ORIGINAL ARTICLE

Russia on the pathways to carbon neutrality: forks on roadmaps

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Abstract

In its 2023 Climate Doctrine, Russia officially committed to carbon neutrality before 2060. However, on the roadmap fork to climate neutrality Russia's Low Carbon Strategy chose the *2F* (*Forest First*) pathway with the dominance of the natural solutions in the LULUCF sector and with a moderate decline or even growth (industry and agriculture) in other sectors. This paper focuses on a discussion of the roadmap to carbon neutrality. The roadmapping approach relies on a system of interconnected models for setting the scale of low carbon technologies and practices deployment. The paper concludes that excessive reliance on the *2F* pathway is unrealistic, and only the *Forest Last* family of scenarios, which focuses on substantial reduction of GHG emissions across all sectors, is able to bring Russia to carbon neutrality in 2060. The paper also presents indicators to assess emission reductions by major sectors and discusses the need to reinforce the five pillars to support this pathway: technologies; regulations and programmes; incentives and financing; institutes; and human capital. These five pillars are required to effectively address three basic models of decisions-making (satisficing, optimization, and system transformation).

Keywords Long-term forecasting · Decarbonization · Carbon neutrality · Roadmaps · Policy packages

JEL O1 · O2 · O3 · O5 · Q4 · Q54

1 Introduction

The 2060 carbon neutrality goal is officially fixed in the 2023 *Climate Doctrine of the Russian Federation*. However, many of the decarbonization plans are not very specific. As a result, they are progressing too slowly, facing increased protectionism, aggravated geopolitical problems (security, reliability of supply chains), and all this hampers progress towards carbon neutrality (ECF 2022). If low carbon action is to be clear, coordinated at all decision-making and implementation levels, and largely supported, we need a clear and understandable action plan – a roadmap – to transform the current raw material-based

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model of economic and socio-political development in Russia into an inclusive and fair innovative low carbon economy.

According to the *Cambridge Dictionary,* a roadmap is "a plan for how to achieve a vision or goal".[1] Alternative definitions of a roadmap include: "the application of a temporal–spatial structured strategic lens"[2]; "a strategic planning technique that places a project's goals and major deliverables (tasks, milestones) on a timeline".[3] The main advantage of roadmapping is not in the deep analysis, but in the use of structured visual representations of the interconnected diverse processes unfolding over time, which are required to achieve the set goals. This paper presents the first iteration, a "pencil sketch" of the future multi-figure composition.

Unlike typical 2D maps, carbon neutrality roadmaps require more dimensions and metrics. In this paper, there are five main pillars, or metrics, of low carbon policies: technologies; regulations, including strategies and programmes; financing and economic incentives to attract investment; institutes to develop and implement the required policies; and human capital to get all low carbon mechanisms moving in the right direction at the desired pace. Roadmaps should ensure coherence not only among all stakeholders within individual sectors, but also coordinate action across the sectors. It is important to ensure the consistency of action over time. Scaling up low carbon technologies requires a certain environment; it must be clear, who is doing what, and when. For each sector, a roadmap should be the result of consultations with all stakeholders and experts. Roadmapping clearly incurs a confrontation between the groups with the traditional values of a raw materials-based economy on the one hand, and the emerging groups engaged in green technologies-based business, which are calling for the "de-fossilization" of the economy, on the other.[4]

The development of a roadmap is urged by the fact that, in compliance with the Paris Agreement, Russia is to prepare the next Nationally Determined Contribution (NDC) in 2025 with a higher level of GHG mitigation ambition to 2035. A roadmap is different from a plan or a programme. The latter have to provide a detailed description of the activities, set deadlines, specify the performers and resources for plans or programmes. One example is the *Action Plan (Operational Plan) for the implementation of the Russian low carbon development strategy to 2050.* A third version of the *Operational Plan* has been developed. This is a document of nearly 200 pages, which includes a list of government activities mostly to 2025 to ensure the implementation of the said *Strategy* (LTS). This plan among other provisions requires the approval of GHG emission reduction targets across emissions sectors and industries by the end of 2024.

It is important to launch a discussion of the trajectories to carbon neutrality. This paper is an attempt to come up with a carbon neutrality vision to 2060 for further discussion.[5] It may be subject to criticism, perhaps even harsh criticism. But hopefully it will give momentum to the transition from rhetoric to actions. The roadmapping process may be

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[1] ROAD MAP | English meaning – Cambridge Dictionary.

[2] Roadmapping is *"the application of a temporal–spatial structured strategic lens"*. Phaal R. and C. Kerr. Guest Editorial: New Perspectives on Roadmapping: Foreword. February 2022. IEEE Transactions on Engineering Management 69(1):3-5. https://doi.org/10.1109/TEM.2021.3094961.

[3] Roadmaps – A Complete Guide with Examples, Tools & Tutorials (officetimeline.com). Roadmaps A Complete Guide with Examples, Tools & Tutorials – PayneGeo.

[4] News (eceee.org).

[5] The full text of the study is available at https://cenef-xxi.ru/articles/russia-on-the-pathways-to-carbon-neutrality:-forks-on-roadmaps (Bashmakov et al. (2023d). Russia on the pathways to carbon neutrality: forks on roadmaps).

even more important, than the resulting roadmap.[6] This process helps elaborate and, possibly, agree on a strategic vision of the future. A consensus, as preferred by the government, might incur high risks, if the government only wants to hear its own voice or selects the stakeholders to take part in the discussion on the basis of loyalty. Any strategy or roadmap should be questioned and criticized. The opinion of a sceptic minority may be more valuable, than the opinion of a loyal majority.

There are many forks in the roadmap. The first fork is as follows: does low carbon transition slow down or accelerate economic growth? After a long debate, the latter was favoured in the Russian *LTS*. The intensive discussions on gradual phasing out unabated fossil fuels use mean that there is no chance that reliance on fossil fuels as the key driver of economic growth can be preserved. In the future, there will be no economy other than low carbon economy.[7] The next fork is as follows: which policies and sectors should be engaged in to tackle the problem? Here the debate in Russia is around whether priority should be given to the natural solutions in LULUCF[8] or to low carbon technologies in fuel combustion, industrial, agricultural and waste management processes. In terms of investment, the fork is as follows: maintaining the priority of the fossil technologies or switching to financing new "green" technologies. In each sector, these forks are multiplied.

The principal fork is, however, as follows: continue talking or start acting? Improving energy efficiency and increasing sinks by Russian forests have long been proclaimed as the two priorities of GHG mitigation policies. This is pure rhetoric and sounds like a skipping record (UNEP 2023). Meanwhile, sluggish action has caused Russia to lose out the energy efficiency race. In 2015–2022, energy intensity of Russia's GDP was growing by an average of 1.4% per year. If non-energy fuel use is excluded, then energy intensity was 0.5% down per year versus 2.7% in the EU, 1.9% in the US and Turkey, 2.1% in China, 3.5% in UK, and 3.9% in the Netherlands. (Bashmakov, 2023d; Bashmakov et al. 2023a, 2023b). Despite the proactive discussion of forest projects, net absorption in LULUCF in 2010–2021 was 213 Mt CO_2eq *down*, rather than *up* (State National Report, 2022). Just before the COP-28, IEA came up with five initiatives: tripling global renewable power capacity in 2030; doubling the rate of energy efficiency improvements; cutting methane emissions from operations by 75%; tripling clean energy investment; and committing to measures that ensure an orderly decline in the use of fossil fuels, including an end to new approvals of unabated coal-fired power plants.[9] 118 countries committed to the first two items.[10] Russia made no pledge, but it can address the first two issues relatively easily.[11]

This paper relies on a series of works accomplished by CENEf-XXI which look in detail into the prospects of Russia's achieving carbon neutrality by 2060 (Bashmakov et al. 2022; 2023c; Bashmakov 2023a; 2023b; 2023d). The second section presents evolution of Russia's GHG emission projections and mitigation pledges followed by the section on methodology and tools. The fourth section discusses the key fork on the carbon neutrality roadmap: *Forest First (2F)* or *Forest Last* pathways. The following section discusses the feasibility of the *2F* pathway. Sections 6 and 7 show emissions reduction targets by sectors

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[6] Roadmapping as process — cambridge roadmapping.

[7] MISSION ZERO—Independent Review of Net Zero (publishing.service.gov.uk).

[8] Such approach is correctly called imitational (Korppoo and Alisson 2023).

[9] What does COP28 need to do to keep 1.5 °C within reach? These are the IEA's five criteria for success – Analysis—IEA.

[10] 118 nations commit to triple renewable energy by 2030 at COP28 (aa.com.tr).

