Center for Energy Efficiency – XXI (CENEf – XXI)

Low carbon technologies in Russia: current status and perspectives

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Introduction

The IPCC has warned: the climate cannot wait and is very dangerously changing. The warming is already above 1.2°C from the pre-industrial level, and so the humanity has already gone beyond the safe and fair climate change (1°C, safe and just Earth System Boundaries (ESBs) for climate).[1] Many countries only recently made their decarbonization commitments. However, the IPCC Assessment Reports, which have been published over the past 30 years, have both warned about the dangers and risks posed by the global warming and proposed a wide range of low carbon technologies and policies to slow it down.

Five responses to warnings. There have been five key reactions to these reports. Some countries have looked into the future and begun to actively develop and promote low carbon technologies and create new markets for them (the EU and the UK). Others first hopped on, but backpedaled as the political situation changed; then returned on the pathway, but the precious time had been lost in hesitations (USA). Some other countries were quick to realize, that in the long run, low-carbon technology markets are a ticket to the future ensuring the best niches in trillion dollars-worth markets. They even tried to get ahead of time by creating large local markets to achieve economies-of-scale effects to break into, and dominate, the dynamically growing global low carbon technology markets (China). However, others (Russia), muddled by the myths of the past, have been trying to look into the future with their back on it, making ironical comments and looking down on the first three groups in a hope that the era of their worshipped fossil fuels will never come to an end and they 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. The fifth group of countries, which is the largest of all, would be happy to uptake low carbon technologies, but are severely limited in resources, primarily financial. The Paris Agreement and the 8 subsequent years became milestones for assessing the correctness of the course chosen by the countries.

On the way to decarbonization, the world has achieved little so far, but has become self-confident. Over the past 30 years, the global energy system has been unable to go through a real transformation and reduce GHG emissions.[2] However, there is an obvious progress: the level of climate ambition and its perception has changed dramatically. Current energy transition is expected to change the global economy and the energy landscape. Today, statements such as: Europe can end its reliance on energy imports; can cut primary energy demand by 55% in 2050 and meet it exclusively through renewable energy; can achieve climate neutrality by 2045-2050; or – China can attain carbon neutrality in 2060 – no longer seem impossible and crazy "myths of the future". The energy transition is becoming universal, intense and significant (changing the technological basis), and rich in opportunities, even if uneven and risky.

Even the optimists turned out to be pessimistic. The last 30 years, and especially the past 10 years, have shown that many of the low carbon technology development projections, quite optimistic for their time, turned out to be pessimistic. 10-20 years ago few people could believe, that in 2023, installed renewable electric capacity in China would be equal to the capacity of coal-

[1] Rockström J., J. Gupta, D. Qin, S.J. Lade, J.F. Abrams, L.S. Andersen, D. I. Armstrong McKay, X. Bai, G. Bala, S.E. Bunn, D. Ciobanu, F. DeClerck, K. Ebi, L. Gifford, C. Gordon, S. Hasan, N. Kanie, T. M. Lenton, S. Loriani, D.M. Liverman, A. Mohamed, N. Nakicenovic, D. Obura, D. Ospina, K. Prodani, C. Rammelt, B. Sakschewski, J. Scholtens, B. Stewart-Koster, T. Tharammal, D. van Vuuren, P. H. Verburg, R. Winkelmann, C. Zimm, E.M. Bennett, S. Bringezu, W. Broadgate, P.A. Green, L. Huang, L. Jacobson, C. Ndehedehe, S. Pedde, J. Rocha, M. Scheffer, L. Schulte-Uebbing, W. de Vries, C. Xiao, C. Xu, X. Xu, N. Zafra-Calvo & X. Zhang. 2023. Safe and just Earth system boundaries. *Nature* (2023). Safe and just Earth system boundaries | Nature

[2] Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G. J., Wiedenhofer, D., Mattioli, G., Khourdajie, A. A., House, J., Pachauri, S., Figueroa, M. J., Saheb, Y., Slade, R., Hubacek, K., Sun, L., Ribeiro, S. K., Khennas, S., de la Rue du Can, S., L. Chapungu, S.J. Davis, I. Bashmakov, H. Dai, S. Dhakal, X. Tan, Y. Geng, B. Gu and Minx, J. C. (2021). A Review of Trends and Drivers of Greenhouse Gas Emissions by Sector from 1990 to 2018. Environmental Research Letters, 16(7), [073005]. https://doi.org/10.1088/1748-9326/abee4e; Bashmakov I.A. Projections of the global energy system evolution 30 years later: Checking the lessons of the future by the past experience. *Voprosy Ekonomiki*. 2022;(5):51-78. (In Russ.) https://doi.org/10.32609/0042-8736-2022-5-51-78.

fired thermal power plants; or that by 2025 their output would exceed one third of total generation in this country; that in 2023, 440 GW of renewable energy capacity will be commissioned worldwide, which is twice the capacity of all generating sources in Russia; that in the first quarter of 2023, more than 50% of electricity generation in Germany will be from RENs; that in many countries, generation from RENs will become cheaper, than from fuel-fired power plants; that in China in 2022, more than 14 million electric vehicles will be sold; that Sweden will launch steel production using hydrogen instead of coke as a reducing agent; or that in Norway, heat pumps will be installed in 60% of buildings (and in more than 40% in Sweden and Finland).

The focus is on the gaps in the ambition and scale of expected low-carbon technologies production and uptake. As of September 23, 2022, 88 UNFCCC member-countries have made long-term commitments to attain net zero CO_2 emissions, covering 79% of global GHG emissions. According to the Net Zero Tracker, as of June 23, 2023, 149 countries have already declared carbon neutrality in one form or another.[3] They account for 88% of GHG emissions, 92% of global GDP, and 89% of the population. In addition, 147 regions in different countries (including Sakhalin), 252 cities and 937 large companies have made similar commitments. 19 of G20 members, including Russia, have made net zero emission pledges. Today, compliance monitoring frameworks are being developed at the national and supranational levels. Progress is monitored by the IEA (Tracking Clean Energy progress[4]), UNEP (Tracking mitigation progress[5]), and other organizations, such as Climate action tracker[6] and Climate policy initiative.[7]

This monitoring has detected three gaps:

- **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 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.

