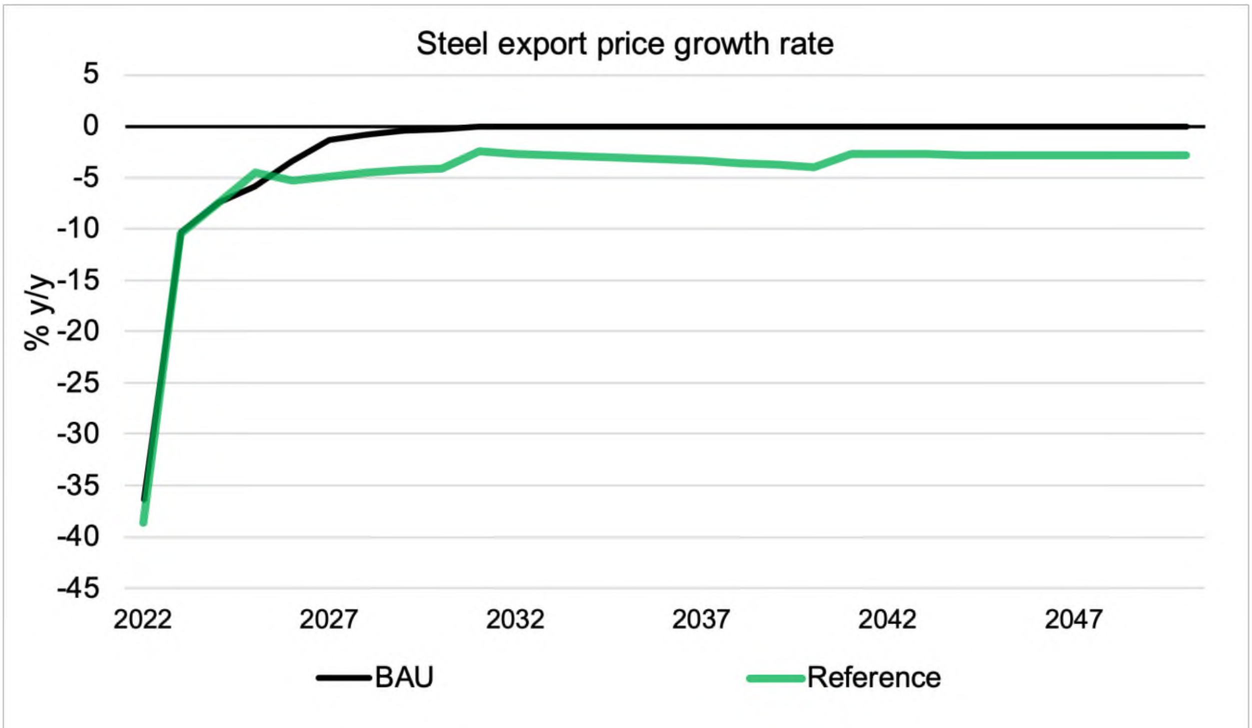
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 17. Metal ores export price growth rate, % YoY



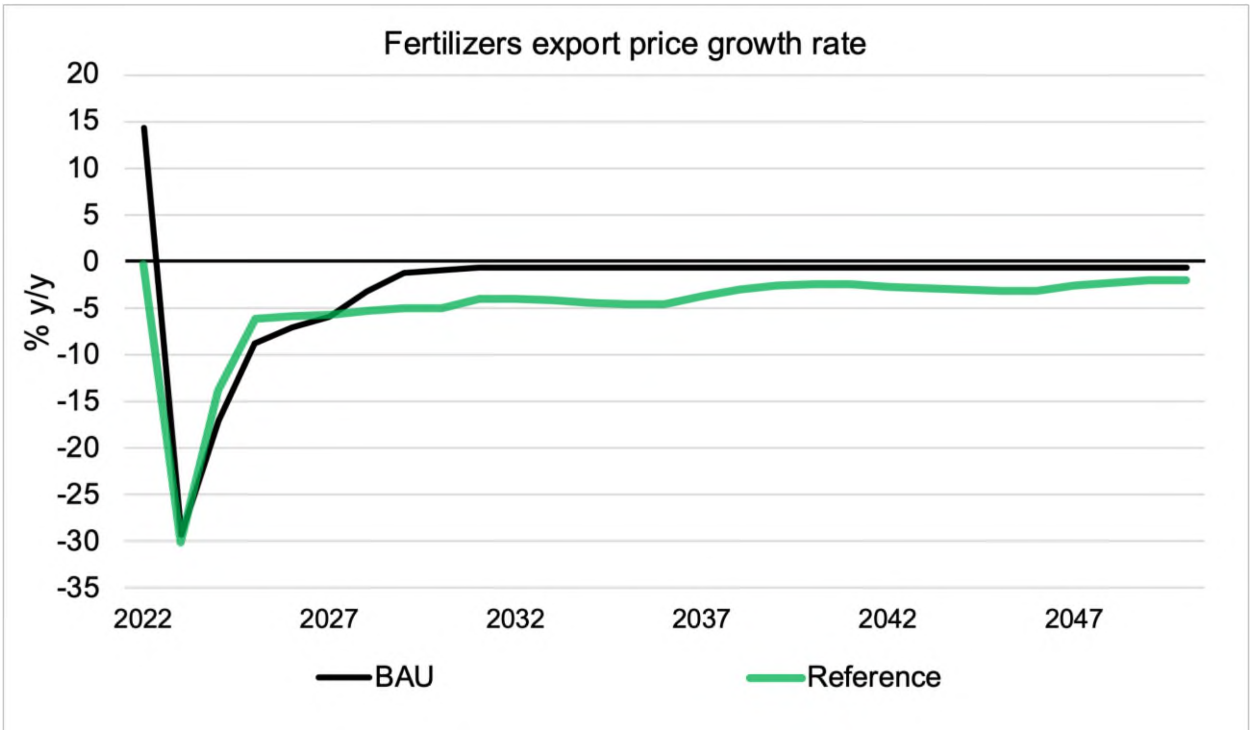
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 18. Steel export price growth rate, % YoY



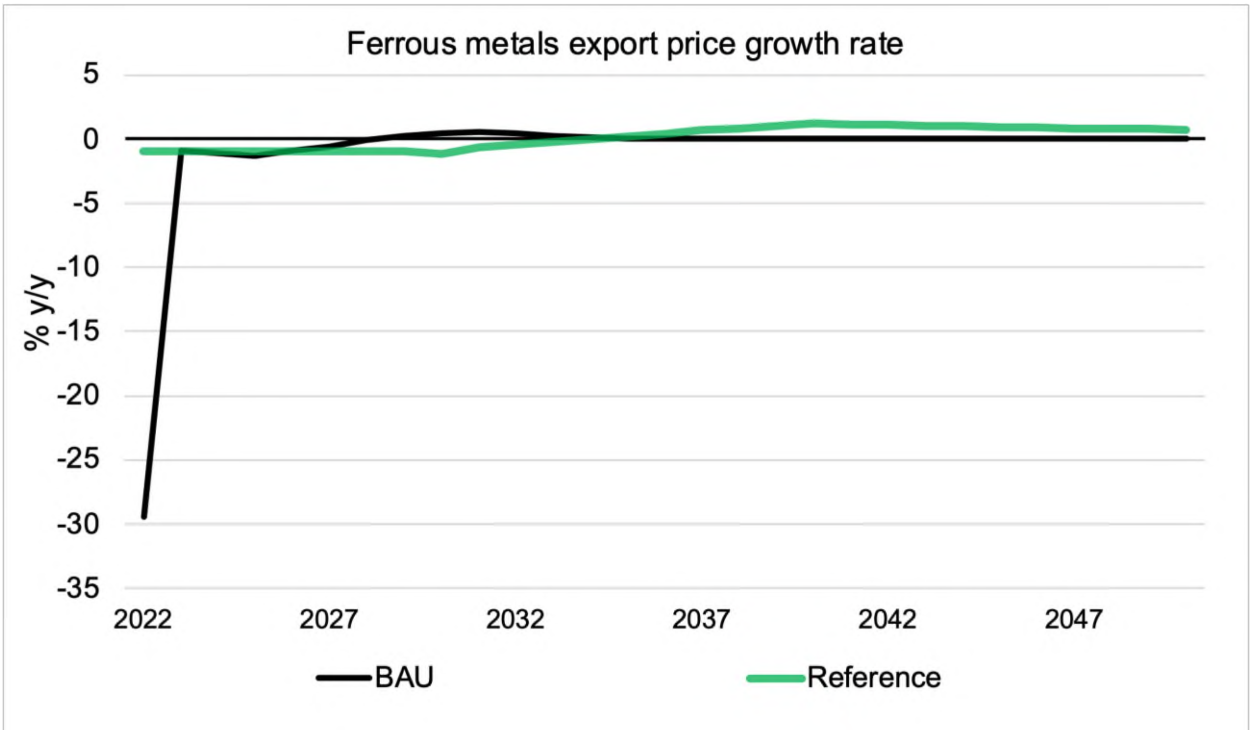
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 19. Fertilisers export price growth rate, % YoY



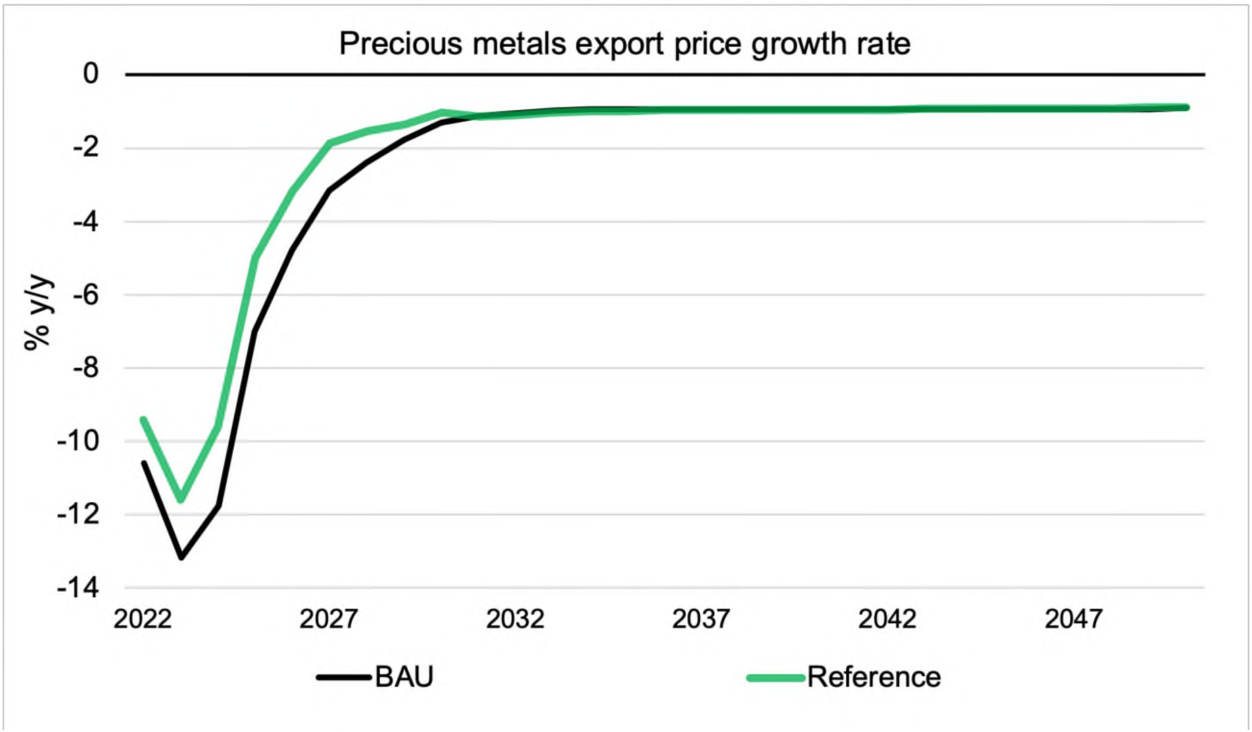
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 20. Non-ferrous metals export price growth rate, % YoY