[11] https://cenef-xxi.ru/articles/tri-plyus-dva

in the *4D* from the *Forest Last* scenarios family and discuss three carbon policy domains and five pillars to support such pathway. This paper contributes to the available literature by presenting emission reduction targets, split by decades, for the *Forest Last* emission pathway, which allows it to attain carbon neutrality by 2060, and explaining what, when, and by whom needs to be done to build and then reinforce the five pillars required to support the sustainable and effective GHG mitigation pathway via addressing three basic models of making investment and management decisions.

2 Literature review. evolution of Russia's GHG emission projections and mitigation pledges

There is vast international experience in decades and nearly centuries long GHG emission projections using IAMs and other models (see assessment in Riahi et al. 2022 and Lecocq et al. 2022). Russian experts have more than 30-years' experience in greenhouse gas emission projections. The first forecasts for the Soviet Union were published in the early 1990s and aimed to limit CO_2 emissions in 2020–2030 to the 1990 levels or to a level 20% below 1990 (Bashmakov and Makarov 1990; 1991). Later on, the geographical scope was narrowed to Russia. Until 2009, the number of research efforts with the 2050 horizon was very limited: 2 scenarios by Makarov (2008), 3 scenarios by Sinyak (2008 with projections to 2060), and 21 scenarios by Bashmakov (2009a, b). In addition, long-term projections (not to 2050) were provided by the IEA and other organizations. All of these scenarios were grouped into four families:"*Sisyphus' Road*", "*Baseline*", "*The carbon plateau*", "and "*Low Carbon Russia*" (Fig. 1) (Bashmakov and Myshak 2014). *"Sisyphus' road"* family
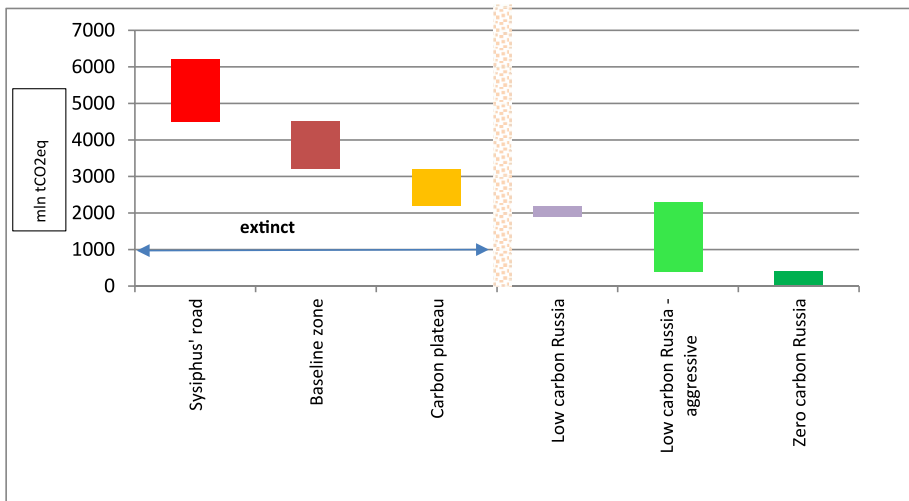

Fig. 1 Evolution of energy related GHG emission projections [Sources: Multiple projections before 2015 were assessed in: Bashmakov 2014 (71 scenarios) and in Bashmakov and Myshak 2014 (another 30 scenarios). More recent projections include: Makarov et al. 2018; IERI RAS and Energy Center of SKOLKOVO 2019; Bashmakov 2020; Laitner et al. 2020; Safonov et al. 2020a, b; Porfiriev et al. 2020; Bashmakov 2021; Veselov et al. 2021; Bashmakov et al. 2022; bp 2023; IEA 2021a; IEA WEO 2015–2023; IEA ETP 2017–2023; Shirov and Kolpakov 2023]

became extinct by 2009. It was shown that: (1) Russia cannot increase its GHG emissions by so much and (2) it can keep its emission below the 1990 level until 2050 without compromising its economic growth. Having assessed the risks, at 2009 COP in Copenhagen Russia committed to limit its 2020 emission to 75% of the 1990 level.

Before the 2015 UNFCCC meeting in Paris, the population of Russian projections grew up significantly. Bashmakov and Myshak (2014) analyzed 71 scenarios from 26 research efforts. Another family of scenarios – "*Low carbon Russia – aggressive policies*" – emerged. As the knowledge accumulated, the models and forecasting methods improved, and the assessments of Russia's economic perspectives and low carbon technological progress became more adequate, the families of scenarios with high GHG emission projections to 2050 (in addition to *Sisyphus' Road"*, two other families—*"Baseline"*, and *"Carbon plateau"*)—became extinct (Fig. 1). Some research groups came to a conclusion that there is an absolute upper limit to GHG emissions (below the 1990 level), which will never be exceeded under any circumstances (Bashmakov 2014).

In 2014, CENEf accomplished a project titled *"Costs and benefits of low carbon transition in Russia"* (Bashmakov 2014). It primarily aimed to identify the costs and benefits associated with low carbon development strategies in Russia to the mid-21 century and beyond, and to look into whether or not a focus on low carbon development is a deterrent or catalyst for economic growth in Russia. Several Russian and foreign research groups participated in order to obtain weighted and balanced answers to this question. One task under this project was to help formulate the position of the Russia on the national pledge under the Paris Agreement. In none of the 30 scenarios (which built on a consistent set of assumptions) was the 2050 GHG emission level higher, than in 1990. GHG emissions baseline was substantially down. The revision of economic development projections shifted the 2050 upper emission range down by 1,5–3,2 GtCO$_2$eq. (Fig. 1). It was not the mitigation ambition that was hampering the economic growth; vice versa, the economic slowdown resulting from the persisting resource-based economic model and subsequent downward revision of economic perspectives led to a substantial correction of GHG emission estimates. Post-2015 scenarios mainly studied the possibility of attaining carbon neutrality in 2050–2060 (Gaida and Grushevenko 2020). Makarov et al. (2018), using a multi-regional general equilibrium model, concluded that global compliance with the Paris Agreement commitments by 2030 will lead to a reduction in the average GDP growth rate in Russia by 0.2–0.3 percentage points, and further tightening of the climate policy will be responsible for additional reduction (0.5 p.p.) in 2035–2050. Other modelling studies agree that global decarbonization is expected to generate large economic losses (up to 26% of GDP to 2060) thus shrinking the Russian economy (Bashmakov et al. 2023d). One question that remains is: will domestic mitigation activities be working to aggravate or mitigate the problem? Safonov et al. (2020a, b), using the TIMES-RUSSIA model, tested the potential scale of energy related CO$_2$ emission reduction and found out that cutting it down to 88% below the 1990 level by 2050 is associated with mitigation costs of no more than 29 USD/tCO$_2$ by 2030, 55 USD/tCO$_2$ by 2040, and 82 USD/tCO$_2$ by 2050. They highlight the myopia of less ambitious strategies, which ignore the benefits of low carbon transition. Laitner et al. (2020) echoes these findings by showing a positive balance of productivity gains, declining energy costs, and reduced reliance of the Russian economy on fuel and basic materials exports (to be delivered by modernization) versus decarbonization costs. According to these authors, positive effects allow to accelerate GDP growth by 0.6% in 2015–2030, and by 1.3% in 2030–2050. In contrast, Porfiriev et al. (2020) and Shirov and Kolpakov (2023), using an analytical toolkit based on the input/output method argue that deep GHG emission reduction (labeled as *Aggressive scenario*) will bring down average annual GDP

growth rate by 1.8 percentage points by 2050. They advocate the *2F* pathway. Porfiriev et al. (2020) call to limit mitigation efforts by allowing to increase fossil fuels use and limit net GHG emission decline to 42% below the 1990 level, compared with -51% reported in the 2022 national inventory. *Russia's Low Carbon Strategy to 2050* specifies few quantitative parameters and – only to 2050. Carbon neutrality is not achieved in the *Strategy's* target scenario.

The estimates to 2060 in the first scenario emerged after 2020. Shirov and Kolpakov (2023) adjusted their earlier projections and extended the time horizon to 2060. They concluded that on the 2060 horizon, economic growth in the *Aggressive scenario* is 0.6 percentage points per year higher, than in the *Inertia scenario*. They push through a less ambitious *Target scenario* with limited emission reduction in many sectors and even some growth in industry and agriculture, but with LULUCF sinks scaled up by about 1Gt (see Section 4 below) arguing that it would allow to generate additional 0.5 percentage points on top of the *Aggressive scenario.* In contrast, (Bashmakov et al. 2022; 2023c; 2023d) argue that *Forest Last* pathways to carbon neutrality are feasible and not associated with additional costs, and that transition to such pathways would be an economic driver. Modelling efforts miss many of the details which are important for roadmapping. This paper contributes to bridging the gap between the modeling outcomes (indicators and costs associated with decarbonization pathways) and the decisions to be made by the policy community to ensure conditions for the transition to, and moving along, the low carbon pathways.