Concerns about these gaps can be seen through the focus shift in analysis and research, and then in political decisions. The IEA released *Energy Technology Perspectives 2017* and *Energy Technology Perspectives 2020* in 2017 and 2020 respectively, which focus on the assessments of the adequacy of supply scale, technical readiness and affordability of low-carbon technologies. The focus was on scaling up markets and stimulating R&D. The role of critical materials for their production was also revealed. Forecasts by the IEA, IRENA, BP, Shell and others have included sections on the balance of demand and potential supply of these materials, and expressed concern about the high regional concentration of their production in a limited number of countries. This concern reflects the reversal of globalization and supply disruptions due to the COVID-19 pandemic.

After the start of Russia's military operation in Ukraine, energy and economic security issues came to the fore with renewed vigor after the energy crises of the 1979s and 1980s. It has become clear, that the past and present reliance on the oil imports from OPEC+ countries and on the Russian gas is being replaced with a reliance of low-carbon technology supply chains on the imports from just one country – China. This is reflected both in the analyses of the IEA, IRENA and others, and in the US (*Inflation Reduction Act*) and EU legislation (*Critical Materials Act* and

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3 Net Zero Tracker | Welcome.
4 Tracking Clean Energy Progress – Topics - IEA.
5 Property:Tracking mitigation progress (quantitative) - Climate Initiatives Platform; UNEP, 2022. *Emissions Gap Report (EGR) 2022: The Closing Window – Climate crisis calls for rapid transformation of societies*. Nairobi. https://www.unep.org/emissions-gap-report-2022.
6 https://climateactiontracker.org.
7 Climate Policy Initiative - expertise in climate finance and policy analysis.

Net Zero Industry Act) aimed to increase the sustainability and localization level of supply chains. In 2022, the urgent task of achieving technological sovereignty was also formulated in Russia.

Practice has shown, that China's response to the decarbonization requirements was the most effective, while Russia's was the most inefficient. The question, whether or not this can be fixed, and to what extent? – is in the focus of the current research. This paper looks to assess the scope and prospects of bridging the three gaps (technological, supply and localization) on the 2060 horizon, when Russia is expected to achieve its carbon neutrality. This work is the continuation of CENEf-XXI' series of works related to the assessment of Russia's ability to achieve carbon neutrality in 2060.

The paper consists of 8 chapters. According to the tradition established in CENEf-XXI, Chapter 1 summarizes all the key findings. Chapter 2 describes the tools and methods used for the analysis and projections. Chapter 3 identifies key low-carbon technologies. Chapters 4 and 5 identify the technology priorities selected by Russia to attain technological sovereignty and the role of low carbon technologies for these selected priorities. Based on the above analysis, 30 technologies were selected for this study. Chapter 6 describes the current state of their production and uptake in Russia and plans for the coming years. Chapter 7 defines key performance indicators (in terms of uptake and annual commissioning) for these technologies in power and heat, industry, transport and buildings, to attain carbon neutrality. Chapter 8 assesses the scope and prospects of bridging the technology gap, the supply gap, and the localization gap. These assessments should serve a basis for decarbonization targeting and roadmaps in Russia's economic sectors.

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1 Summary for policy makers

1.1 The IPCC warns: climate cannot wait and is very dangerously changing

Practice shows, that China's response to the decarbonization urge is the most effective, while Russia's is one of the most inefficient. Five responses to the IPCC' warnings:

- Facing the future – active development and promotion of low-carbon technologies (EU, UK);
- Fluctuations driven by political change (USA);
- Expansion to new low carbon technology markets – creation of large local markets to gain economy-of-scale benefits and dominate in the global markets (China);
- Trying to look to the future with one's back on it in a hope that the era of the worshipped fossil fuel will never come to an end (Russia);
- Willingness to set off for the future with severe resource limitations - primarily financial (emerging economies).

On the way to decarbonization, the world has achieved little so far,[8] yet we have developed self-confidence.

Even the optimists appeared to be pessimistic and were unable to believe that:

- in 2023, installed electric capacity of renewable energy sources in China would come to parity with the coal-fired capacity;
- by 2025, renewable-based output will be more than one third of total generation;
- 440 GW of renewable energy capacity will be commissioned in 2023 alone, which is twice Russia's total power generation capacity;
- in the first quarter of 2023, Germany will generate more than 50% of its electricity from RENs;
- in many countries, generation from RENs will become cheaper than from fuel-fired power plants;
- in China, more than 14 million electric vehicles will be sold in 2022;
- Sweden will launch steel production using hydrogen instead of coke as a reducing agent;
- in Norway, 60% of buildings will be equipped with heat pumps.

The focus is on the gaps in the level of ambition and expected scale of low carbon technologies production and penetration

- **technology readiness level gap** – lack of affordable low-carbon technologies with a high level of technology readiness;
- **supply gap** – deficit of technologies, installation and operation capacities in the markets to enable progression along the carbon neutrality pathways;
- **localization gap** – lack of self-sufficiency in equipment and critical materials manufacturing to mitigate the risk of potential interruptions in equipment imports and of monopolistic abuses in these markets by dominant suppliers, similar to what has been observed for decades in the fossil fuel markets.

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

1.2 Tools and methods of analysis

The "cloud" of models developed by CENEf-XXI was used to determine the key performance indicators for carbon neutrality

- The 4D Scenario, as amended in 2023, was used as part of research titled '*Foreign trade, economic growth, and decarbonization in Russia*'.[9]
- The penetration scale and supply sources for low-carbon technologies were estimated by decades to 2060.
- Average annual demand for capacity commissioning were estimated to match the low-carbon technologies penetration targets.

Current scales and supply sources were assessed for low-carbon technologies penetration based on:

- the information resources of Rosstat and Federal Customs Service, national programmes and strategic documents;
- an extensive search for information in the literature and websites of Russia's leading companies, industry associations, and think tanks.
- Two or three links in the process chain are explored for the production of low-carbon technologies, and the levels of technological readiness are assessed on a 11-point scale.

1.3 Key low carbon technologies

Key low-carbon technologies are:

- those with relatively large GHG emissions reduction potential;
- those that can be implemented at reasonable cost.

In many cases, low-carbon technologies are already more economically attractive, than traditional technologies, so the implementation incurs no additional costs.