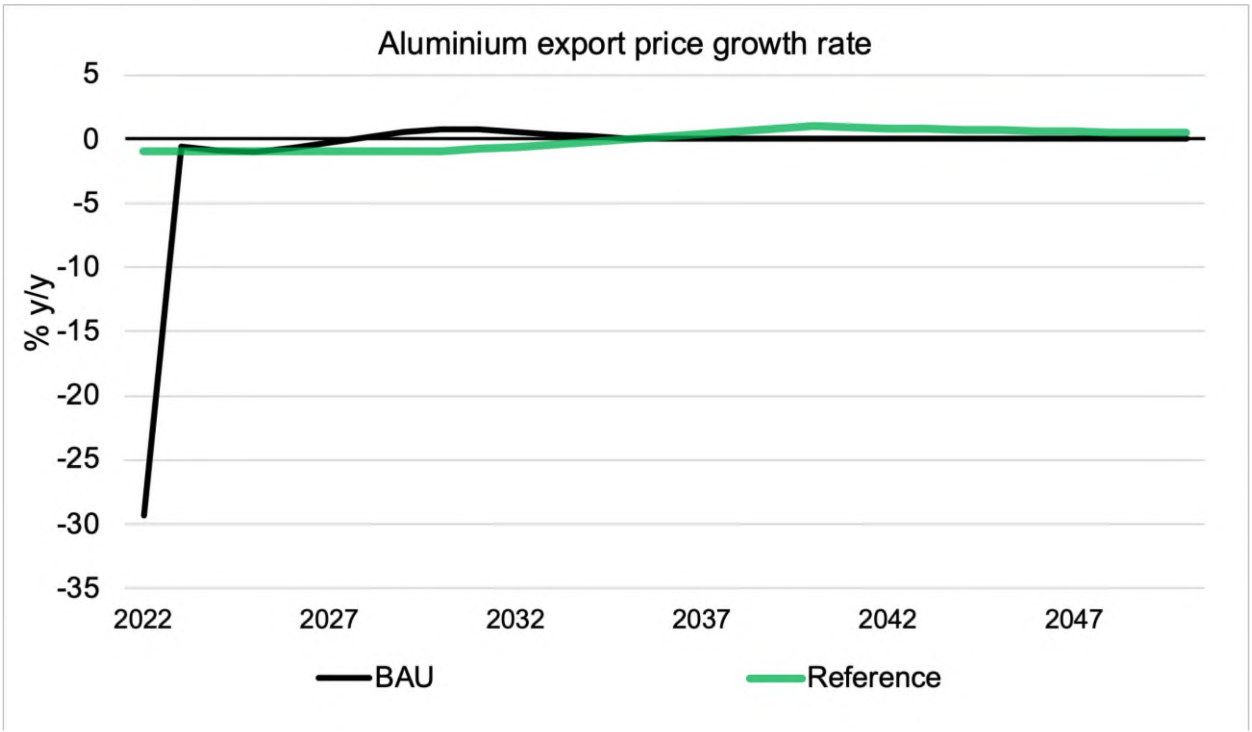
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 21. Precious metals export price growth rate, % YoY



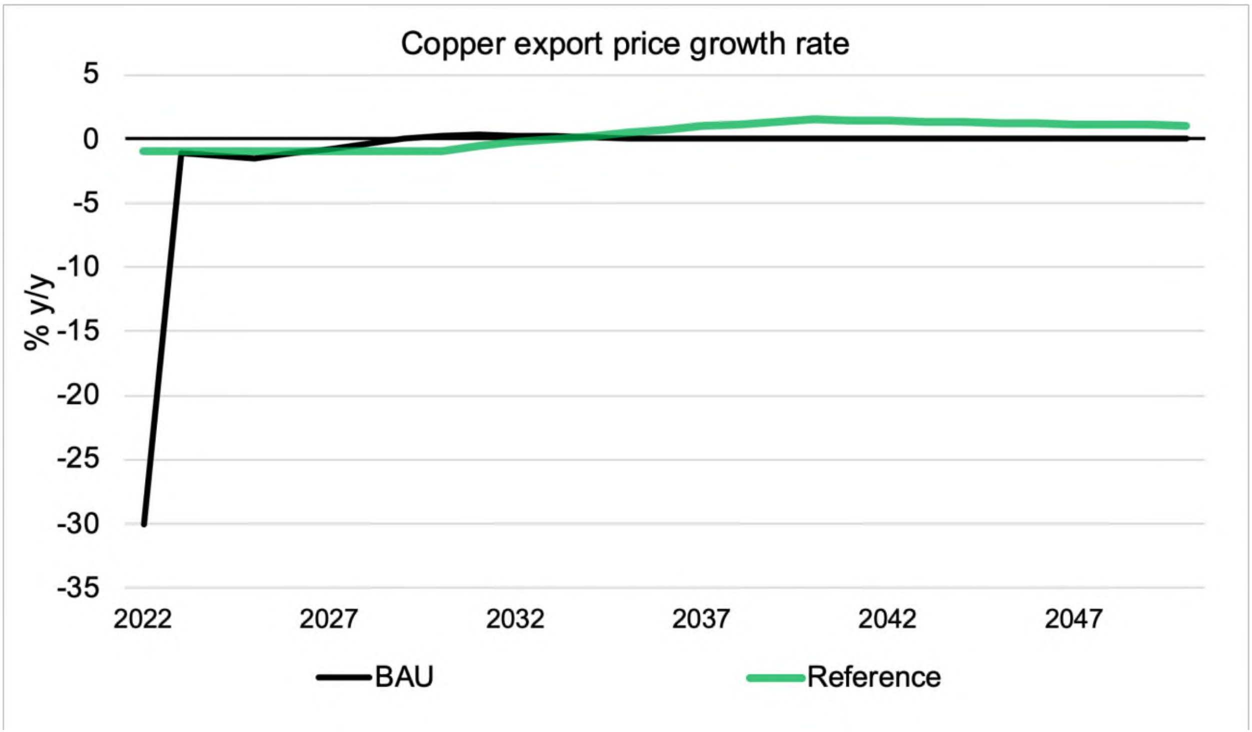
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 22. Aluminium export price growth rate, % YoY



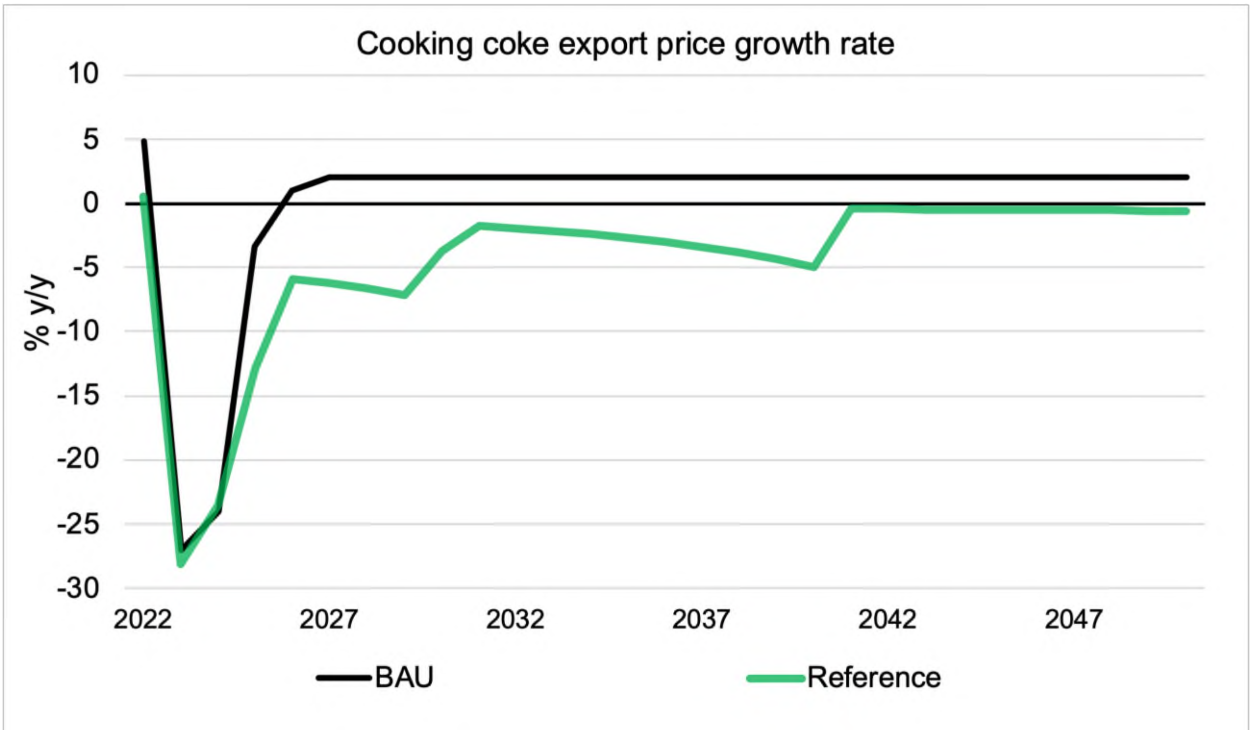
Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

Figure 23. Copper export price growth rate, % YoY



Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

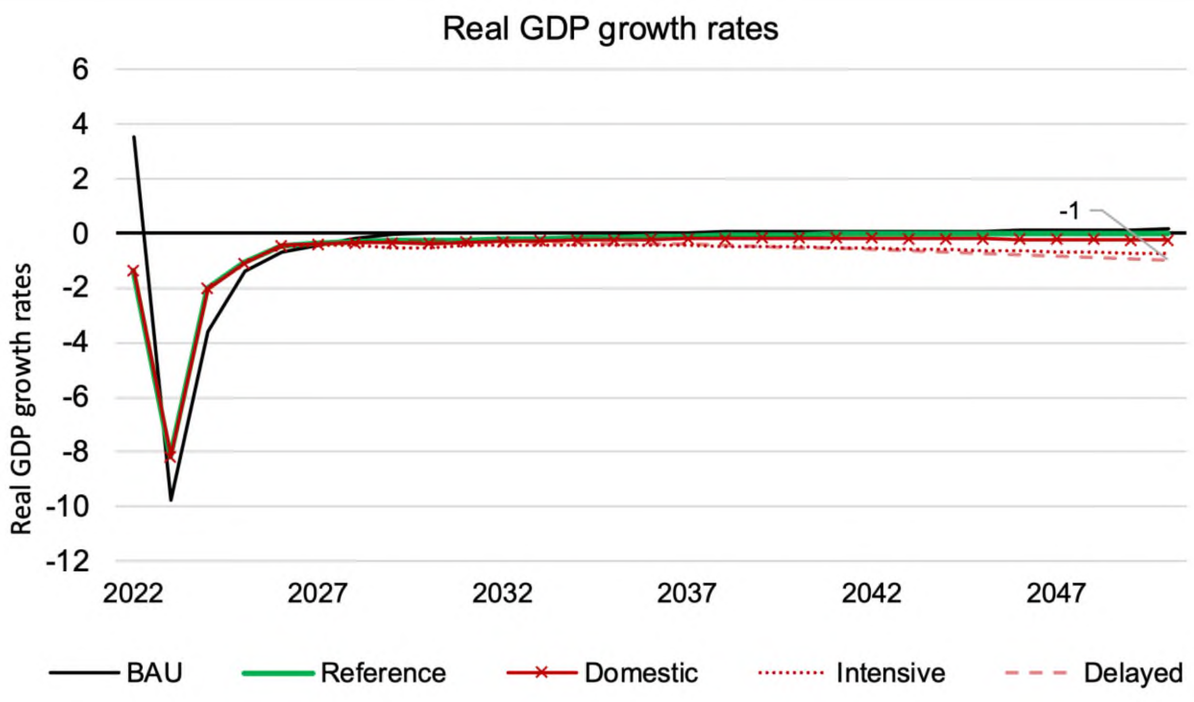
Figure 24. Coking coal export price growth rate, % YoY



Sources: authors' calculations based on the NGFS Net Zero 2050 (NGFS 2021) and consultations with industry experts.