3 Methodology and tools

The development of energy transition roadmaps for the economy has become an important tool for climate policies, as it allows to coordinate the actions of stakeholders both spatially (between the sectors, authorities, business circles, and population, between individual policies, their developers and implementers), and temporally (early commercialization of the required low carbon technologies and the development of regulations to expand the market niches for these technologies; setting up institutes that are capable of implementing the developed administrative or market incentives; timely and good-quality personnel training; etc.

This paper describes the roadmaps developed for the entire economy, for the power sector, district heating sector, carbon intensive industries, road transport, residential buildings, and hydrogen production. There are a variety of approaches to the development of roadmaps and different coverage of activities: national (see SDSN and FEEM 2019; Shankar et al. 2022.); sectorial (UNEP and IEA 2020) and for promotion of individual technologies (IEA 2020, 2021b). Five metrics, or pillars, of the Russian low carbon transition policy are used: technologies; regulations, including strategic documents and programmes; financing and economic incentives to attract financing; institutes responsible for the implementation of the specified policies; human capital capable of setting all of the low carbon transition mechanisms to work in the desired direction and at the desired pace. A number of technologies are considered for each sector; the target scale of deployment of these technologies ensures that Russia will attain its carbon neutrality target in 2060 (Bashmakov et al 2023c). A regulations and incentives roadmap is essentially a motivation roadmap (Rinaudo et al. 2023) since it includes administrative and economic mechanisms that help push the low carbon goals higher on the decision-makers' agenda by providing additional propulsion with financial incentives and professional status improvement perspectives. An important

aspect of the development of effective climate policies is a careful analysis of how these policies can impact the positions of the economic agents and their ability to consolidate – formally or informally – to use a variety of institutes to promote or confront these policies (Bashmakov 2023b).

The institutes and human capital roadmap is the one required to provide resources for the policy interventions to both competently design and give momentum to low carbon policy mechanisms. The phrase "Cadre are the key!" is well-known. However, one often has to add: "but a wrong one". So as to set the low carbon transition mechanisms to work, we need institutes to give them momentum. The charters or statutes of these institutes should clearly spell out the low carbon transition objectives. However, even this is not enough. All of these institutes must be provided with well-trained, highly qualified personnel. The importance of this component can be illustrated using the energy efficiency policy in Russia as an example. After the State Programme "*Energy Saving and Energy Efficiency Improvement to 2020*" was adopted in Russia in 2010, followed by a number of regional and municipal programmes, many national and regional ministries and agencies appointed officials responsible for the development and implementation of these programmes. More than 100 energy efficiency agencies were set up on the regional and municipal levels. Dozens of thousands of experts worked to implement these programmes. However, after 2014, these activities were curtailed. Today, one will hardly find 5 people in all of the federal ministries and agencies who are working on energy efficiency policies in Russia. In addition, qualifications are as important, as the numbers. To sum up, Russia has lost the energy efficiency race. In 2021, it was 186th in the list of 193 countries ranked by their energy productivity (energy productivity is the inverse of energy intensity).

In this paper, the target scale of deployment of low carbon technologies and the effects of using low carbon policies were estimated using a system ("a cloud") of interconnected models developed by CENEf-XXI (Bashmakov et al. 2022).[12] Scenario *4D – Development Driven by Decarbonization and Democratization*, which opens the door for Russia to return to the global economy, was selected for following roadmapping.[13] It relays on the following assumptions:

- progress towards termination of Russia's military operation in Ukraine will relax sanctions and enable Russia to regain some of its positions in the global value chains after 2030;
- proactive decarbonization policies in Russia will help the country to get a market niche in some global regions for a variety of products with low or no carbon footprint and get access to the hardware and software needed to produce low carbon products and services;

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[12] They are grouped around ENERGYBAL-GEM-2060, which is the core multisectoral model. The 'cloud of models' includes: macroeconomic model RUS-DVA; model for the power and heat sector P&HMOD; model for industry INDEE-MOD; model for transport TRANS-GHG; models for residential and public buildings RESBUILD and PUBBUILD. Some of the calculations for residential buildings were made using "EKR Assistant" –a model developed by CENEf-XXI for the Housing and Utility Reform Foundation –and a model for GHG emissions from the waste sector WASTE.

[13] Two more scenarios were considered in Bashmakov et al. (2022): *4S – Stagnation, Sanctions, Self-Sufficiency,* which may be alternatively titled *Forward-to-the-Past* (as the opposite to the *Back-to-the-Future*), and *4F – Fossil Fuels for Feedstock*, which builds upon *4D* and allows Russia to use its fossil resources for non-energy use.

- democratization will develop, as the role of the oil and gas sector will be shrinking, and reliance on a wider political and social spectrum will become key for sustaining social stability and inspire business activity. All this will bring more competition into the economy (while the role of the government will be declining), free up initiative, reduce migration intentions of qualified workforce, and attract skilled professionals from abroad to work in Russia. It will reduce corruption and provide incentives for investment and rewarding based on skills, rather than on loyalty;
- relaxed or removed high-tech import sanctions, competition-based incentives to invest in new technologies, and re-gained access to international financing will improve total factor productivity and therefore spur the NOG sector development with a growing potential to fill the income gap from the oil and gas revenues drop;
- growing potential to increase low carbon products/services production will accelerate phasing out obsolete capacities and boost modernization of the remaining capacities;
- higher demand for additional production in the domestic and international markets will significantly scale up capacity additions that perform to the BAT standards;
- low carbon footprint requirements for products and services will provide incentives to reduce scope 1 emissions via improved energy and material efficiency, circular economy, and electrification, CCUS and hydrogen application and scope 2 emissions via promoting low carbon energy penetration, including renewables, both in grid and off-grid systems; hydrogen-based technologies; CCUS; electric vehicles; and other low carbon technologies, as they reach the commercialization stage;
- the need to make low carbon technologies competitive at their initial deployment stages, along with a potentially wide geographical and products-wise spread of CBAM-like mechanisms supported by the Sakhalin experiment results (if positive), will inspire the launch of a CO_2 price mechanism at the national level.

In the *4D* scenario, GDP is only 10% above the 2021 level. These modest growth rates are determined by 54% reduction in GDP resulting from the global decarbonization and lack of sophisticated oil and gas extracting technologies, on the one hand, and only 24% growth in non-oil-and-gas GDP as limited by severe labour shortage and low multifactor productivity, on the other. In this scenario, 3 USD/tCO_2 carbon price is introduced in 2031 and steadily grows to 108 USD/tCO_2 in 2060 (for more details see Bashmakov et al. 2022).

The logic behind roadmapping necessitates getting clear answers to the following seven questions: what do we know about the problem? what do we want to change? what is in the way? what we will and will not do? who will be responsible for what? are we doing this right? how will we know that we have made the changes we need?[14] We already have a clear answer to the first question (What do we know about the problem?) – the climate is changing very dangerously, including in Russia. The answer to the second question – what do we want to change? – is provided in the *Climate Doctrine of the Russian Federation: "The key long-term goal of the climate policy is to achieve no later than in 2060 – with an account of national interests and social and economic priorities – a balance between the anthropogenic greenhouse gas emissions and sinks"*.[15] This is an even more ambitious goal, than attaining carbon neutrality (a balance of emissions and absorption for CO_2 alone). The answer to the third question – what is in the way? – is as follows: a weak

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[14] How Do We Create Our Roadmap? (Logic Model) (promoteprevent.org).

[15] Executive Decree of the President of the Russian Federation No. 812 of October 26, 2023 "On approving the Climate Doctrine of the Russian Federation".

(imitational, Korppoo and Alisson 2023) GHG emission control policy. Russia, disorientated by the myths of the past (Bashmakov 2018), has long tried to look into the future with its back on it, making ironical comments and looking down on the other countries in a hope that the era of its worshipped fossil fuels will never come to an end and it will be able to skillfully balance on the tip of the oil-and-gas "needle" for a long time or even use this tip for their political purposes Bashmakov 2023a). The roadmap should aim to answer the last four questions: what we will and will not do? who will be responsible for what? are we doing this right? how will we know that we have made the changes we need? The roadmap should ensure: correct prioritization; clear key and intermediate strategic goals; consistency of both goals and tools; division of labour and coordination between all stakeholders to achieve the goals; and it should lay the basis for negotiations with the key parties and provide a basis for compromise, if need be. Two time intervals are considered: short-term – to 2030; and long-term – to 2060. Standard roadmap templates are used for all sectors. An important part of the template is five pillars (technologies; regulations and programmes; incentives and financing; institutes; and human capital) structured in a way which allows it to address three domains of low carbon policies (satisficing, optimization and system transformation). Such methodological approach allows it to bridge the gap between the modeling outcomes (decarbonization pathways) and the inputs to enable effective policy decision-making.