An important element that determines the boundaries for the analysis is the choice of metrics to describe individual low-carbon technologies:

- Market niche
- Technology implementation costs
- Technology readiness level
- Scale of penetration in Russia
- Level of production localization
- Availability of the necessary infrastructure
- Scale and sources of possible imports
- Export perspectives

Power generation:

- Nuclear, wind, solar, energy storage systems.

Industry:

- Eleven technologies in iron and steel and in the aluminium, cement and ammonia manufacturing.

Transport:

- Electrification of passenger cars and buses, production of electric batteries for road transport; installation of charging stations.

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[9] Bashmakov I. Russia's foreign trade, economic growth, and decarbonisation. Long-term vision. CENEf-XXI. https://cenef-xxi.ru/uploads/Policy_paper_0b89e06980.pdf.

Buildings:

- Insulation of buildings envelopes, heat supply regulation, heat pumps, decentralized photovoltaic power generation, solar water heaters and smart metering.

Hydrogen:

- Production of hydrogen and electrolyzers along with production of equipment for hydrogen transport and storage.

CCUS

- Carbon capture, transport, storage, and use.

1.4 Low-carbon development strategy and technology priorities

The "Low carbon development strategy to 2050" does not provide:

- estimates of the required scale of low-carbon technologies application;
- estimates of their effects;
- localization targets for low-carbon equipment and technologies.
- The Strategy only provides a list of low-carbon technologies.
- Many provisions of the *Action Plan (Operational plan for the implementation of the Low carbon development strategy)* only set the time lines for the development of a regulatory framework for the application of these technologies, but do not encourage their development or provide incentives for their upscaling.

1.5 Low carbon technologies and technological sovereignty policy priorities

In 2022, the goal of upscaling low carbon technologies to achieve carbon neutrality has been obscured by attempts to ensure the technological sovereignty

- In the recent policy and regulatory documents, preference is given to the development of nuclear power plants, hydrogen, production of electric vehicles, and energy storage systems – of all low carbon technologies.
- These documents do not specify key performance indicators in terms of technologies uptake or production.
- No clear parameters are specified for the level of government support to the development of these technologies. Decisions regarding such support are made on the basis of the conclusions provided by expert organizations or the Interdepartmental Commission of the government.

1.6 Current scale of low-carbon technologies penetration, production, and the level of localization

LOW CARBON ENERGY SYSTEMS **TRL - 11** **Localization -70-100%**	• The level of localization is noticeably higher, than in the fossil fuel energy sector; • In 2020-2022, RES contributed 33-57% to the capacity additions. • The scale of the domestic market is significant only for nuclear and hydro. • RES have reached price parity either in the wholesale electricity markets (wind), or retail markets (solar). • There is some (limited) technology export. The key task is: • to scale up the use of low-carbon technologies and to further increase the level of localization
Nuclear **TRL – 11** **Localization – 98-99%**	• Commissioning over 2015-2022: 930 MW per year; generation in 2022 – 224 kWh. • Specific capital investment in new units at nuclear power plants: 2,000-3,450 USD/kW, for construction abroad: 4,100-7,605 USD/kW. • There is a complete set of the required infrastructure in place. • The share of imports is low. • Global leader in the portfolio of orders: 33 power units in 10 countries are at various stages of construction.
Wind power **TRL – 11** **Localization – 55-68% to reach 100% in the next 2-3 years**	• Annual commissioning over 2015-2022: 287 MW. Installed capacity in 2022: 2,298 MW. Generation in 2022: 4.2 billion kWh. • Price parity with thermal generation in the wholesale market. • All the infrastructure demand for the production, installation and maintenance of wind plants has been met. • In 2020, the export of blades for wind farms began. Export targets are set in the auctioning conditions for agreements to supply capacity 2.0 (DPM-REN 2.0).
Solar **TRL – 11** **Localization – 70%** **Annual scale of solar panels production is 700 MW and is expected to grow up to 1.7 GW per year**	• Annual commissioning of grid-scale solar over 2015-2022: 229 MW. Installed capacity: 2.1 GW. Generation in 2022: 2.4 billion kWh. • Price parity with thermal generation in the retail market. • The infrastructure for the production, installation and maintenance of solar power plants is in place. • 30% of components are imported. This share is declining. • Since 2018, solar modules and cells have been exported. Export targets set in auctioning conditions for agreements to supply capacity 2.0 (DPM-REN 2.0).

Grid level energy storage systems **TRL – 11** **Localization – high, but all of the lithium is imported and some lithium suppliers are lost because of the sanctions**	• Annual commissioning over 2015-2022: 2.7 MW. The potential market for energy storage systems in Russia for 2030 is estimated at 10–15 GW. • The infrastructure for the production, operation, and maintenance of grid energy storage capacity in Russia is being created. • The necessary lithium feedstock is not produced in Russia. 27 tons of lithium will be required for grid energy storage systems in 2030 and 272 tons in 2060. Full localization is expected by the end of 2027. • There are no export plans.
INDUSTRY **TRLs – 5-11** **Localization - 0-100%** **Even for BATsy, localization level is 30-85% (except for aluminium)**	• The level of localization is noticeably lower, than in low-carbon energy systems. • There is no experience in CCUS or hydrogen technologies and no production of relevant equipment. The key tasks are: • To untap the large BATs potential before 2030. • Technologies with low TRL (hydrogen and CCUS) will then be expected to enter the market.
Steel production in electric arc furnaces (key for scrap and DRI) **TRL – 11** **Localization – 60%**	• The goal for 2024-2026 is to bring the localization up to 80%. • Share of steel production in electric arc furnaces was 35% in 2022, growth to 100% in 2050 is required. • All the necessary infrastructure is available for the production and use of electric arc and induction furnaces. • Some equipment has to be imported. China can supply it. • There are no export plans for electric arc furnaces.
DRI production with CCUS **TRL – 9** **Localization – 0%**	• Not currently implemented. • No infrastructure in place. • The scale of imports is determined by the level of capacity increase. • There are no export plans.
DRI production with hydrogen **TRL – 5** **Localization - 0%**	• Not currently implemented. • No infrastructure in place. • The scale of imports is determined by the level of capacity increase. • There are no export plans.