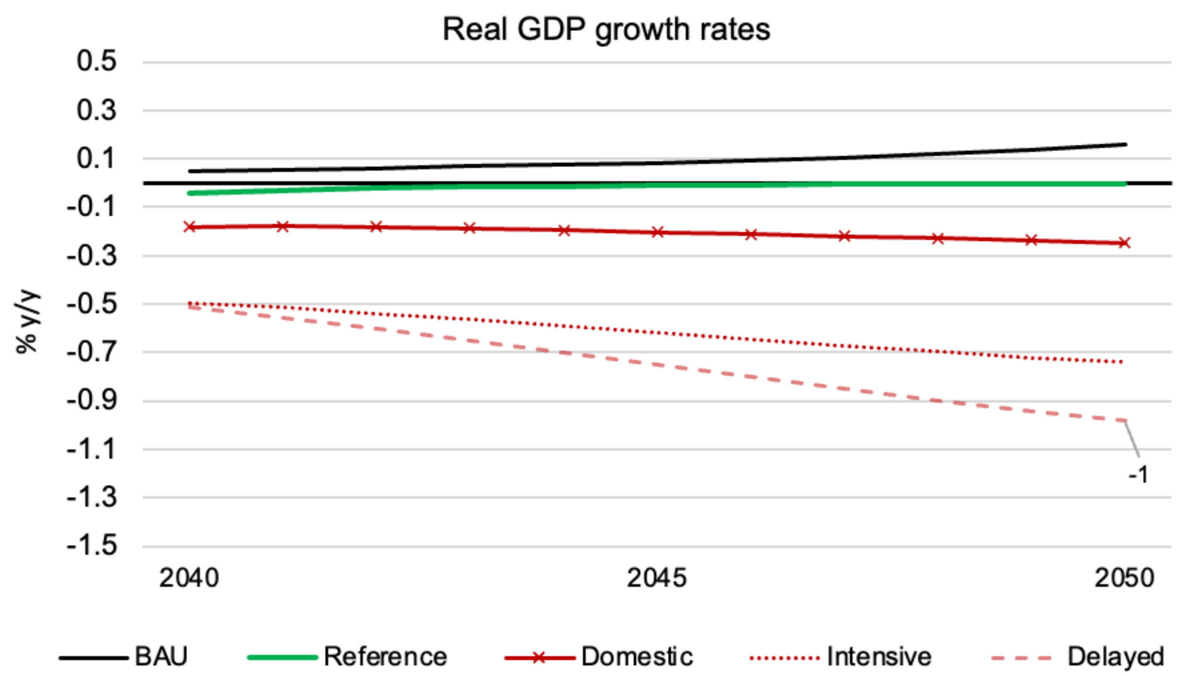
Appendix III. Simulation results

Figure 25. Real GDP growth rates, % YoY



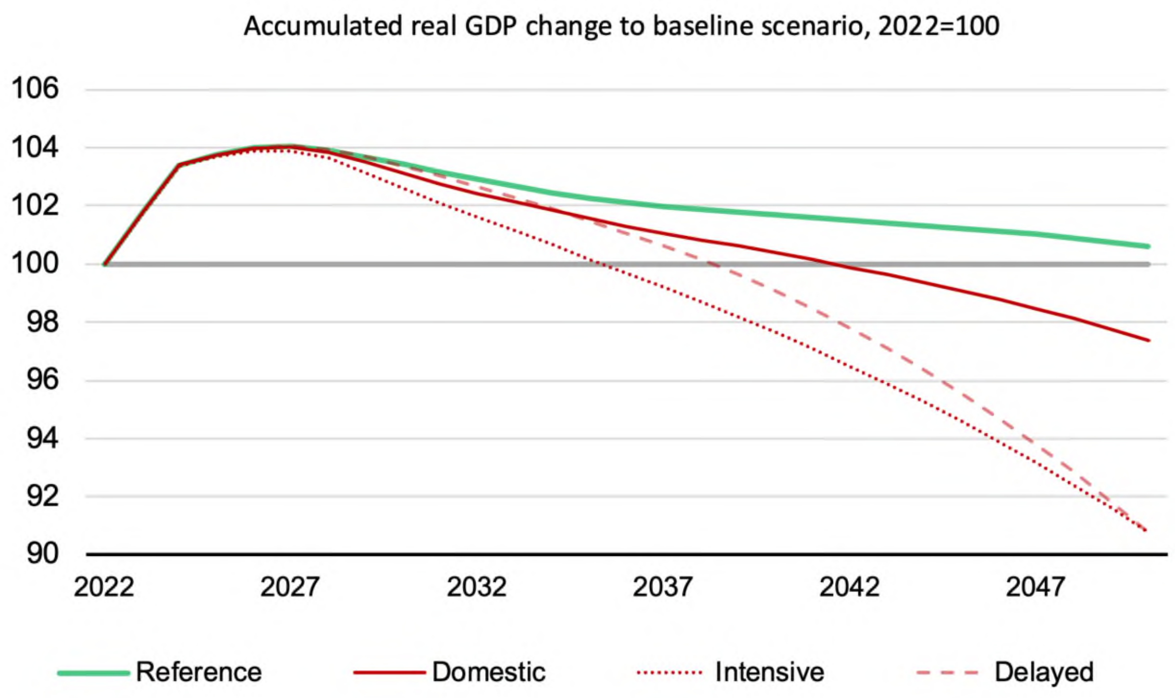
Source: authors' calculations.

Figure 26. Real GDP growth rates, 2040–2050, % YoY



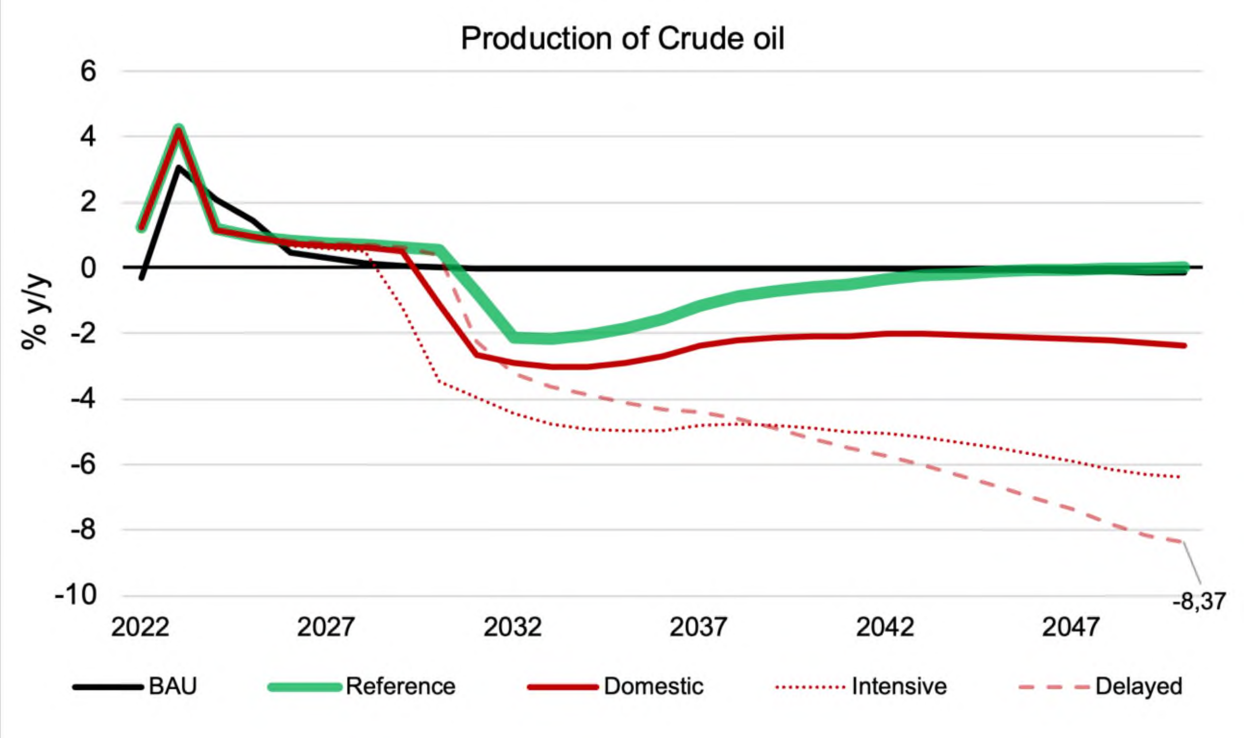
Source: authors' calculations.

Figure 27. Accumulated real GDP change to baseline scenario, 2022=100



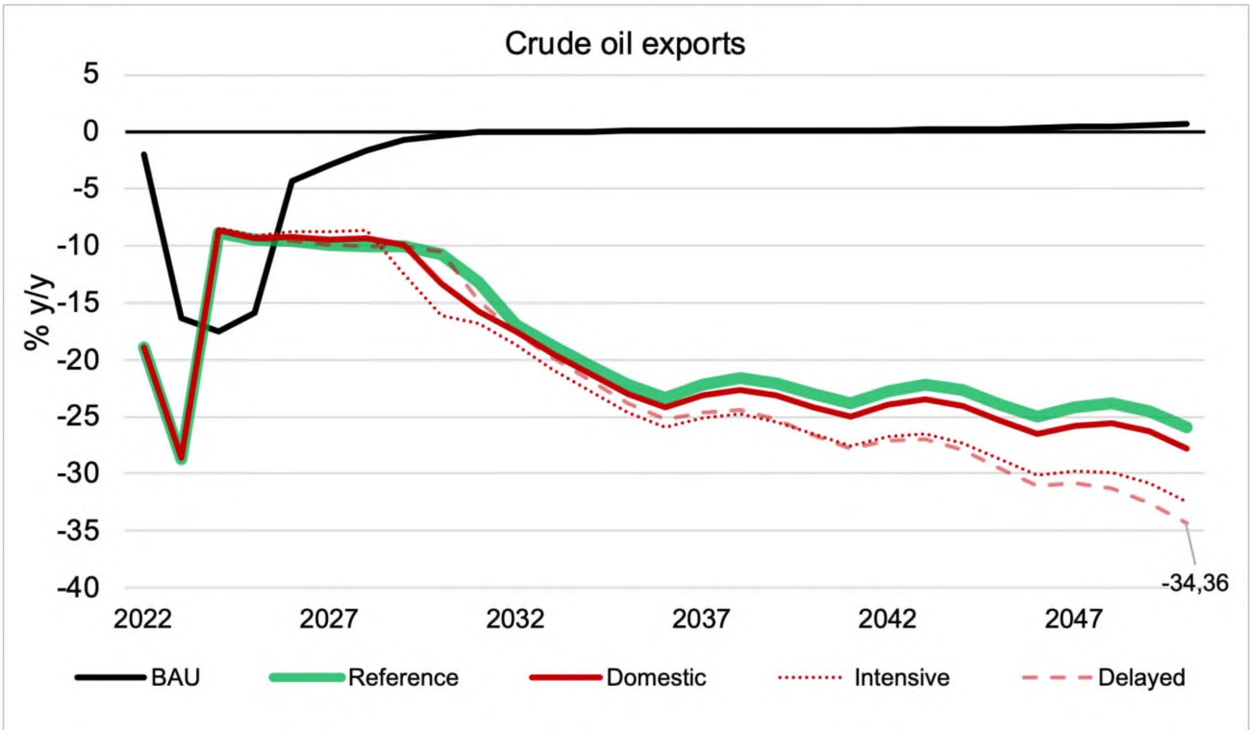
Source: authors' calculations.