4 Key fork in carbon neutrality pathways

Russia made an ambitious pledge to attain a balance between anthropogenic emissions and sinks in 2060; these involve not only CO_2 (which would mean attaining carbon neutrality), but all of the greenhouse gases. This might have happened because *Climate Doctrine* drafters do not read the IPCC reports carefully. The Sixth AR of WG III shows, that the global warming can be limited to 1.5–2 °C without bringing *all GHG* anthropogenic emissions balance to zero in 2060. A net zero is only required for CO_2, whereas for methane, N_2O, and other GHG, emissions are to be cut substantially, yet not to zero. The family of scenarios describing the transition to carbon (GHG) neutrality by 2060, as developed after Russia made a carbon neutrality pledge in October 2021 and started its military operation in Ukraine in February 2022, is still quite limited. In fact, as of late 2023, there are three scenarios developed by CENEf-XXI (Bashmakov 2022; Bashmakov et.al. 2022; Bashmakov et al. 2023d) and a few scenarios by IEF RAS (Shirov and Kolpakov 2023), The latest research provides the results to 2060 only for the *Target scenario*. The results of their other two scenarios are presented only to 2050. The estimates published by Klepach et al. (2023) are also confined to the 2050 and present rather pessimistic assessments of GHG mitigation possibilities in many sectors (even more cautious, than those by Shirov and Kolpakov 2023) and an uncertain conclusion on the possibility to attain carbon neutrality.

The first fork was manifested during the preparation of the *Russian Low Carbon Development Strategy to 2050* and produced two fundamentally different visions of the low carbon strategy. This fork persisted in the scenarios that emerged after the carbon neutrality commitment was made in October 2021 (Fig. 2):

- *Forest First (2F)*. *Russian Low Carbon Development Strategy to 2050* and the calculations by Shirov and Kolpakov (2023) that supported this document make a focus on doubling CO_2 net sinks in LULUCF along with a moderate reduction, or even increase,
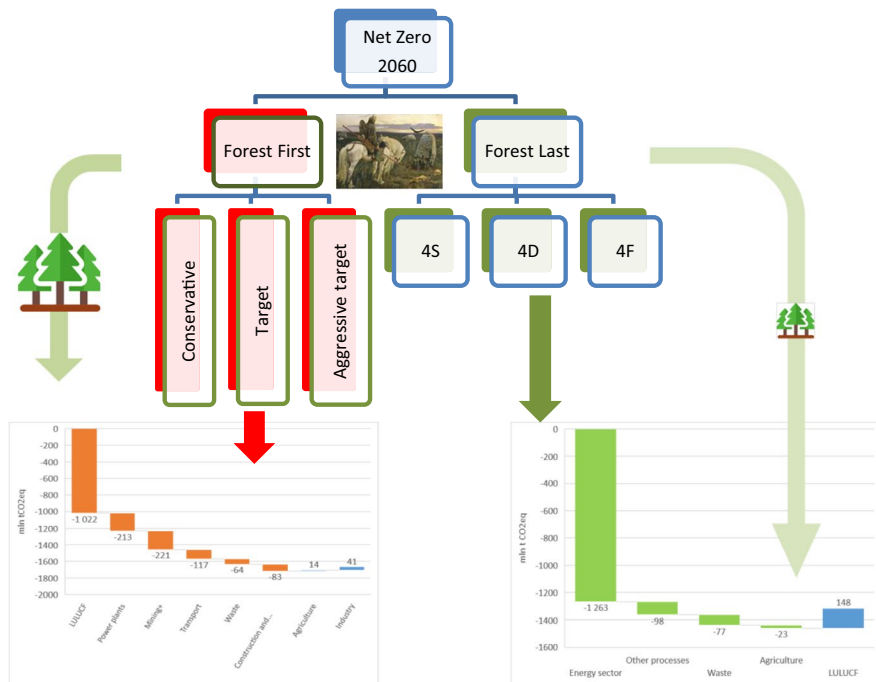
Fig. 2 Key fork in carbon neutrality pathways [Sources: Bashmakov 2022; Bashmakov et al. 2022; Bashmakov et al. 2023d; Shirov and Kolpakov 2023)]

of GHG emissions in some sectors (industry, agriculture) to achieve carbon neutrality. Additional sequestration in LULUCF seems an extremely ambitious, not to say unrealistic, target (see below). The entire *Strategy* is practically based on one 'forest' pillar, which entails substantial risks of not achieving carbon neutrality in 2060.

- *Forest Last.* This vision is reflected in the works by CENEf-XXI (*4S, 4D,* and *4F* scenarios Bashmakov 2022; Bashmakov et al. 2022; Bashmakov et al. 2023d).[16] It focus on substantial reduction of GHG emissions from all sectors, and see reductions in LULUCF as Russia's last hope for achieving carbon neutrality. Therefore, net sinks in LULUCF are defined as those to close the balance to achieve carbon neutrality in 2060.

Take to the left – … and you'll find *Forest First.* This pathway ensures that GHG emissions will freeze until 2030. Then there is expected an unrealistic growth in LULUCF sinks, an increase in industrial and agricultural emissions, a moderate decline in buildings, a substantial drop in the power sector, other energy and transport sectors with a totally unfeasible drop to zero in the waste sector. Take to the right – … and you will find *Forest Last.* This pathway ensures carbon neutrality, which leads to zero net CO_2 emission in 2060 and brings net all GHGs emissions 75% down. This decline is relatively smooth and covering all sectors. In contrast to the *Forest First* net sinks in LULUCF scale down (Fig. 2).

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[16] Experts from IEA, bp, HSE and RANEPA (bp 2023; IEA. 2021a; IEA WEO 2015-2023; IEA ETP 2017-2023; Laitner et al. 2020; Safonov et al. 2020a, b; Fujimori, et al. 2020) have similar visons with projection horizon limited to 2050.

A low carbon strategy should that much not rely on sink increase in LULUCF. Moreover, the sector which the Russian government is putting high hopes on may become the key driver behind net GHG emission growth. Net sinks in LULUCF were down from the 2010 peak (698 $MtCO_2$eq) to 485 $MtCO_2$eq in 2021. In 2021, this decrease was the main driver behind the net GHG emission growth in Russia. On average, the sinks were declining at a rate of 19.4 $MtCO_2$eq per year over this period. If this trend persists, the sinks will be 756 $MtCO_2$eq down in 2060, and so this sector will become a significant emission not sink, but source (756 $MtCO_2$eq – 485 $MtCO_2$eq = 271 $MtCO_2$eq). Estimates from the ROBUL-M model were used as a baseline; they showed that LULUCF may become an emission source in 2050 with 56 $MtCO_2$eq, or the sinks will be down to 277 $MtCO_2$eq. (Zamolodchikov et al. 2017). According to Korotkov[17] (based on the CBM-CFS3 model), net CO_2 sink will not increase in 2050, but will shrink to 367 $MtCO_2$ due to ageing forests. However, the *Strategy* relies on the potential increase in LULUCF sinks to amazing 1.2 $GtCO_2$ in 2050, and in the projection by IEF RAS this logic is extrapolated to 2060 (to fantastic 1.626 $GtCO_2$eq). This means an increase in sinks by over 1 $GtCO_2$eq, using the estimates of IEF RAS for 2021 sink, or by 1.141 $GtCO_2$eq, using the 2021 national inventory data. With an account of the downward trend in net sinks, LULUCF projects should deliver additional sinks of fantastic 1.26–1.9 $GtCO_2$eq.

5 Is *2F* pathway feasible?

According to the Shvarz and Ptichnikov (2022) by reducing fire emissions, undertaking climate change adaptation measures in the forestry, implementing climate projects in the Russian forests and revising the accounting methodology for GHG absorption by forests, it is possible to increase the sinks by a maximum of 380 million tCO_2 per year. Another studies (Ptichnikov et al. 2023; Ptichnikov and Shvarz 2023) indicate, that the potential for cost effective sequestration through climate projects (with costs below USD30/tCO_2) is limited to 200 $MtCO_2$eq/year to 2050, and the potential for GHG sink increase through methodology revisions is about additional 85 $MtCO_2$. The analysis of data from forest projects against the field measurements shows, that the large part of the projects either did not manage to reduce deforestation, or the results were much below ones expected (West et al. 2023). Romanovskaya (2023) believes, that the focus on increased GHG absorption by forest and other ecosystem projects in the Russian strategic documents raises questions, and that these projects incur larger risks, than projects in the industrial sector.