Aluminium – pre-baked anodes **TRL – 9** **Localization – 40-85%**	• 14% of primary aluminium is produced using this technology. • An infrastructure for the use of pre-baked anode technology is being developed. • The goal for 2024-2026 is to bring the localization up to 60-100%. • There are no export plans.
Aluminium – inert anodes **TRL – 9** **Localization – 100%**	• In 2022, 3,960 tons of aluminium were produced using this technology at the pilot site of Krasnoyarsk aluminium plant. • An infrastructure for the use of inert anode technology is being developed. • There are no export plans.
Energy-saving methods of cement production **TRL – 11** **Localization – 30%**	• The main problem is the critical reliance on equipment imports. • The goal for 2023-2027 is to bring the localization up to 80-85%, and for 2028-2035 up to 90-95%. • All the necessary infrastructure is in place.
Reducing the clinker-cement ratio **TRL – 11**	• In 2020-2022, the clinker factor was high – 88-91%, sometimes reaching 83%. Global average is 25%, and BAT is 32% (India). • Additives can replace up to 40-50% of clinker. • All the necessary infrastructure is in place. • There is no need for the imports of mineral additives.
Increasing the share of alternative fuels in cement production **TRL – 11**	• In 2010-2022, the share of alternative fuels grew up from 0.2 to 3%, while some plants reached 26% and the target set to reach 43%. (It is 70% in Germany). • The shortage of capacity for waste recovery to produce alternative fuels is estimated at 88-95% for 2022. • No reliance on alternative fuel import.
Cement production with CCUS **TRL – 7** **Localization – 0%**	• Not currently applied. • No infrastructure in place. • There are no export plans.
Ammonia production with CCUS **TRL – 7-8** **Localization – 0%**	• Localization target for ammonia production using the conventional technology is 75% for 2035. • The current CCUS schemes for urea production will be complemented with ammonia production based on steam reforming of methane with CCUS. • The infrastructure for large-scale production, storage, and transport of ammonia is in place, but not for CCUS.

Ammonia production with green hydrogen **TRL – 7-8** **Localization – 0%**	• The technology was in use as early as the beginning of the 20th century, but when cheap gas appeared, its use practically ceased. • The infrastructure for large-scale production, storage, and transport of ammonia is in place in Russia, but not for hydrogen.
TRANSPORT **TRLs – 9-11** **Localization – below 25%**	• The park of electric vehicles and electric buses has started to grow rapidly. • Electric cars and electric buses are expected to reach cost parity (the cost of ownership) by 2040. • The infrastructure is dynamically developing. The key tasks are: • To increase the level of localization for electric vehicles; • To launch domestic production of lithium
Electric cars **TRL – 9** **Localization – low**	• In the early 2023, the share of electric cars reached 1% in the sales of new passenger cars. • In 2040, electric vehicles will reach the cost parity (the cost of ownership) with ICE passenger cars and then will become cheaper. • The charging infrastructure is rapidly developing. • Imports of electric cars amount to nearly all of the park increase, and the geography of imports has shifted towards China. • There are plans for export.
Electric buses **TRL – 10** **Localization – 25-40%**	• At the end of 2022, the park of electric buses in Russia included 1,275 units. • Almost all of the electric buses were produced in Russia. • Expected annual production of electric buses in 2023 is 450-700 units. • Cities are dynamically developing their charging infrastructure. • There are plans for export.
Batteries **TRL – 11** **Localization – 95%, yet all of the lithium is imported**	• The infrastructure for battery production is being developed. • The necessary lithium feedstock is not produced in Russia. • In 2030, electric cars and buses will need 18 GWh in batteries, which would require about 3,000 tons of lithium.
Charging stations **TRL – 10** **Localization – below 25%**	• More than 7.5 thousand public charging points operate in Russia. • The required infrastructure is rapidly developing. • A lot of components (more than 75%) are imported. • There are plans for export.

BUILDINGS **TRLs – 9-11** **Localization – 20-98%**	• New low-energy multifamily buildings (MFBs) and passive MFBs will reach life cycle cost parity with buildings that meet the current energy efficiency requirements. The key tasks are: • to scale up the use of insulation and heat supply regulation technologies until 2030; • to increase and then upscale the level of localization of other technologies.
Insulation **TRL – 11** **Localization – 97-98%**	• In 2017-2021, 50.5-54.2 million m^3 of insulation materials were produced in Russia; • Large-scale production, supply and installation of different insulation materials is established in Russia. • There are both imports and exports.
Automated regulation of buildings heat supply **TRL – 11** **Localization – 60-80%**	• The heat savings are on average 17% per building. • Saving (producing) natural gas in Russian buildings is 3-5 times cheaper, than gas production in Yamal. • On average, 30 thousand heat supply regulation units are annually installed in the country. • Large-scale production of heat supply regulation units is established in Russia to meet the whole of domestic demand.

Heat pumps
TRL – 9
Localization – 20-30%
	• In Russia:
	  ○ Only a few thousand heat pumps are installed, but
	  ○ Production of equipment used in heat pumps has been launched.
	• The main source of imports is small-capacity heat pumps and their components from China.

Smart meters **TRL – 11** **Localization – below 40%**	• The schedule of mandatory installation of smart electric meters are shifting. • Almost 2 dozen enterprises have been created to produce smart accounting systems. • With the maximum possible localization, the cost of smart meters will increase.
Solar heaters **TRL – 11** **Localization – low**	• Russian companies are assembling products from imported components. • Russia's share in global solar heat production is 0.002%. • 4 MW are installed annually, while 140-150 MW are required in 2030 and 1,700-1,800 MW in 2060. • In 2021, 2,878 solar collectors were imported. • Solar cogeneration systems have emerged and are developing dynamically in some countries.