Figure 28. Crude oil production, % change YoY



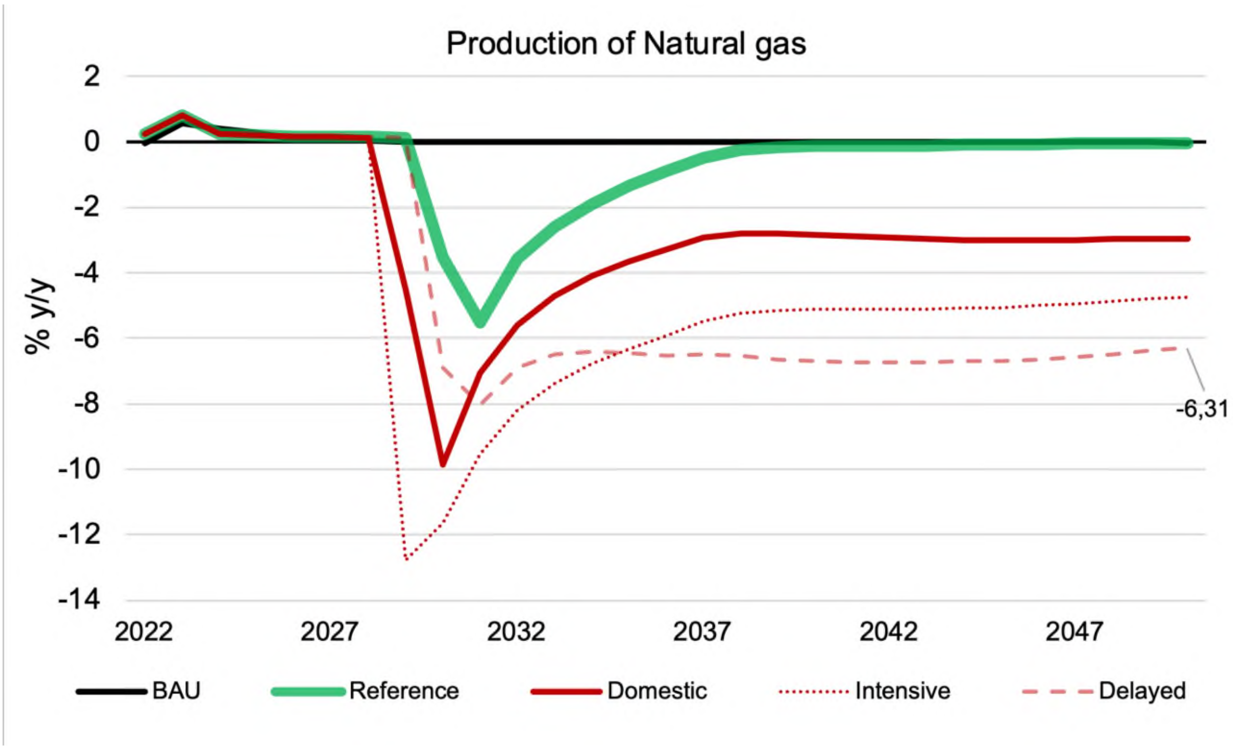
Source: authors' calculations.

Figure 29. Crude oil exports, % change YoY



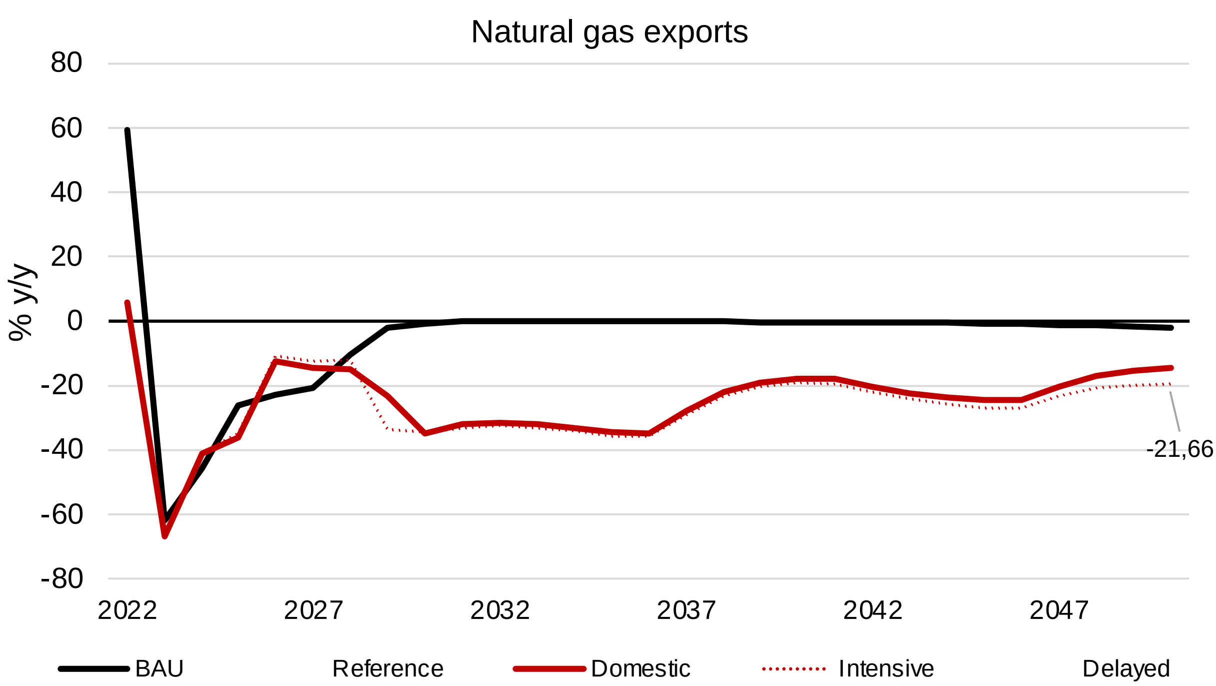
Source: authors' calculations.

Figure 30. Natural gas production, % change YoY



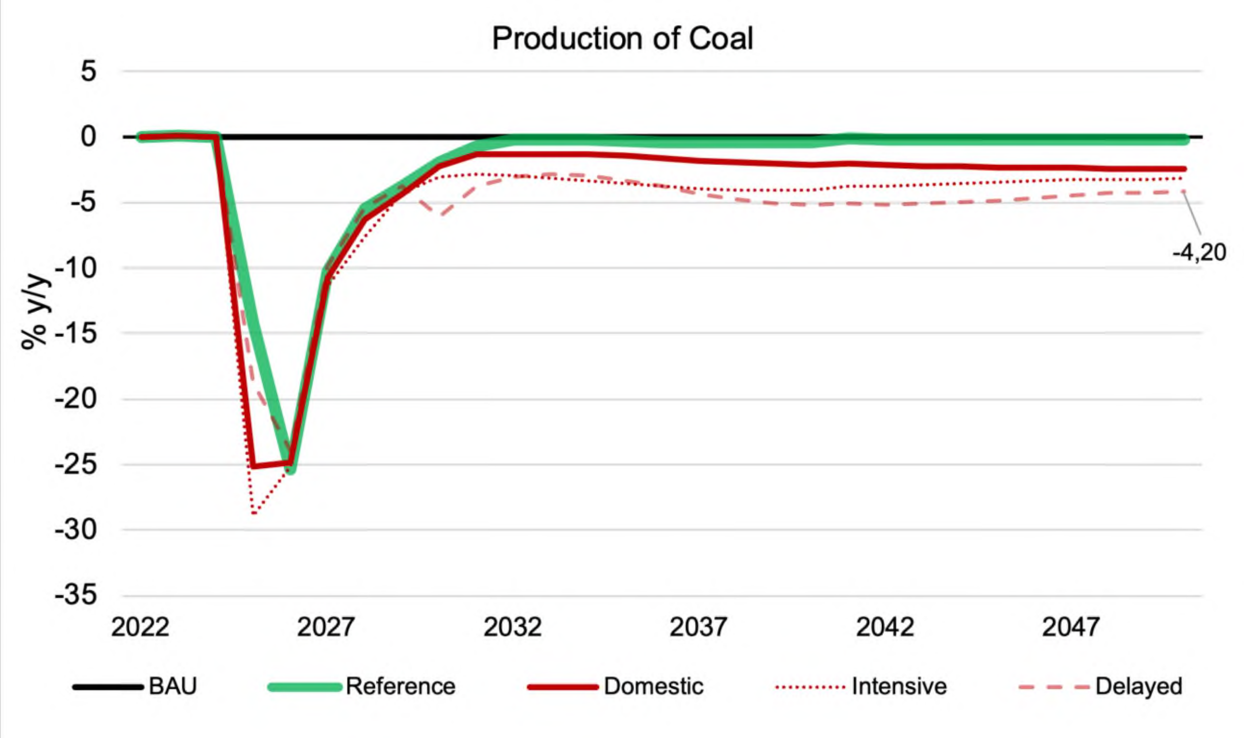
Source: authors' calculations.

Figure 31. Natural gas exports, % change YoY



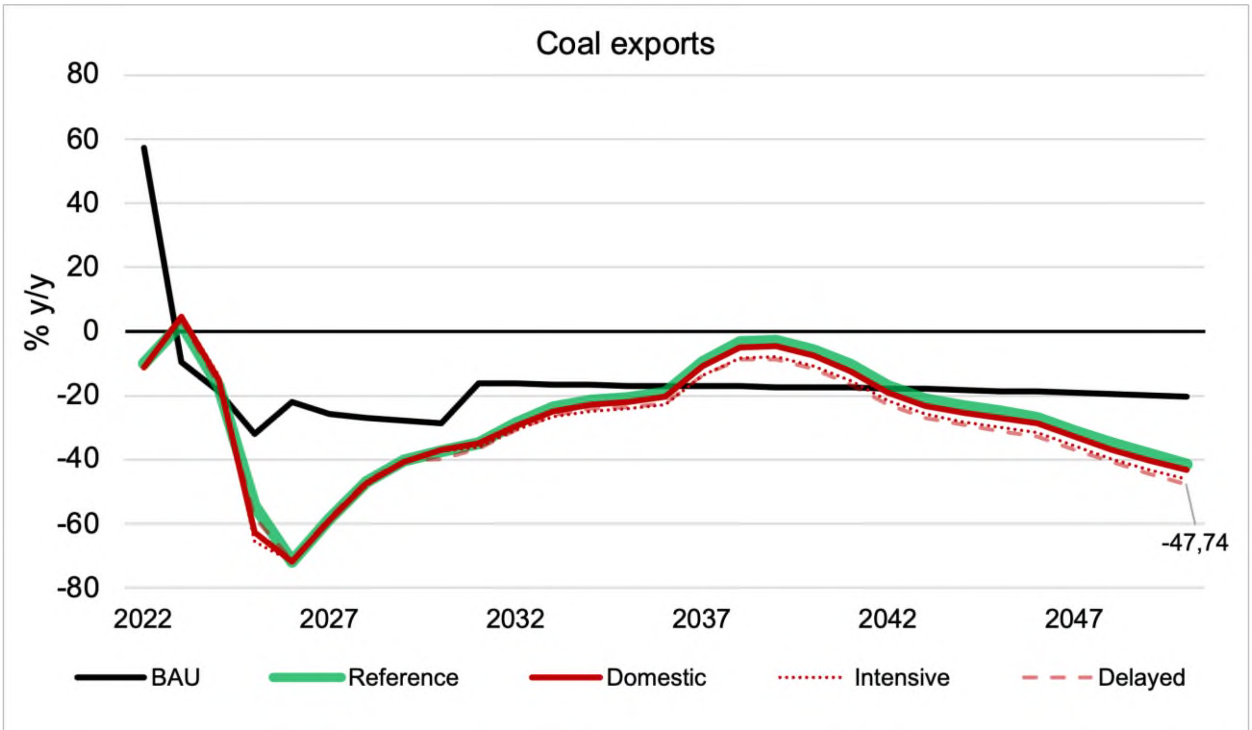
Source: authors' calculations.