2F is essentially a scenario of Russia abandoned by its population. According to Roslesinforg, it takes a forest planted on 2.5 ha to reach the age of 10 years to be able to absorb 1 ton of carbon (3.7 tCO_2). That is, the ratio is 1 tCO_2/0.68 ha. According to other data, given the current species/age structure of mature forests in Russia, it takes 0.56 ha (Schepaschenko et al. 2021) to absorb 1 ton of carbon, or 1 tCO_2/0.15 ha. If this is the case, then it is necessary to plant 857–1,292 Mha of forest (according to the Roslesinforg estimates) or 189–285 Mha (according to the alternative estimates) to increase the sinks by 1.26–1.9 $GtCO_2$. And this is provided that there will be no losses from wildfires and pests. According to Rosstat, total land area in Russia is 1,712 Mha, farmland is 222 Mha, forest-covered

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[17] How much CO_2 do Russian forests absorb and how much more can they absorb? (climate-change.moscow).

area is 871 Mha, developed property and road-covered land is 14 Mha, water-covered land and swamps are 227 Mha, other land is 393 Mha, including 335 Mha of reindeer pastures in tundra, where forest does not grow, 4 Mha of deserts, and the remaining land is covered by landfills, urban waste disposal sites, ravines, and bare rock.[18] This is to say, that the *2F* pathway requires that a substantial part of, or all of the farmland, and part of other land where forest cannot grow, be planted with forest.

Before proceeding to the development of a *4D* roadmap, it is important to make a few comments about the scenario trajectories to carbon neutrality as developed by the IEF RAS (Shirov and Kolpakov 2023). First. The *Aggressive Target* scenario developed by IEF RAS *ensures that Russia achieves carbon neutrality in 2050, providing GDP grows acceleration at a rate of 0.6% per year compared to the Inertial scenario,* in which net emission is 19% up in 2050 (the paper provides no data for this scenario to 2060). Addition in average annual growth rate for household consumption is even higher – 0.8% per year. This is an important result: according to IEF RAS, carbon neutrality can be attained even in 2050, providing the economic growth is accelerated. Low carbon investment is 3.5% of GDP. It appears that the models used take no account of the learning curves, which show that specific costs go down as the technology uptake grows. Investment in conventional fuel technologies should go down; however, this is not reflected in the projections, and so the change in the overall investment cannot be estimated. Real electricity price is projected to rise by 61% over 29 years, which means 1.7% growth per year. However, all this does not hamper GDP growth. It is not clear, how fossil fuel costs will be declining, but they should be going down along with the declining demand; therefore, the share of energy costs should not increase.

Second. *The Target scenario* extends the carbon neutrality horizon to 2060 accelerating the growth of GDP and household consumption by another 0.5% per year. The authors conclude that the optimal share of low carbon investment is 1.7% of GDP in 2050. It is not clear, however, how this conclusion was arrived at. Annual GDP growth in Russia of 2.6% in this scenario seems clearly overestimated, because the country faces severe labour shortages on the whole 2060 horizon and has had negative multifactor productivity values for the last 15 years (Bashmakov 2023a). Average annual GDP growth rates in 2008–2022 did not exceed 1%, while IEF RAS arbitrary sets it at 1.5% even for the Inertial scenario.

Third. The authors use an indicator – specific capital investment per unit of GHG emission reduction – to assess the costs. It is determined by dividing total investment over the entire projection period by the associated reduction in net GHG emission in 2060 (it doesn't say cumulative reduction). However firstly, the usual practice is to assess incremental capital investment (IEA 2022 ; IEA, 2023; Bashmakov 2014; Bashmakov et al. 2023d; Safonov et al. 2023), because money is invested not so much to reduce GHG emissions, but to generate revenues from power generation, products manufacturing, transport work, housing construction, etc. The share of incremental investment associated specifically with GHG emission reductions can vary between 0 and 100% depending on the technology, and so attributing the entire investment to only one effect is incorrect. Secondly, when estimating the costs of GHG mitigation it is typical to assess levelized costs with an account of energy cost savings, reduced emissions of harmful substances, reduced down time, increased product output, etc., rather than only specific capital investment. And thirdly, even in the selected method of comparing the costs, the authors do not take into account the fact that the GHG mitigation effects will persist even beyond 2060, for some

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[18] State (National) Report on the status and use of land in the Russian Federation in 2021. Federal Service for State Registration, Cadastre, and cartography. Moscow, 2022.

technologies and buildings for several decades. In other words, specific capital investment as given by IEF RAS is well overestimated, and technologies should be compared using different metrics, such as levelized costs, building lifecycle costs, car ownership costs, etc. If wrong metrics are chosen for cost assessments, optimization of these metrics makes little sense. Moreover, the applied model has no price elasticities to allow for demand reactions and technologies competition, and so carbon pricing doesn't affect investment decisions.

6 4D scenario: GHG and CO_2 emissions reduction targets setting

A *roadmap* is a plan to achieve a goal or a given vision of the future.[19] In this paper, the vision of the future is the *4D* scenario from the *Forest Last* family of scenarios (Fig. 2). Its parameters in terms of economic growth, changes in the structure of technologies used, the dynamics and structure of GHG emissions, and assessments of the distributional effects of low carbon policies are described in detail in the series of works of CENEf-XXI (Bashmakov 2023a, 2023b; Bashmakov et al. 2022; 2023c). There is no single solution in sharing emission quotas and setting emission reduction targets for sectors. Below only one option is presented developed based on 4D scenario to contrast the *2F* scenarios family.

The resulting dynamics of GHG and CO_2 emissions by the key sectors as shown in the national GHG inventory is shown in Fig. 3 and 4 along with the milestones by decades (Table 1). The net balance of emissions and sinks will be achieved in 2060 for CO_2. As to all GHG, net emissions will be 91% down from the 1990 level, but will remain positive. Reduction in net emissions is expected as soon as in 2030 with a subsequent continuation by a nearly linear trajectory. At the same time, sinks in LULUCF will be gradually decreasing (dark green zone at Fig. 3), while the efforts made in this sector will allow for a partial offset (by 248 $MtCO_2$ – light green zone at Fig. 3) of this loss of 396 $MtCO_2$. Emissions will be going down in all sectors. There is no CO_2 emissions from the waste sector. There are small amounts of CCS in power and industry sectors. Absorption of CO_2 by concrete is shown only for illustrative purposes as it is not yet part of GHG inventories (see GCCA 2021; Cao et al. 2020; Guo et al. 2021; Bashmakov 2023c). Some countries already started evaluation of national potential for such sink (Sanjuan and Mora 2020).

The less progress is achieved in mitigating emissions from fuel combustion and industrial processes, the larger the light green zone needs to be for 2060 neutrality commitment to be met. Weak progress in emission reduction ultimately would shift the pathway at Fig. 2 from *Forest Last* to *Forest First*. But the last has severe limitations in providing needed sinks volumes, thus making neutrality commitment without reach.

7 Three domains and five pillars of low carbon policies

On the business-as-usual pathway, none of the decarbonization goals as outlined above can be achieved. Solutions that can help change the inertial trajectory are required. There are three basic models of making investment and management decisions (Grubb et al. 2023):

- *Satisficing* is a 'non-optimal behavior', or 'limited rationality' model; in this model, people follow the established stereotypes and are not economic locators looking for,

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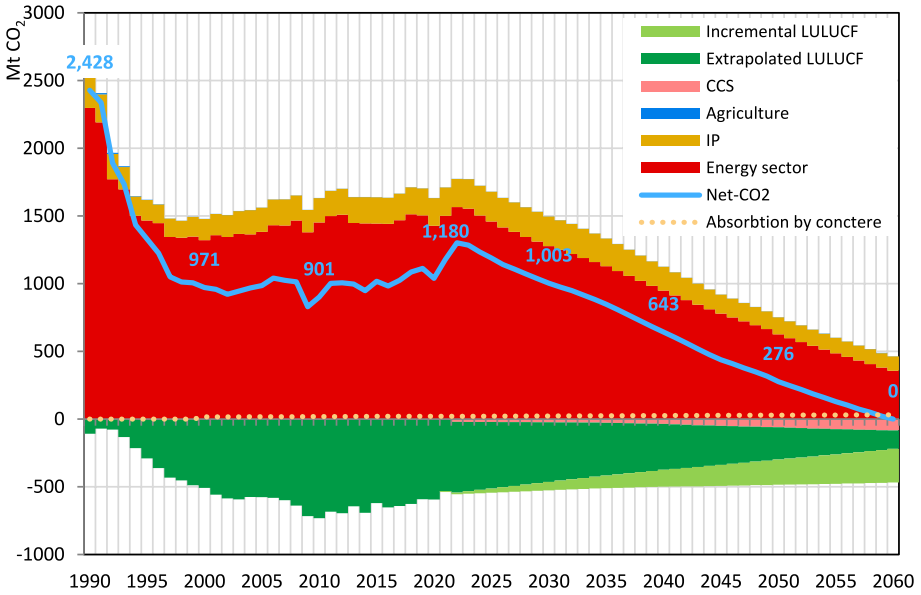[19] ROADMAP | English meaning—Cambridge Dictionary.