Photovoltaic panels for decentralized power supply **TRL – 10** **Localization – 70%**	• The current market for distributed and micro-generation is 250-300 million kWh (125-230 MW). • In the US, total capacity of PV installed in residential buildings exceeds 10 GW, and the number is 3 million. • PV panels are coming to price parity with grid electricity. • The infrastructure is dynamically developing. • The key supplier is China. 2022 imports from China were 20 MW.
HYDROGEN **TRLs – 8-9** **Localization – 100% for hydrogen production, but very low for electrolyzes manufacturing**	• In Russia, the development of infrastructure for hydrogen production and use outside of oil refining and petrochemicals is just dawning. • There are some domestic technological developments. • The plans for hydrogen production and exports have been revised down by an order of magnitude. The key task is: • To set up large-scale production of electrolyzers
Hydrogen **TRL – 8-9** **Localization – 100%**	• In 2021-2022, about 2.4 billion m^3 of hydrogen were produced (0.2 Mt), or 0.2% of global production. • In Russia, the development of infrastructure for hydrogen production and use outside of oil refining and petrochemicals is just dawning. • The euphoria is gone, some potential markets have closed, and hydrogen export plans were revised down by an order of magnitude.
Electrolyzers **TRL – 8-9** **Localization – low**	• Installed pot capacity is 25 MW, or 0.2% of the world's 11 GW. • Before 2022, hydrogen electrolyzers had been imported mainly from the US, China, Belgium, and Italy. After the sanctions were imposed, they stopped equipment supply and maintenance support. • There are domestic developments and prospects for large-scale domestic production. • Exports of pots are a long-range prospect.
CCUS **TRLs – 4-9** **Localization – very low**	• Like the global market, Russian CCUS market is only dawning. • According to Rosstat, Russia produced 1.4 Mt of CO_2 in 2022. In addition, another 6.9 Mt of CO_2 were captured from ammonia production and used for urea production. • Cost estimates for this technology vary greatly, because there is very little empirical evidence. • In Russia, CCUS technology is mostly at the planning and experimental stage. • Russia has a huge potential for CO_2 storage ranging between 10 and 160 Gt CO_2 The key task is: • To launch pilot projects before 2030 and prepare the ground for their subsequent replication.

1.7 Key performance indicators for sectors and technologies to ensure carbon neutrality

Power generation key performance indicators and contributions from individual generation sources

	2021	2030		2040	2050	2060	
Primary energy use for power generation, Mtce	301	286	x0.95	323	372	401	x1.3
Power generation, billion kWh	1159	1130	x0.97	1296	1540	1723	x1.5
Share of electricity in final energy use	14%	15%	x1.1	18%	24%	29%	x2
Share of non-fuel sources	39%	42%	x1.1	52%	67%	76%	x2
Share of renewables	19%	22%	x1	25%	34%	42%	2x
Share of intermittent RENs	0,6%	2%	x4	7%	17%	27%	48x
Wind	0.3%	1.4%	x4.5	4.6%	10.6%	15.4%	48x
Solar	0.2%	0.7%	x3	2.6%	6.7%	11.2%	49x
Geoternmal	0.04%	0.08%	x2	0.08%	0.08%	0.07%	2x
Hydro	19%	19%	x1	17%	16%	15%	0.8x
Biofuels	0.2%	0.2%	x1	0.3%	0.3%	0.4%	1.7x
Nuclear	19%	20%	x1.1	27%	33%	34%	1.8x
Power storage systems, 1,000 kWh	22	169	x7	566	1 116	1 700	x77
Carbon intensity of power, gCO$_2$/kWh	324	282	x0.9	207	121	61	x0.2

Source: CENEf-XXI.

Key performance indicators for industry

	2021	2030		2040	2050	2060	
Final energy use, Mtce	276	245	x0.9	207	182	162	x0.6
Share of electricity in final use	22%	25%	x1.1	33%	41%	49%	x2.2
CO_2 emissions, Mt	340	244	x0.7	131	82	54	x0.2
Steel production, Mt	71	78	x1.1	80	74	70	x1
Share of electric arc steel in steel production	35%	53%	x1.5	83%	100%	100%	x3
DRI production, Mt	8	18	x1	37	45	47	2x
incl. hydrogen-based DRI production, Mt				H_2 5	H_2 12	H_2 13	∞
natural gas-based DRI production with CCUS, Mt				CO_2 5	CO_2 11	CO_2 12	∞
Primary aluminium production, Mt	3.7	3.7	x1	3.7	4.3	5.0	x1.4
Share of pre-baked anodes technology	0%	38%		58%	71%	64%	∞
Share of inert anodes technology	0,1%	6%	x60	13%	26%	36%	x490
Cement production, Mt	61	75	x1.2	81	83	83	x1.4
Share of dry cement production	58%	70%	x1.2	84%	98%	100%	x1.7
Clinker-factor	74%	68%	x0.9	61%	54%	49%	x0.7
Ammonia production	17	14	x0.8	18	22	26	x1.5
incl. hydrogen-based ammonia production				H_2 0	H_2 2%	H_2 4%	∞
natural gas with CCUS				CO_2 0	CO_2 22%	CO_2 43%	∞

Source: CENEf-XXI.

Key performance indicators for transport

	2021	2030		2040	2050	2060	
Final energy use, Mtce	135	101	x0.7	79	58	42	x0.3
Share of electricity in final use	8%	9%	x1.1	15%	23%	38%	x4.8
CO2 emissions, Mt	236	172	x0.7	125	81	46	x0.2
Cargo turnover, billion tkm	5,701	5,107	x0.9	4,882	4,083	3,492	x0.6
Passenger turnover, billion pass-km	1,327	1,198	x0.9	1,238	1,241	1,194	x0.9
Share of road transport in cargo turnover	5%	5%	x1.5	4%	5%	5%	x3
Share of road transport in passenger turnover	51%	46%	x0.8	41%	37%	32%	x0.6
Passenger cars fleet, mln pcs.	50	41	x0.9	37	32	27	x0.5
Share of electric cars	0,03%	6%	x200	22%	37%	53%	x1767
Bus park, thou. pcs.	844	760	x0.9	797	811	792	x0.9
Share of electric buses	0,003%	4%	x1300	26%	56%	74%	x26667
Battery capacity for road transport, GWh	2	128	x64	410	637	765	x383
Number of charging stations (10 chargers per station)	208	25,473	x0.9	54,845	61,363	76,049	x0.9

Source: CENEf-XXI.