Figure 32. Coal production, % change YoY



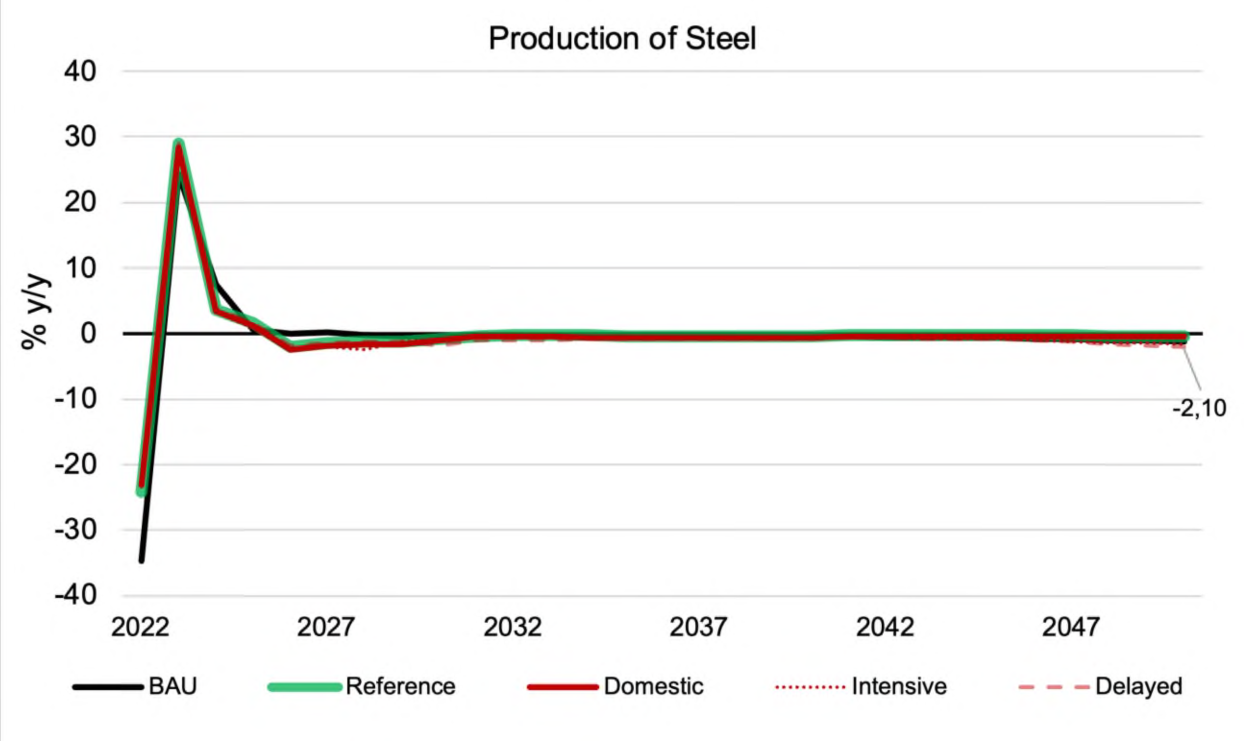
Source: authors' calculations.

Figure 33. Coal exports, % change YoY



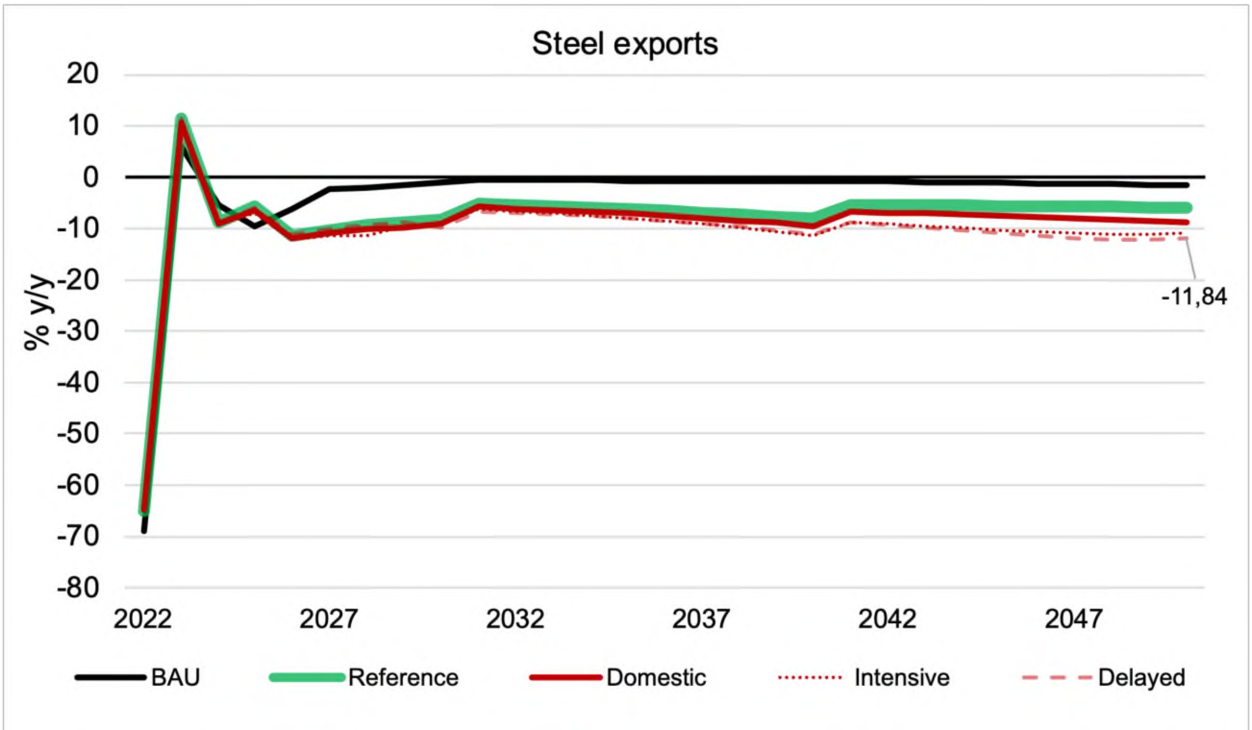
Source: authors' calculations.

Figure 34. Steel production, % change YoY



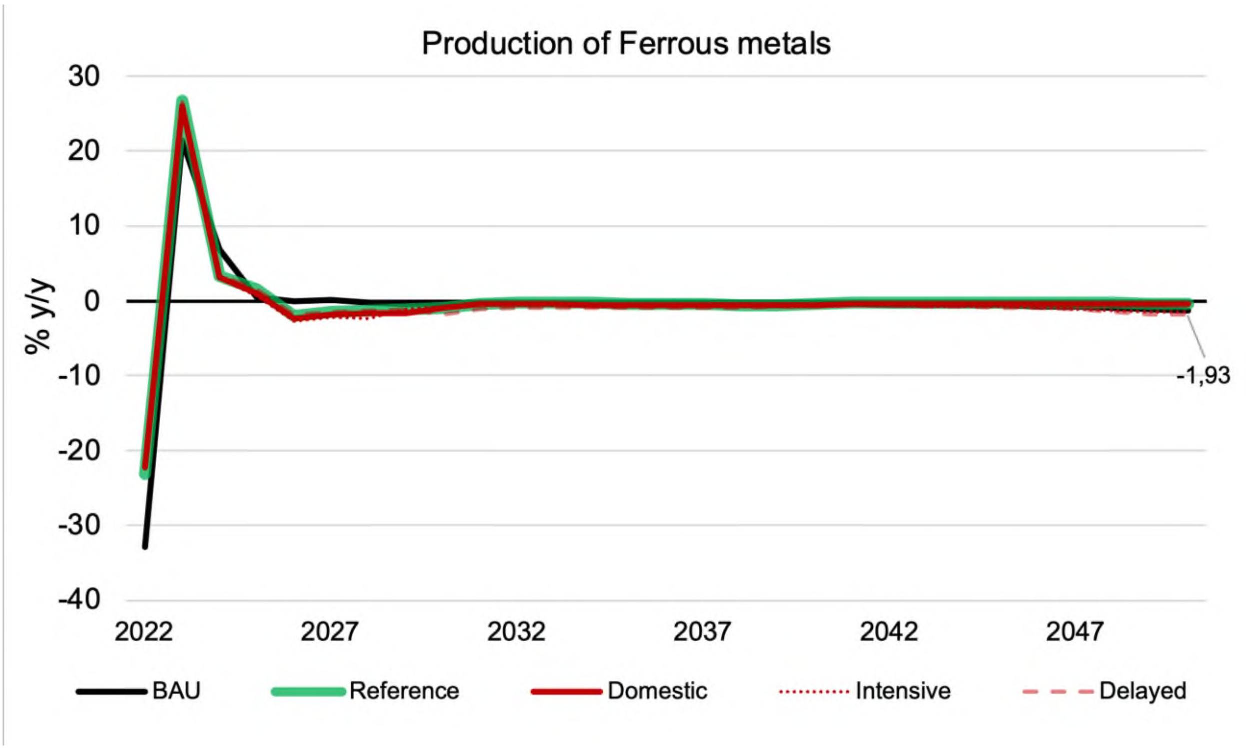
Source: authors' calculations.