Fig. 3 Evolution of CO$_2$ emission by sectors to achieve carbon neutrality in *4D* scenario [Source: estimated by author using CENEf-XXI's model set]
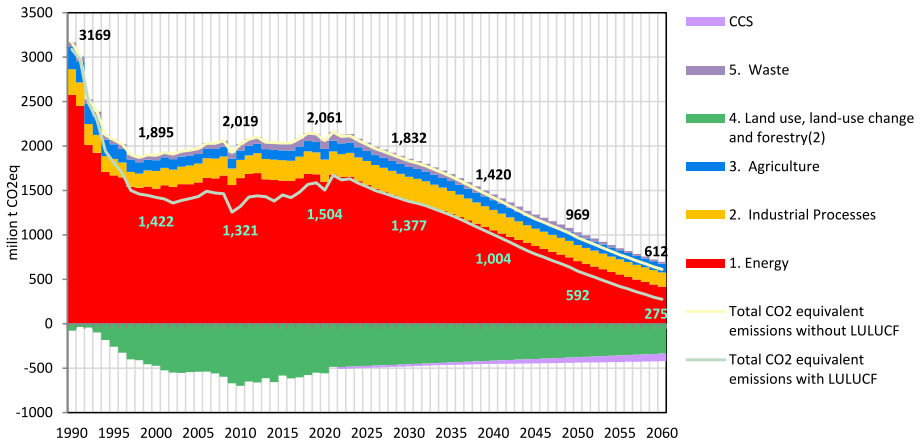

Fig. 4 Evolution of GHG emissions by sectors in *4D* scenario [Source: estimated by author using CENEf-XXI's model set]

and using, every opportunity to reduce costs or maximize their wealth. The role of price factors in decision-making is limited, as long as the energy cost share is moderate. As a result, excessive amounts of energy and other resources are used due to the lack of information, motivation, access to financing and to centers of decision-making.

- *Optimization* is the area of neo-classical theories and theories of wealth maximization, which assume that a typical market agent (*homo economicus*) aspires to optimize his costs and benefits. It is largely used by companies with a relatively high energy cost

Table 1 GHG and CO_2 emissions reduction targets in 4D scenario

	2021	2030		2040	2050	2060	
Net GHG emissions, MtCO2eq	1504	1375	-9%	1003	592	275	-72%
Net CO2 emission, MtCO2eq	1180	1001	-15%	642	276	0	-100%
Energy related emissions, MtCO2eq	1501	1275	-15%	932	618	353	-76%
Power generation, MtCO2eq	557	482	-13%	371	243	117	-79%
District heat production, MtCO2eq	355	315	-11%	280	228	174	-51%
Industry and construction, MtCO2eq	344	243	-29%	141	74	49	-86%
Transport, MtCO2eq	264	207	-22%	149	96	60	-77%
Buildings, MtCO2eq	516	491	-5%	432	342	245	-53%
Agriculture, MtCO2eq	27	26	-4%	21	20	15	-44%
Housing and utilities MtCO2	9	6	-33%	3	1,4	0,3	-97%
Industrial processes MtCO2eq	210	220	+5%	176	126	107	-49%
LULUCF, MtCO2eq	-532	-510	-4%	-479	-447	-415	-22%
CCUS MtCO2eq				8	31	52	

* Including indirect emissions. Therefore, total by sectors exceed the emissions in the energy sector.

Source: Bashmakov et al. 2023d

share, which – in a perfect market – choose the most cost-effective technology. Price and market incentives are key for this model. This is an area dominated by general equilibrium models, in which carbon price is the key GHG emission control tool. In these models, the behavior dictated by the *satisficing* model is typically reflected through low price elasticity coefficients. The values of the coefficients are mainly calibrated using

marginal price changes, but then they are applied to quite high carbon prices. Therefore, the fact that price elasticities are asymmetric and are determined by the energy cost share, is ignored (Bashmakov et al. 2024). For this reason, general equilibrium models overestimate the carbon price required to ensure that a given GHG emission reduction is achieved. In addition, part of the additional costs incurred is passed on to the consumers, thus diluting the decarbonization incentives. Another problem faced by general equilibrium models is looking at technological progress as an exogenous "manna from heaven".

- *System transformation* is the restructuring of the technological base and of the economic structure to promote going beyond the "limits of growth" or beyond the existing "limits of change" to address important strategic challenges, such as climate change. It is the responsibility of governments and international organizations to handle such strategic tasks. It is not an optimization problem, because both the set of perspective key technologies, and many of their cost parameters may be unknown at the start. This decision-making model relies on the innovation and structural change, creating large markets for new products, and building technological production chains based on the visions of the future and on the strategic investment.

The need for strategic decisions emerges when the existing technological and management systems run into the "limits of growth" or "limits of change". Scarce resources, and resources which can cause significant environmental or climate damage, get so much more expensive (either directly – via the internalization of externalities, or indirectly – through the damage/loss compensation costs), that the economic growth is terminated or substantially slowed down. When the energy and carbon cost share is low, other factors determine economic growth rates, while the role and effectiveness of price instruments is extremely limited (Fig. 5).

Thus, the combination of decision-making follows the change in the energy cost share in GDP (*ECS*). With small *ECS* satisficing behavior dominates. When the *ECS*, including carbon price, stays at 6–9%, economic agents optimize their costs trying to avoid going beyond the *ECS* thresholds. When *ECS* gets beyond the thresholds, economic growth slows down and strategic decisions are required to return to the positive dynamics. The deployment of carbon pricing mechanisms helps increase *ECS* and move decision-makers from the satisficing zone to the system transformation zone. External price shocks (energy price growth, enforcement of *CBAM*, etc.) can provoke going beyond the thresholds, therefore, carbon pricing mechanisms should ensure that *ECS* stays in the pre-threshold zone, including through proactive and effective system transformation.

A set of low carbon policies should foster the required change in the first two decision-making models and lay a basis to launch the third model. Policies, such as standards, product bans, labeling and other information tools, primarily aim to implement cost-effective measures, which are not being implemented for a variety of reasons under the *"satisficing"* decision-making model (Fig. 6). Carbon pricing mechanisms make low carbon solution more economically attractive, while strategic policies look to enlarge the emission reduction potential and to reduce the costs of new technologies.

Progress in any sphere helps ensure progress in all other spheres. Carbon pricing mechanisms work much more effectively, if carbon-intensive products are removed from the market by standards and product bans; energy consumption is metered and can be controlled; and there are calculators for timely and effective assessment of solutions. All the above factors help significantly reduce the share of economic agents who rely on the satisficing model. Setting a carbon price at a level that will keep the *ECS* close to the upper threshold
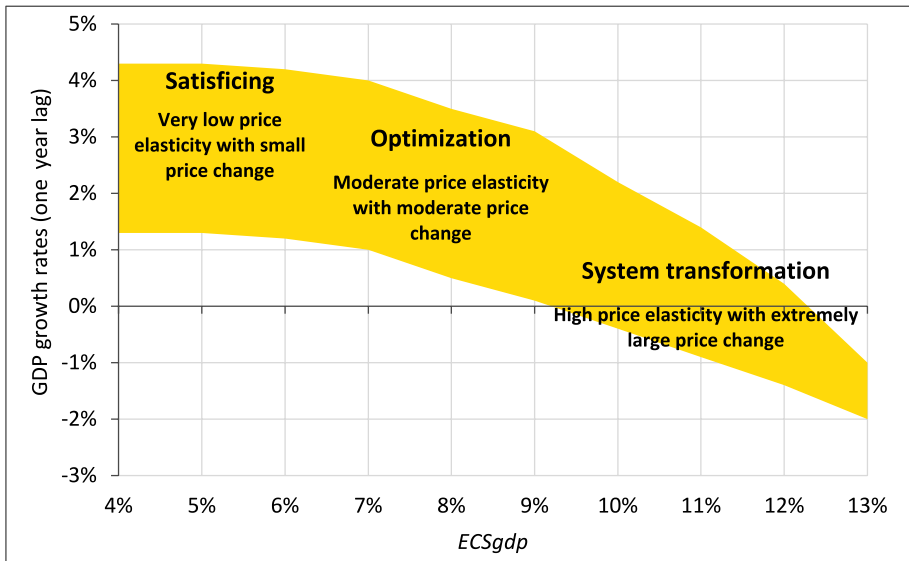
Fig. 5 Stylized "wing" function (the function of GDP growth (1 year lag) of ECSgdp) and three types of investment and management decision-making [Sources: Bashmakov 2017; Bashmakov et al. 2024]

helps to avoid the rebound effect, encourages R&D in low carbon technologies, and helps reach price parity more quickly.