Key performance indicators for residential buildings

	2021	2030		2040	2050	2060	
Final energy use, Mtce	153	141	x0.9	132	126	122	x0.8
Share of electricity in final use	14%	18%	x1	19%	20%	24%	X1.1
Direct and indirect CO2 emissions, Mt	315	240	x0.8	207	179	139	x0.4
Average energy consumption for space heating, kWh/m^2/year	204	150	x0.7	129	114	94	x0.5
Average energy consumption for DHW, kWh/m^2/year	34	18	x0.5	13	11	11	x0.3
Average energy consumption for other purposes, kWh/m^2/year	66	53	x0.8	42	34	30	x0.5
Share of MFB with A++ energy efficiency levels	0,1%	0,4%	x4	23%	45%	70%	x700
Share of MFB with energy efficiency capital retrofits	0.1%	2.0%	x20	2.0%	2.0%	2.0%	x20
Share of MFB with heat supply regulation	14%	43%	x3	65%	84%	99%	x7
Heat supply from heat pumps, million GCal	0.2	2.6	x13	9.6	27.0	76.6	x383
Heat production by solar heaters, million GCal	0.1	2.0	x20	4.5	8.9	18.6	x186
Electricity generation in buildings, billion kWh	0.002	0.15	x75	7.6	20.6	39.5	x19,750
Share of electric smart meters	0,1%	99%	x1,000	99%	99%	99%	x1,000

Source: CENEf-XXI.

Key performance indicators for hydrogen (thou. t)

	2021	2030		2040	2050	2060	
Hydrogen production	174	366	x2	659	974	1289	x7.4
Blue hydrogen production*	174	358	x2	630	888	1010	x5.8
Turquoise hydrogen production		4		8	19	37	
Yellow hydrogen production		4		9	22	55	
Green hydrogen production		4		12	45	186	
Share of CCUS in blue hydrogen production	0%	19%		46%	73%	100%	
Exports		123		312	500	688	
DRI and HBI		0		64,5	149	159	
Ammonia		0		0,0	59	180	
Oil refinery	174	172	x1	174	172	127	x0.7

* including hydrogen obtained as oil refinery by-product.

Source: CENEf-XXI.

Key performance indicators for CCUS (million t)

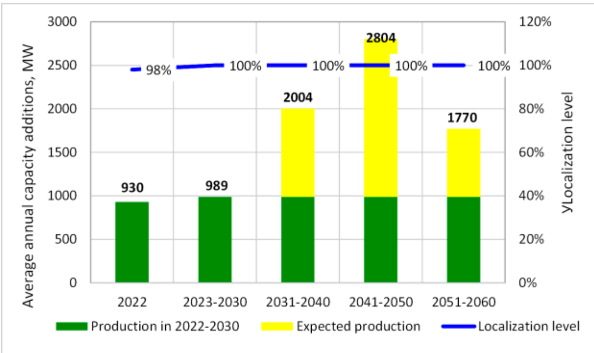
	2021	2030	2040	2050	2060
CO_2 capture			9.0	31.9	52.9
Power sector			1.0	2.7	3.6
Steel production			1.1	2.2	2.2
Cement production			4.9	11.5	16.2
Ammonia production			0.0	10.7	22.8
Hydrogen production			1.9	4.9	8.0
CO_2 use	6.6	6.5	8.0	9.3	10.7
Sponge effect	20.3	22.4	25.3	27.9	30.1

* Emissions from ammonia production include CO_2 use for urea production, which is shown in “CO2 use”.

Source: CENEf-XXI.

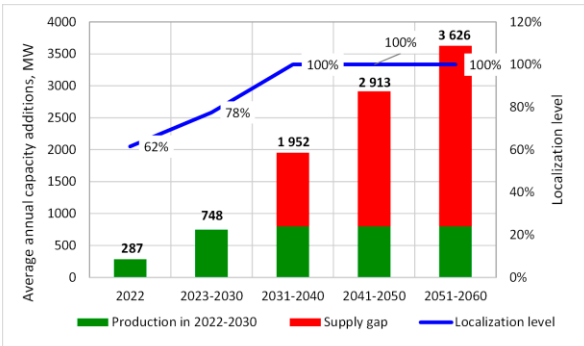
1.8 Three gaps. Low carbon technologies: critical uptake scales, expected production and localization levels

Nuclear. Rosatom is able to fully and independently meet the nuclear capacities additions demand to 2060.
Since 2022, Rosatom has negotiated 20 new nuclear plant construction projects



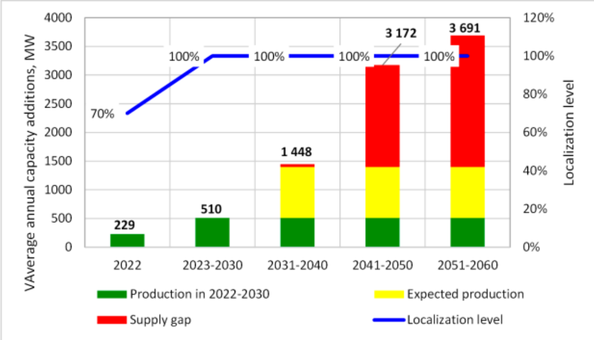
Nuclear: average annual capacity additions and coverage sources in 2023-2060

Wind. It is expected that in 2027 the technological gap will be bridged and a localization level close to 100% will be achieved. Supply gap will be 2,9 GW in 2060.
Russia has been approached by Vietnam, Myanmar, Turkey, Eurasia, and the CIS countries for the development of wind power capacities.



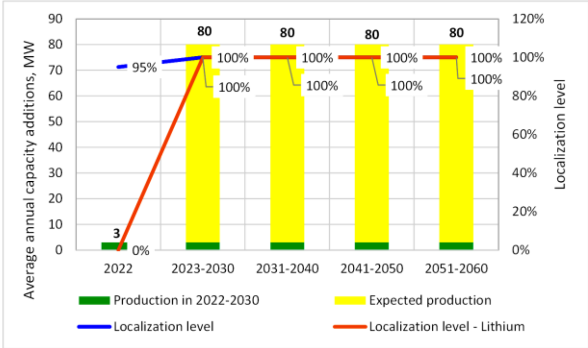
Wind: average annual capacity additions and coverage sources in 2023-2060

Solar. Currently, there is no technological gap; localization level is close to 100%. However, there will be a 2.2 GW supply gap in 2060. A wide range of products are being supplied to Europe and Asia (mainly Kazakhstan and Japan).