Figure 35. Steel exports, % change YoY



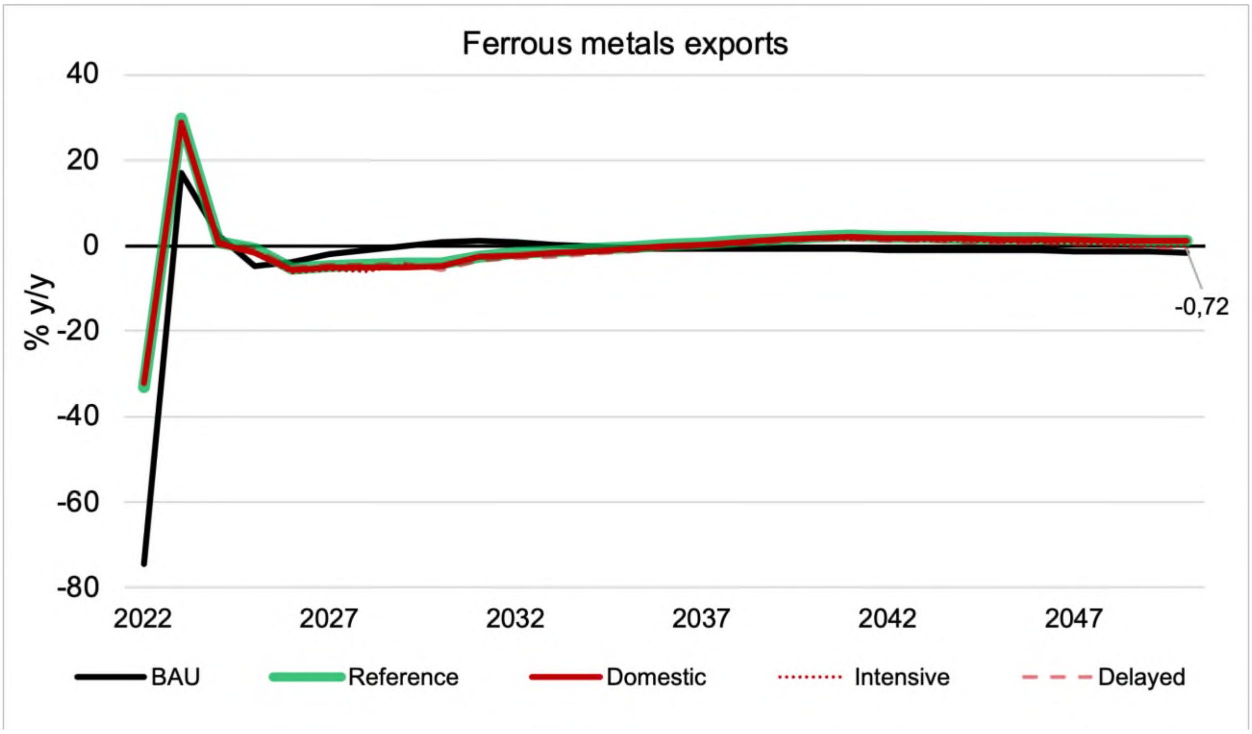
Source: authors' calculations.

Figure 36. Ferrous metals production, % change YoY



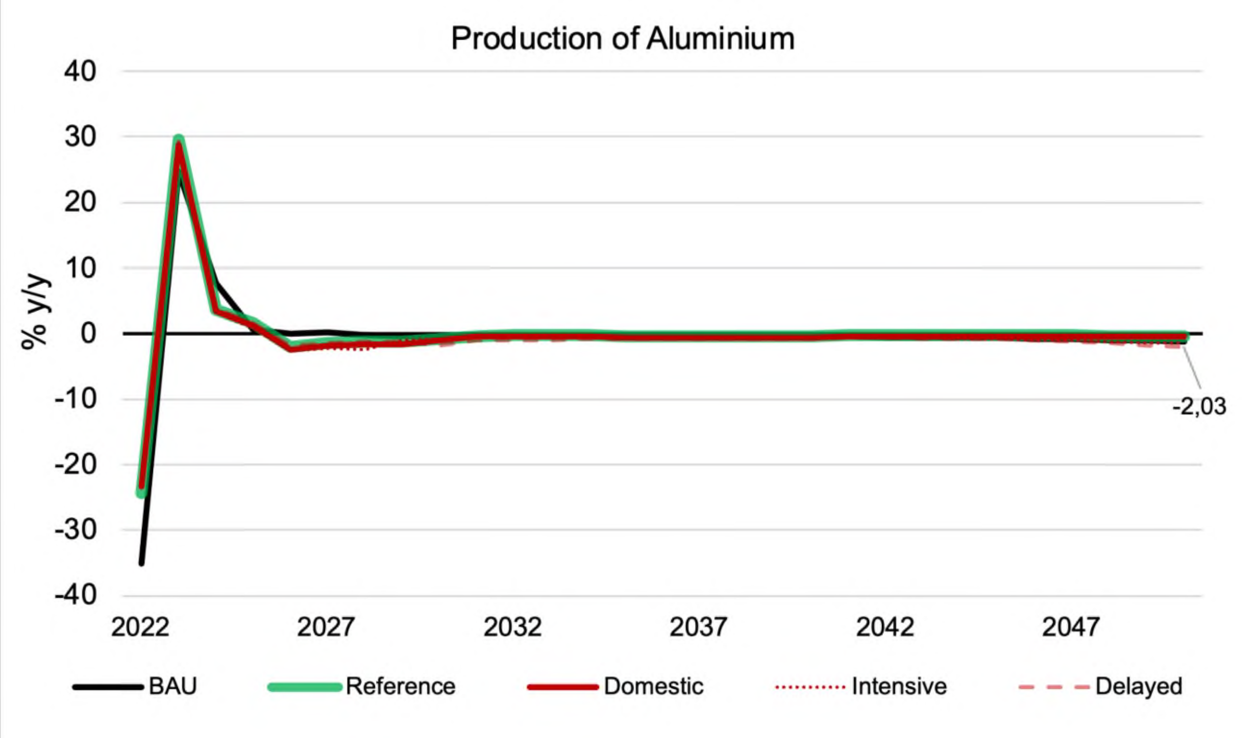
Source: authors' calculations.

Figure 37. Ferrous metals exports of, % change YoY



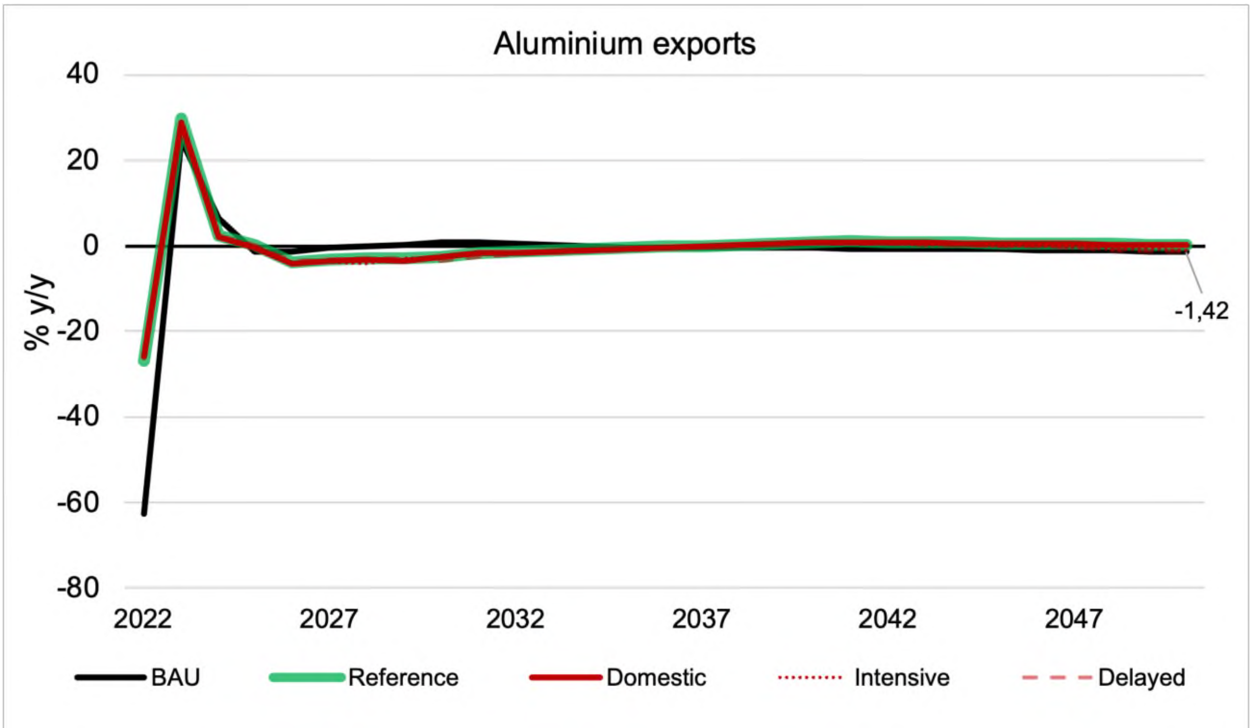
Source: authors' calculations.

Figure 38. Aluminium production, % change YoYy/y



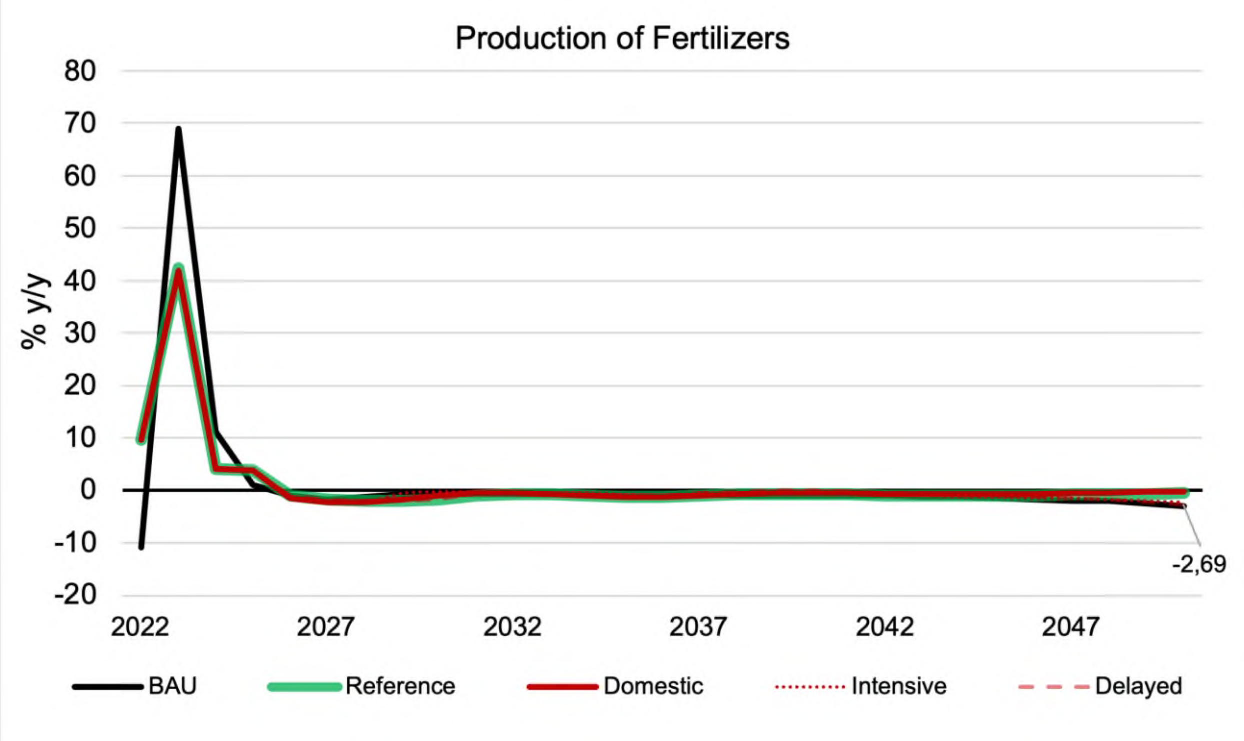
Source: authors' calculations.