The above targets can be achieved through a variety of policies to introduce the low carbon component into the three decision-making models as specified above, and to develop and reenforce five pillars for sustainable and effective GHG mitigation (Table 2):

- **Technologies** – availability of a wide variety of technologies and equipment for GHG mitigation in all sectors. Three technological gaps are to be addressed: technology readiness level gap – lack of affordable low-carbon technologies with a high level of technology readiness; supply gap – lack of technologies, installation and operation capacities in the Russian markets at a scale sufficient for moving along the traced pathways to carbon neutrality; localization gap – lack of self-sufficiency in equipment and critical materials production to mitigate the risks of potential interruptions in equipment imports, or the risks of monopolistic abuses in these markets by dominant suppliers, similar to what has been seen in the fossil fuel markets for decades (Bashmakov et al. 2023c);
- **Regulations and programmes** – mandatory requirements that allow for policies and coordinated action to achieve the targets as specified in the national strategies and programmes;
- **Incentives and financing** – measures aiming to improve the economic attractiveness of low carbon technologies and to provide access to financing which is essential to comply with regulations and attain the targets;
- **Institutes** – organizations that are authorized to launch and coordinate decarbonization processes and are responsible for the results, and agencies that represent low carbon transition stakeholders;
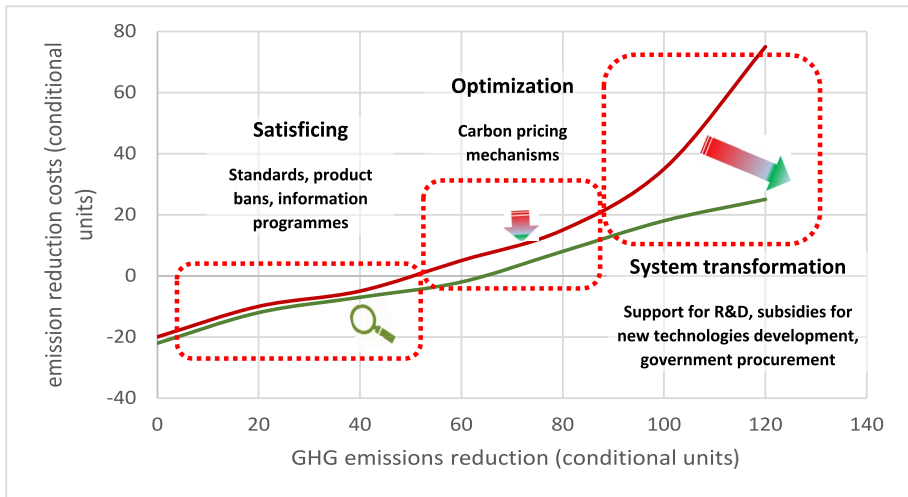
Fig. 6 Low carbon policies as a function of GHG mitigation costs [Sources: adapted by the author from: The World Bank (2016)]

- **Human capital** – a sufficient number of experts with adequate training who are engaged in policy development, organization and implementation of low carbon transition; providing these experts with knowledge, information, and tools for decision making.

Five pillars of the economy-wide low carbon policy are shown in a quite general way in Fig. 7.[20]

8 What needs to be done?

In each sector, the combination of technologies, policies, incentives, institutions, and human capital is quite specific (Bashmakov et al. 2023d). Below only the key components are listed for several sectors. Combination of such components allows to address all three basic models of decisions making (Table 2). An effort is made to go beyond just the scale of technologies application, emission trajectories and associated costs, which are typically reported by modelers. The goal is to highlight the importance of other pillars, such as regulations and programmes, incentives and financing, institutes, and human capital, which are required to induce the projected mitigation (Table 1).

Power sector: setting GHG mitigation targets; launching national mega-project for renewable energy with ultra-megawatt windfarms and off-shore wind; higher scale and better performance of solar; development of new generation of nuclear power plants including small ones; closure nuclear fuel cycle; scale up grid accumulation systems, including pumped storage plants, hydrogen and battery storage systems; improve power tariffs, carbon pricing and fiscal mechanisms to support the penetration of wind, solar and nuclear

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[20] More details by sectors and technologies are provided in (Bashmakov et al. 2023d).

Table 2 Five pillars and three domains of low carbon policies

Five pillars	Investment decision-making models		
	Satisficing	Optimization	Transformation
Technologies	Technologies are in place. They are economically attractive, but for different reasons, incl. lack of motivation—low ECS*, or high monopolization their potential is untapped	Technologies are in place with acceptable payback parameters. They are basically used by market agents with high ECS, who are looking to optimize their costs in sectors with high competition	New technologies, which can shift the technological frontier; while they have high upfront costs, they have a potential to bring these costs down through the learning curve, as the deployment scale grows and through additional R&D
Regulations and programmes	Standards, product bans, licenses, certification, labeling and other information tools to increase the uptake of available technologies	Regulations to launch incentives and financial mechanisms and to set criteria for investment decision-making to improve the economic attractiveness of the available technologies	Regulations and programmes to develop innovative technologies, increase the localization levels, and to expand the application niche. Taxonomies
Incentives and financing	Subsidies, 'green' and 'white' certificates; programme financing	Tariff mechanisms; elimination of energy subsidies; carbon pricing mechanisms (emission trading, carbon tax); subsidies for low carbon solutions, tax and loan benefits; programme financing	R&D financing; priority access to the market; government procurement; programme financing, benefits and subsidies, carbon pricing mechanisms
Institutes	Development and adoption of regulations and programmes: Presidential Office, national government, Federation Council, regional and local governments. Enforcement of regulations and programmes – national executive bodies and agencies. Government support leverage – development agencies and other financial institutions. Monitoring – Rosstat, regional and local governments and subordinate agencies. Stakeholders: industrial and professional associations, civil society institutes. Human capital development – educational institutions and professional training agencies		Developers of new technologies and strategic technology priorities: national government and other development agencies; corporate sector, think tanks in different sectors, Russian Academy of Science (RAS), universities, innovative research centers, state research institutes
Human capital	Technological capacity building; personnel training to encourage technology uptake. Fostering new "green" skills and behavioral patterns		Availability of highly qualified personnel in strategic planning and development of new technologies

*ECS – energy cost share

Source: CENEf-XXI

Entire Economy

Technologies	Regulations and programmes	Incentives and financing	Institutes	Human capital

• Identifying key low carbon technologies
• Product carbon footprint upper levels, based on benchmarking
• Increasing technological readiness levels of low carbon technologies
• Low carbon technologies deployment targets
• Low carbon technologies domestic production targets
• Low carbon technologies localization level targets
• Development of infrastructure to upscale low carbon technologies deployment
	• Revisions of NDC every 5 years to increase the level of ambition
	• Development of a carbon neutrality strategy to 2060 and its subsequent revisions once in 5 years
	• GHG emission quotas or reduction targets by sectors and industries
	• Regulation to launch market and financing mechanisms and to set insitutions
	• Standards, bans and other administrative mechnisms
	• Integration of low carbon transition sections in sectorial strategies
		• Development of carbon pricing mechanisms, including CBAM adjustment, in sectors, and setting price change caps
		• Establishing a Low carbon innovations fund
		• Subsidies for low carbon technologies production and deployment
		• Tariff mechanisms to incentivize low carbon technologies uptake
		• Loans and guarantees
		• Tax benefits
		• Government procurement of products with low carbon footprint
		• Financing for high-potential R&D
			• Presidential Office
			• Russian government – substantial capacity building for low carbon transition process
			• Russian legislature
			• Regional governments
			• Municipalities
			• Institutional development
			• Sectorial associations
			• Corporations
			• Research and innovative organizations, think tanks, educational and engineering centers
			• Civil society institutes
				• Educational and corporative centers, work placements, and training for:
				  • Government officials
				  • Designers and experts
				  • Financial experts
				  • Households
				• Benchmarking systems, calculators to estimate carbon footprint, BAT inventories
				• Guidelines, trainings, menu of typical solutions
				• Certification of experts
				• Development of carbon and statistical reporting systems
				• New behavioural patterns