Solar: average annual capacity additions and coverage sources in 2023-2060

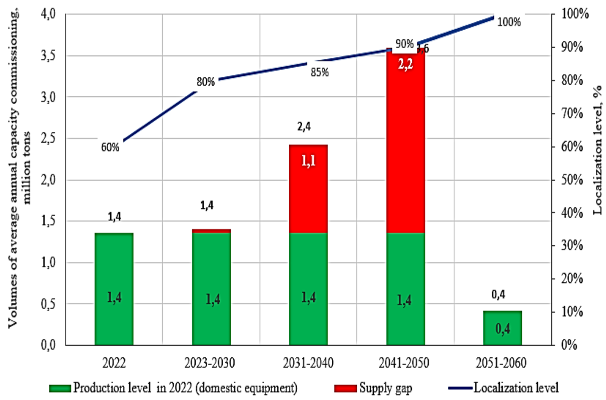
Storage. There is still no adequate understanding of the Russian market's actual storage capacity demand. With an account of the facilities under construction, there will be sufficient capacity to introduce energy storage systems into the country's energy sector, but manufacturers of batteries for electric vehicles will be competing for these capacities, and their load level will be determined by lithium supplies to Russia.



Storage: average annual capacity additions and coverage sources in 2023-2060

Electric steel. There is no technological gap; localization level is 60% and will grow up to 80% in 2026.

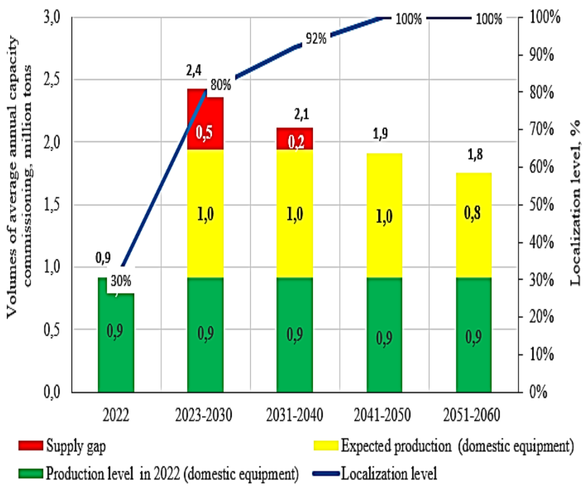
Supply gap will be 1.1 Mt per year in 2031-2040 and 2.2 Mt per year in 2050.



Electric steel: average annual capacity additions and coverage sources in 2023-2060

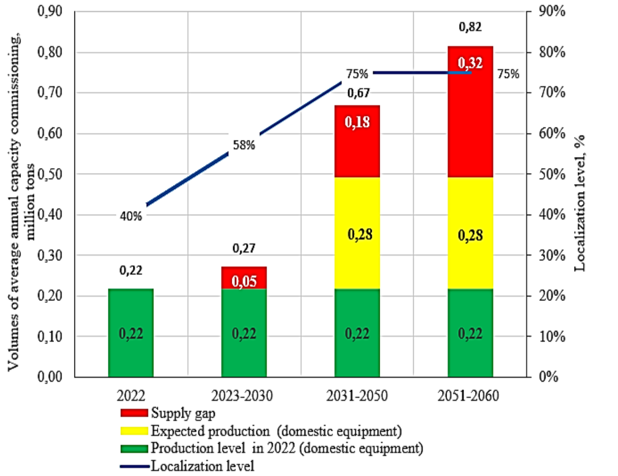
Dry cement production. There is no technological gap. Localization level is currently 30% and will grow up to 80% in 2027 and to 92-100% in 2035.

Supply gap will be 0.5 Mt per year in 2030 and down to 0.2 Mt per year in 2040.



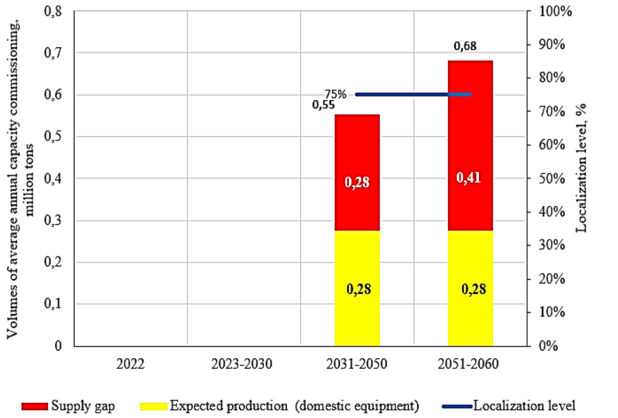
Dry and combined cement production: average annual capacity additions and coverage sources

Ammonia. There is no technological gap. Localization level was 40% in 2022, but will grow up to 75% in 2040. Supply gap is 0.2-0.3 Mt of capacity additions per year



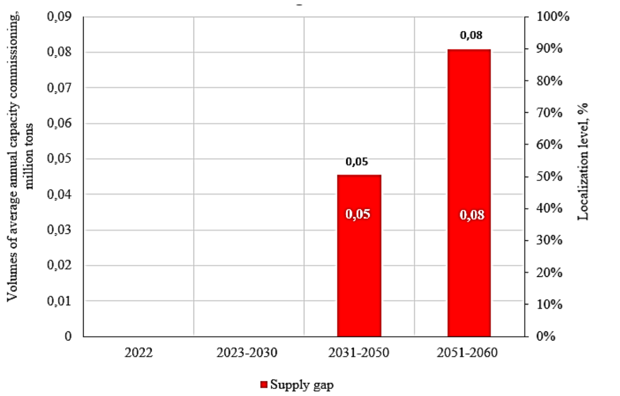
Ammonia: average annual capacity additions and coverage sources in 2023-2060

Blue ammonia with CCUS. Technological gap: this technology is only at the planning stage in Russia.
Localization level – 0%.
Supply gap is 0.5-0.7 Mt of capacity additions per year.