Figure 39. Aluminium exports, % change YoY



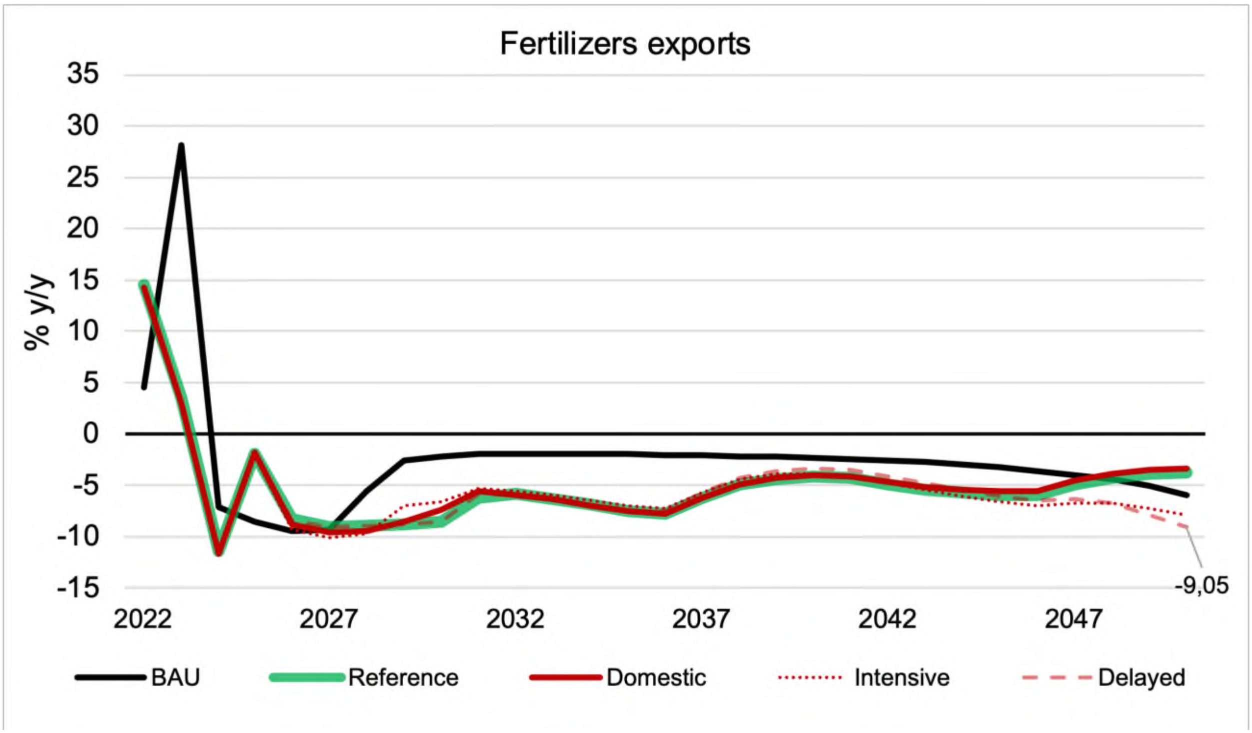
Source: authors' calculations.

Figure 40. Ferilisers production, % change YoY



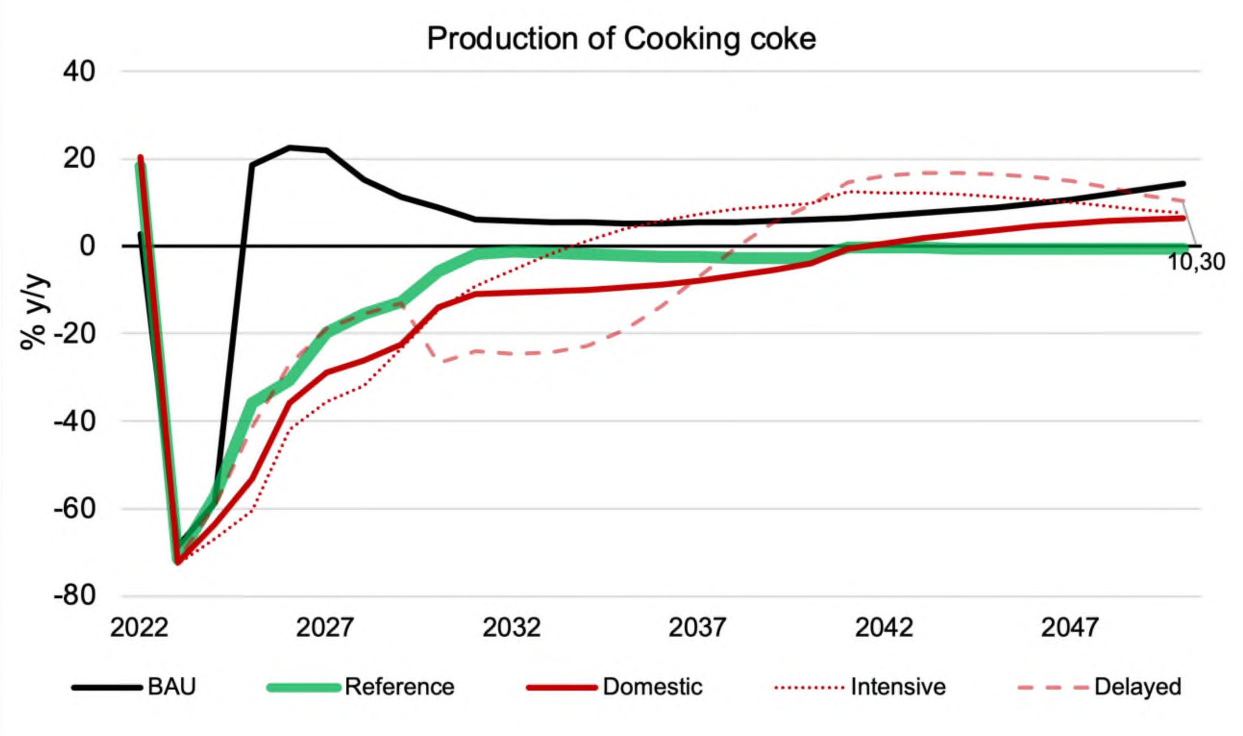
Source: authors' calculations.

Figure 41. Fertilisers exports, % change YoY



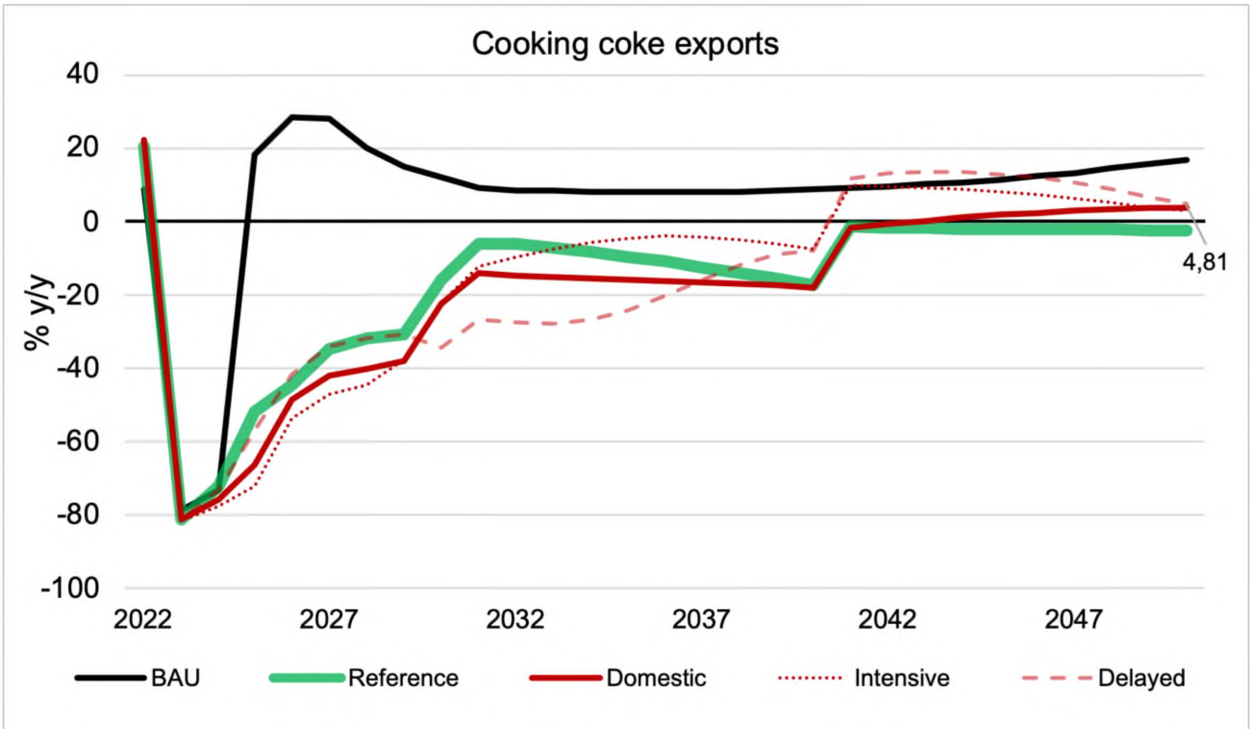
Source: authors' calculations.

Figure 42. Cooking coke production, % change YoY



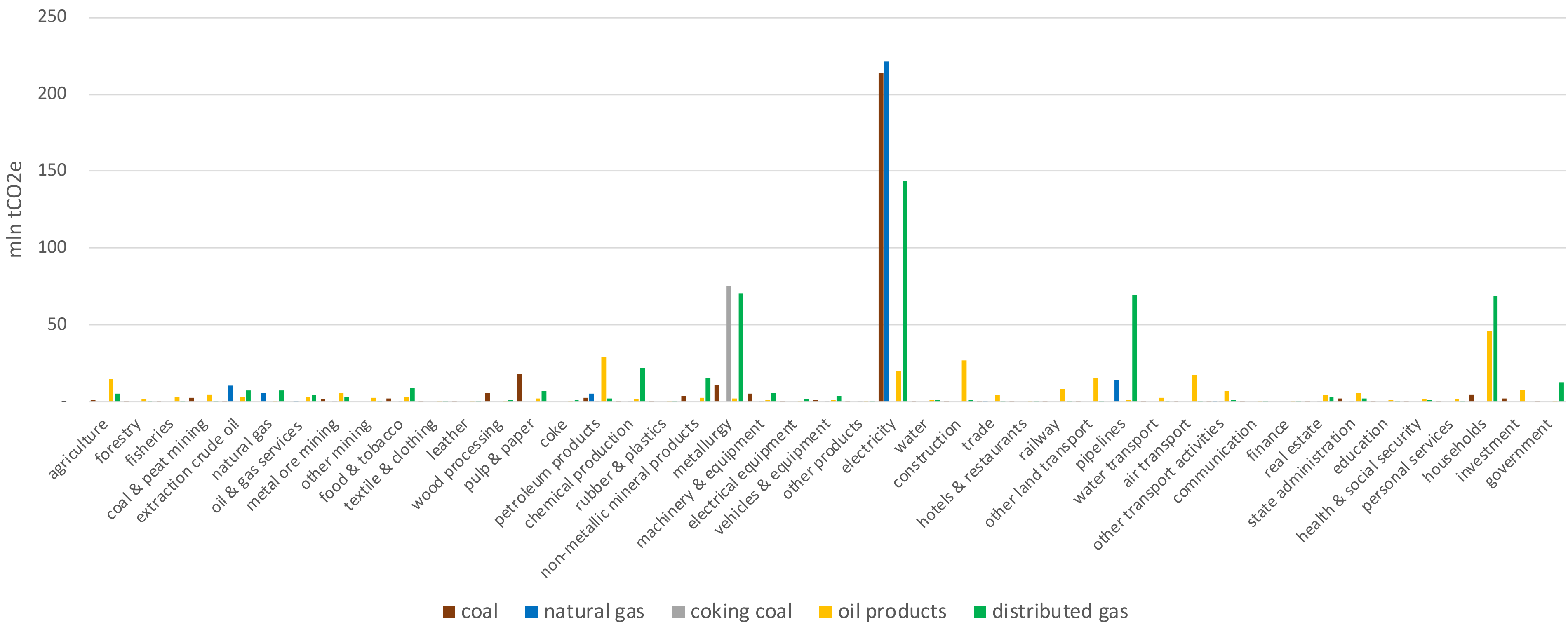
Source: authors' calculations.