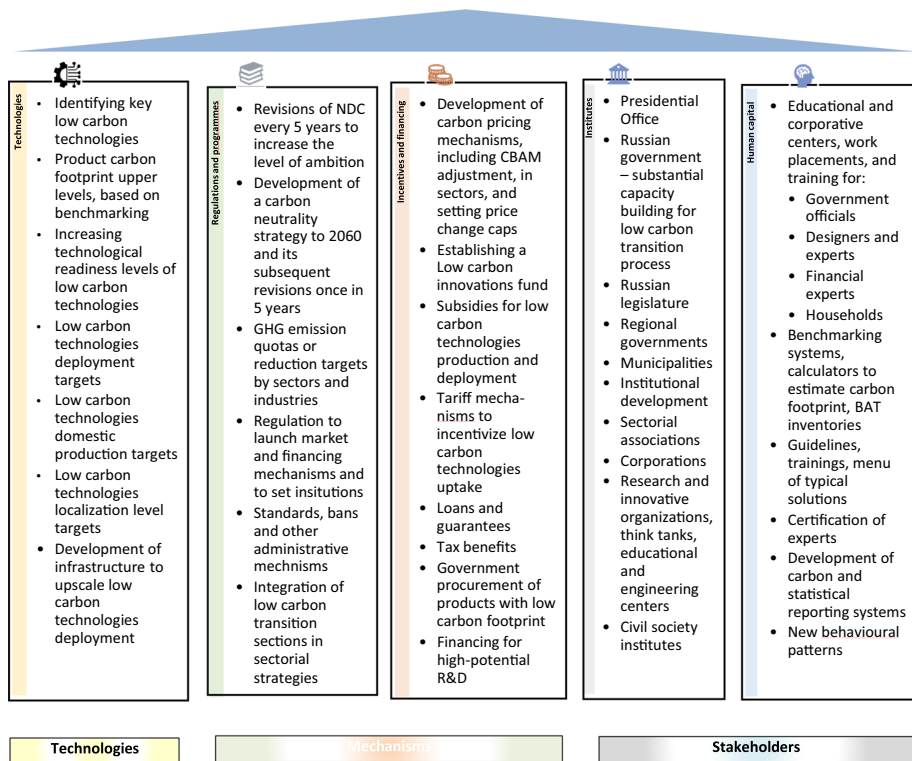| Technologies	Mechanisms	Stakeholders

Fig. 7 Five pillars for economy-wide decarbonization [Source: the Author]

along with power flexibility resource pricing; launch government procurement of 'green' energy and 'green' certificates schemes.

Heat supply sector: increasing penetration of 4th and 5th generation of district heating systems (DHS) with low temperature heat sources; integration of heating and cooling systems and integration of DHS into smart energy systems; setting minimum mandatory requirements to the share of district heat produced from zero carbon sources; introduction a ban of connecting new multifamily, public and commercial buildings to DHS below 4th and 5th generations; development of new heat market models and tariff setting practices including uptake of carbon pricing.

Energy intense industries: development of sectorial low carbon strategies, long-term agreements or decarbonization plans to promote low carbon technologies uptake including: DRI production with hydrogen and CCUS; aluminium production using pre-baked and 'inert' anode technology; cement production with increasing share of additives and secondary resources, using alternative fuel and CCUS; ammonia production using 'green' hydrogen and CCUS; create Low carbon innovations fund and focus existing Industrial development fund on supporting low carbon technologies; co-financing for R&D; introduce GHG carbon pricing mechanisms and launch government procurement of low carbon basic materials.

Road transport: develop of a national mega-project to enhance electric transport with a wide variety of electric vehicle (EV) models for various consumer groups, including of EV

for cold climates; develop of supply chains for EV production and localization; enforcement of low carbon car standards; launch agreements with car manufacturers on minimum required share of EV in output; government procurement of EV; carbon pricing for fossil motor fuels; co-financing for R&D.

Buildings: develop Federal programmes "*Active construction of passive buildings*" and "*Deep and large-scale renovation*"; develop and deploy of promising heat transfer resistance technologies: aerogels, foam ceramics, phase change materials and new technologies to balance heat supply and demand in buildings for 4th and 5th generation DHS, which integrate all energy supply and storage systems in buildings; provide tax benefits for developers demonstrating high energy efficiency performance and co-finance for deep energy efficient renovations; launch "green" mortgage and "white" certificates schemes; develop of a programme "*Renewable energy in buildings*".

Hydrogen: provide support based on hydrogen carbon footprint and localization levels of hydrogen and electrolyzers production; launch and increase mass production of gigawatt class electrolyzers with high localization levels; launch large-scale production of equipment and development of infrastructure for safe production, transport, and storage of hydrogen and hydrogen-based products with eventually increasing localization levels; launch regional hydrogen clusters (hubs) and first large-scale industrial projects as well as production of new generation hydrogen fuel cells; upscaling hydrogen production and use for energy storage.

Stakeholders are to undertake the responsibility. There are lack of institutions and human capital—competent personnel. These resources may be mobilized by making the decarbonization of the economy a national priority to be deeply integrated in sectorial strategies. It would require a breakthrough in administrative competencies and setting up decarbonization departments at the national and regional levels and improving their competencies including Russian President's Office, the ministries of economic development, energy, industry and trade, transport, construction, finance, agriculture, natural resources as well as in and other ministries, and agencies. Training programmes for these institutions for *ongoing* capacity building using information resources of research organizations, innovative think tanks, educational and engineering centers are needed. Financial institutions are important part of the overall picture. There is already taxonomy on low carbon technologies in place and some capacities built for low carbon programmes in the Central Bank, Sber; VEB.RF; DOM.RF; and other financial institutions.

Professional associations and corporations are key government counterparts in developing sectorial decarbonization strategies, long-term agreements or company level decarbonization plans. Some decarbonization capacities are built in large state corporations: Rosatom, Rosnano, Skolkovo, Territorial development fund, as well as in private corporations in such industries as power and heat generation, oil&gas, metallurgy, chemicals, building materials, innovative equipment, transportation, etc. As decarbonization moves to the forefront the number of employees and their competencies both need to scale up significantly. Till now SME are left aside. Much need to be done to take them onboard in travelling along decarbonization pathways.

Research, innovative, educational, engineering think tanks, design bureaus are key stakeholders in development of competencies and technologies and transfer them to stakeholders. Effective cooperation with government, development institutions and corporations is needed for commercialization of low carbon technologies. An order of magnitude increases in the number of trained specialists in renewable energy, electric vehicles, energy storage, 4th and 5th generation DHS, production of equipment for low carbon technologies and their deployment in the industrial sector, including hydrogen production; in

construction of low carbon buildings; in transportation, as well as environmentally friendly utilization of retired low carbon equipment is needed to make *4D* scenario happen. Government institutions need multiple increase in personnel training in the development, implementation and monitoring of low carbon policies.

For such policies to be effective the development of effective communication channels is a prerequisite: both top-down – to inform the business community and the civil society of the low-carbon decisions made; and bottom-up – to ensure participation of civil society in decision-making. Civil society needs development of competencies for climate-friendly behavior and decision-making as well as to ensure an ability to impact the national GHG mitigation policy. Analysis of distributional effects of proposed GHG control policies and deployment of policy decisions to make them neutral or progressive is a key in mobilizing the social support (Bashmakov 2023b) as well as networking for the leading GHG emissions experts and journalists to provide media with unbiased and top-quality information.

9 Conclusion

The carbon neutrality goal for 2060 is officially stated in the adopted in 2023 *Climate Doctrine of the Russian Federation.* However, many of the decarbonization plans are still short visioned and not too specific. This paper focus on a discussion of the forks on roadmap to carbon neutrality in Russia to inspire further discussion.

The main fork is: should the priority be given to the natural solutions in LULUCF or to deep modernization via applying the low carbon technologies in fuel combustion and industrial processes. Paper shows that official preference with dominant reliance on *2F (Forest First)* pathway is unrealistic as there is no space to plant forests to escalate carbon sinks by 1–2 $GtCO_2$. *Forest Last* family of scenarios, which focuses on substantial reduction of GHG emissions across all sectors is the only pathway capable to bring Russia to carbon neutrality destination by 2060. The less progress is achieved in mitigating emissions from fuel combustion and industrial processes, the smaller are Russia's chances to meet its carbon neutrality commitment by 2060.

This paper highlights the importance of bridging the gap between the models' outcomes (emission pathways and associated costs) and the framework needed for decision-making and ensuring the conditions for inducing the transition pathways. These conditions include five pillars: technologies; regulations and programmes; incentives and financing; institutes; and human capital. The load bearing capacity of these pillars in Russia should be considerably reinforced by policies which address and integrate three basic decision-making models: satisficing, optimization, and systems transformation. More research is required to bridge the knowledge gap on how to create an effective architecture for regulations, programmes, incentives, institutes, and human capital to deliver the desired mitigation outcomes.

Declaration

Competing interests The authors declare no competing interests.

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