Figure 43. Cooking coke exports, % change YoY



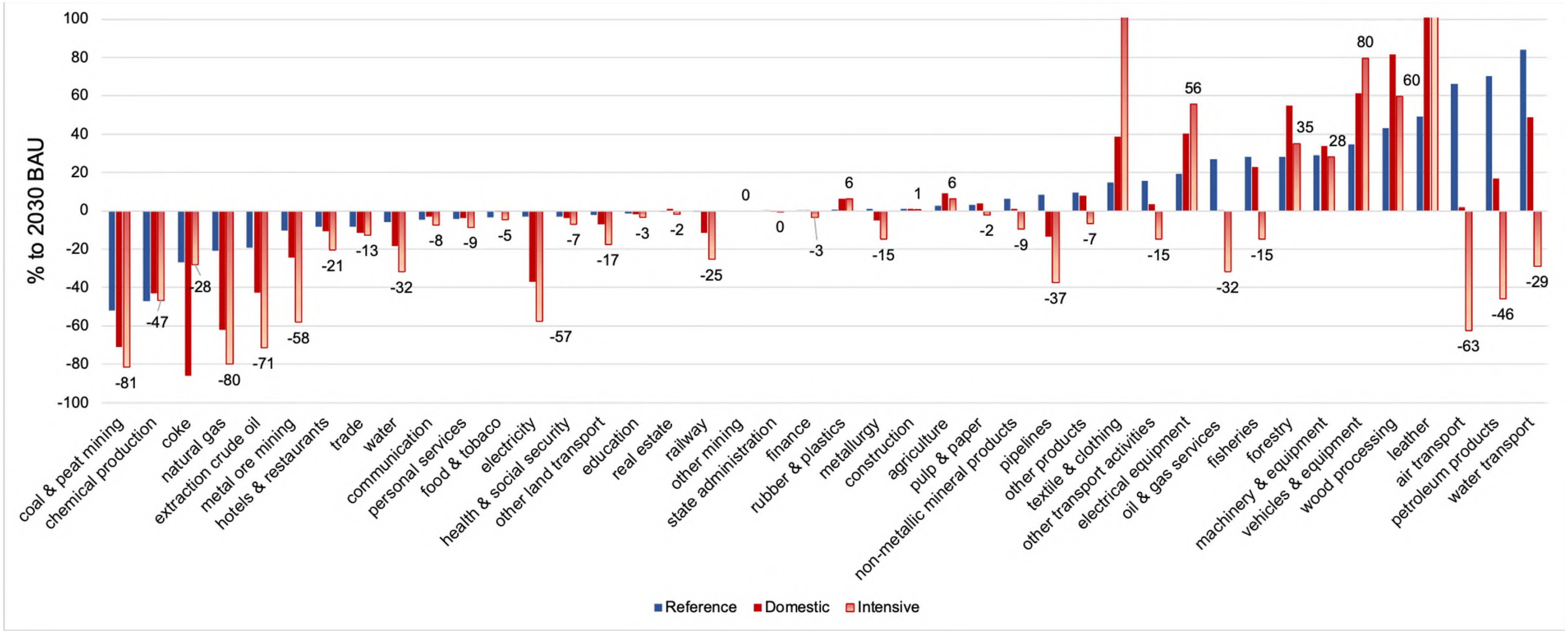
Source: authors' calculations.

Figure 44. Benchmark emissions from combustion by fuel type in 2016, mln tCO2e



Sources: authors' calculations, 4-TER dataset, 2016 Russian input–output tables.

Figure 45. Real industrial output, changes in 2050 under climate scenarios, % «*BAU*» scenario



Source: authors' calculations.

Table 13. Projections of world prices for Russia's export commodities for 2022–2050: *«BAU»* and *«Reference»* (cli) sets, % change vs 2016 benchmark world prices

	alu		cop		pmt		ore		cru		gas		frt		col		cke		stl		fmp	
	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli	bls	cli
2021	27%	27%	43%	43%	86%	85%	102%	102%	-4%	-4%	126%	126%	26%	25%	64%	65%	200%	200%	81%	81%	36%	36%
2022	-10%	26%	0%	41%	66%	68%	51%	39%	-6%	-19%	179%	127%	44%	25%	92%	62%	215%	202%	15%	11%	-4%	35%
2023	-11%	25%	-1%	40%	44%	48%	17%	5%	-16%	-34%	68%	35%	1%	-13%	43%	21%	130%	117%	4%	0%	-5%	33%
2024	-12%	23%	-3%	39%	27%	34%	-5%	-10%	-25%	-36%	29%	9%	-16%	-25%	12%	-4%	74%	66%	-4%	-8%	-6%	32%
2025	-12%	22%	-4%	37%	18%	27%	-12%	-25%	-33%	-39%	15%	-6%	-23%	-29%	-4%	-24%	68%	45%	-10%	-12%	-7%	31%
2026	-13%	21%	-5%	36%	13%	23%	-15%	-30%	-34%	-42%	5%	-11%	-29%	-34%	-11%	-39%	70%	36%	-13%	-17%	-8%	29%
2027	-13%	20%	-6%	35%	9%	21%	-16%	-35%	-35%	-45%	-3%	-16%	-33%	-37%	-17%	-49%	74%	28%	-14%	-21%	-9%	28%
2028	-13%	19%	-6%	33%	7%	19%	-17%	-40%	-36%	-48%	-6%	-20%	-35%	-41%	-22%	-55%	77%	19%	-15%	-24%	-9%	27%
2029	-13%	18%	-6%	32%	5%	18%	-17%	-44%	-36%	-51%	-7%	-24%	-36%	-44%	-27%	-60%	81%	11%	-15%	-28%	-8%	26%
2030	-12%	16%	-6%	31%	3%	16%	-17%	-48%	-36%	-53%	-7%	-28%	-37%	-47%	-32%	-64%	84%	7%	-15%	-31%	-8%	24%
2031	-11%	16%	-6%	30%	2%	15%	-17%	-49%	-36%	-56%	-7%	-32%	-37%	-49%	-33%	-67%	88%	5%	-15%	-32%	-7%	24%
2032	-11%	15%	-5%	30%	1%	14%	-17%	-52%	-36%	-58%	-7%	-35%	-37%	-51%	-35%	-70%	92%	3%	-15%	-34%	-7%	23%
2033	-11%	14%	-5%	30%	0%	13%	-17%	-54%	-36%	-61%	-7%	-39%	-38%	-53%	-36%	-72%	95%	0%	-15%	-36%	-7%	23%
2034	-10%	14%	-5%	30%	-1%	11%	-17%	-56%	-36%	-63%	-7%	-42%	-38%	-55%	-38%	-73%	99%	-2%	-15%	-38%	-7%	23%
2035	-10%	14%	-5%	31%	-2%	10%	-17%	-58%	-36%	-66%	-7%	-46%	-39%	-57%	-39%	-75%	103%	-5%	-15%	-40%	-7%	23%
2036	-10%	14%	-5%	32%	-3%	9%	-17%	-60%	-36%	-69%	-7%	-49%	-39%	-59%	-41%	-76%	107%	-8%	-15%	-42%	-7%	24%
2037	-10%	15%	-5%	33%	-4%	8%	-17%	-63%	-36%	-71%	-7%	-51%	-39%	-61%	-42%	-76%	112%	-11%	-15%	-44%	-7%	24%
2038	-10%	16%	-5%	35%	-5%	7%	-17%	-65%	-36%	-73%	-7%	-53%	-40%	-62%	-44%	-77%	116%	-14%	-15%	-46%	-7%	26%
2039	-10%	16%	-5%	36%	-5%	6%	-17%	-67%	-36%	-75%	-7%	-54%	-40%	-63%	-45%	-77%	120%	-18%	-15%	-48%	-7%	27%
2040	-10%	18%	-5%	39%	-6%	5%	-17%	-70%	-36%	-77%	-7%	-55%	-41%	-64%	-46%	-77%	125%	-22%	-15%	-50%	-7%	28%
2041	-10%	19%	-5%	41%	-7%	4%	-17%	-71%	-36%	-79%	-7%	-57%	-41%	-64%	-47%	-78%	129%	-22%	-15%	-51%	-7%	30%
2042	-10%	20%	-5%	43%	-8%	3%	-17%	-71%	-36%	-81%	-7%	-58%	-41%	-65%	-49%	-78%	134%	-23%	-15%	-52%	-7%	31%
2043	-10%	21%	-5%	45%	-9%	2%	-17%	-72%	-36%	-82%	-7%	-59%	-42%	-66%	-50%	-80%	138%	-23%	-15%	-54%	-7%	33%
2044	-10%	21%	-5%	46%	-10%	1%	-17%	-73%	-36%	-83%	-7%	-61%	-42%	-67%	-51%	-81%	143%	-23%	-15%	-55%	-7%	34%
2045	-10%	22%	-5%	48%	-11%	0%	-17%	-74%	-36%	-85%	-7%	-62%	-43%	-69%	-52%	-82%	148%	-24%	-15%	-56%	-7%	35%
2046	-10%	23%	-5%	50%	-11%	-1%	-17%	-74%	-36%	-86%	-7%	-64%	-43%	-70%	-53%	-83%	153%	-24%	-15%	-57%	-7%	37%
2047	-10%	24%	-5%	52%	-12%	-2%	-17%	-75%	-36%	-87%	-7%	-65%	-43%	-70%	-55%	-85%	158%	-25%	-15%	-59%	-7%	38%
2048	-10%	24%	-5%	54%	-13%	-2%	-17%	-76%	-36%	-88%	-7%	-66%	-44%	-71%	-56%	-86%	163%	-25%	-15%	-60%	-7%	39%
2049	-10%	25%	-5%	55%	-14%	-3%	-17%	-76%	-36%	-89%	-7%	-66%	-44%	-72%	-57%	-87%	168%	-26%	-15%	-61%	-7%	40%
2050	-10%	26%	-5%	57%	-15%	-4%	-17%	-77%	-36%	-90%	-7%	-67%	-44%	-72%	-58%	-89%	174%	-26%	-15%	-62%	-7%	41%

Source: authors' calculations.

Table 14. CO2e emission goals in climate policy scenarios, mln tCO2e

Years	*«Domestic»*	*«Intensive»*	*«Delayed»*
2021	1,351.0	1,351.0	1,351.0
2022	1,313.8	1,287.9	1,351.0
2023	1,277.6	1,227.8	1,351.0
2024	1,242.4	1,170.5	1,351.0
2025	1,208.2	1,115.9	1,351.0
2026	1,175.0	1,063.8	1,351.0
2027	1,142.6	1,014.1	1,351.0
2028	1,111.2	966.8	1,351.0
2029	1,080.6	921.7	1,351.0
2030	1,050.8	878.6	1,264.7
2031	1,021.9	837.6	1,183.9
2032	993.7	798.5	1,108.3
2033	966.4	761.2	1,037.5
2034	939.8	725.7	971.2
2035	913.9	691.8	909.2
2036	888.7	659.5	851.1
2037	864.3	628.8	796.7
2038	840.5	599.4	745.8
2039	817.3	571.4	698.2
2040	794.8	544.8	653.6
2041	772.9	519.3	611.8
2042	751.7	495.1	572.7
2043	731.0	472.0	536.1
2044	710.8	449.9	501.9
2045	691.3	428.9	469.8
2046	672.2	408.9	439.8
2047	653.7	389.8	411.7
2048	635.7	371.6	385.4
2049	618.2	354.3	360.8
2050	601.2	337.7	337.7

Source: authors.