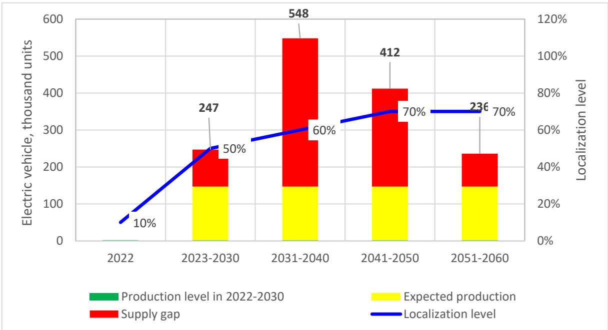
Blue ammonia with CCUS

Green ammonia with hydrogen. Technological gap: in Russia, there are no plans related to this technology.
Localization level – 0%.
Supply gap is 0.05-0.087 Mt of capacity additions per year.



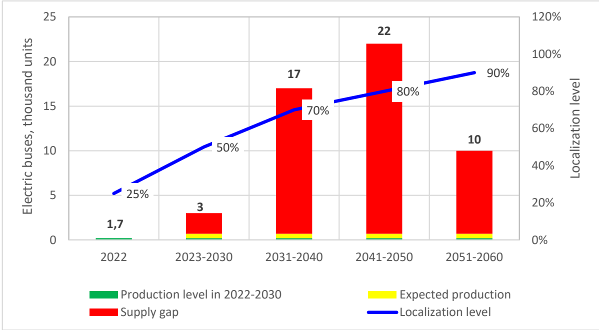
Green ammonia with hydrogen: average annual capacity additions and coverage sources

Electric vehicles. There is no global technological gap. In Russia, there are no domestic models, and localization level is 10% at the best. It is expected to gradually rise to 50% in 2030 and then further to 60-70%. Supply gap will be 100 thou. In 2030. It will peak at 400 thou. And then will eventually decline.



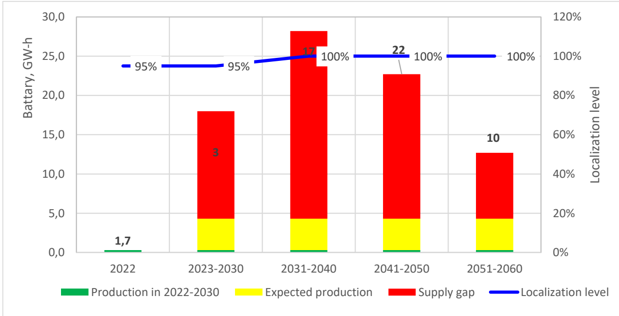
Electric vehicles: average annual capacity additions and coverage sources

Electric buses. There is no technological gap, yet localization level is only 25-40%. Supply gap will be 3,000 in 2030 and 20,000 in the 2040s. It can be fully covered through domestic production increase.



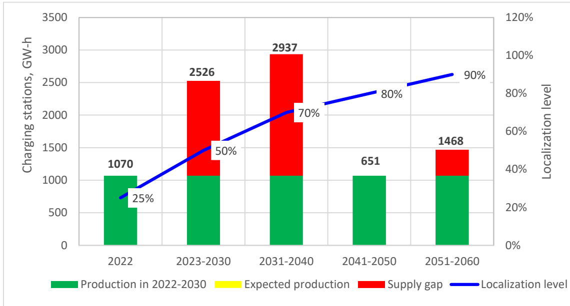
Electric buses: average annual capacity additions and coverage sources

Batteries. There is no technological gap, localization level is 95%. The key problem relates to lithium availability. Supply gap will be 1.3 GWh in 2030 and 15-20 GWh in 2031-2050 with subsequent decline. It will be fully covered through domestic production increase, as long as Russia can timely roll out domestic lithium production.



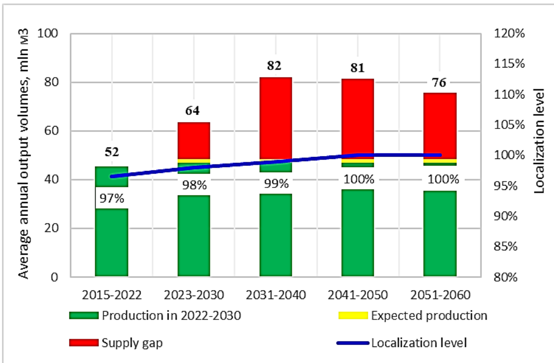
Batteries: average annual capacity additions and coverage sources

Charging stations. There is no technological gap, yet localization level is only 25%. Supply gap will be 2.5 thousand stations in 2030. As the saturation level increases, it will be down to 400 in 2060.



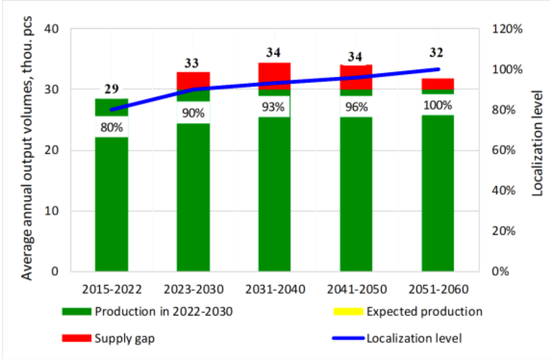
Charging stations: average annual capacity additions and coverage sources

Thermal insulation materials. There is no technological gap; localization level is close to 100%. Beyond 2030, supply gap will be 20-30 million m^3. It can be fully covered through domestic production increase.



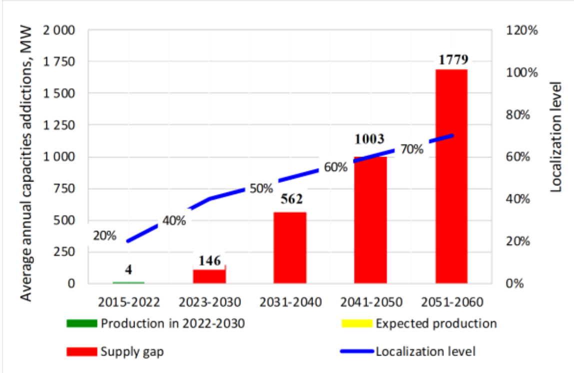
Thermal insulation materials: average annual output volumes and coverage sources

Automated heat supply stations. There is no technological gap; localization level will rise to 90% in 2030 and then to 100%. Supply gap will amount to 2-5 thousand units and can be fully covered through domestic production increase.



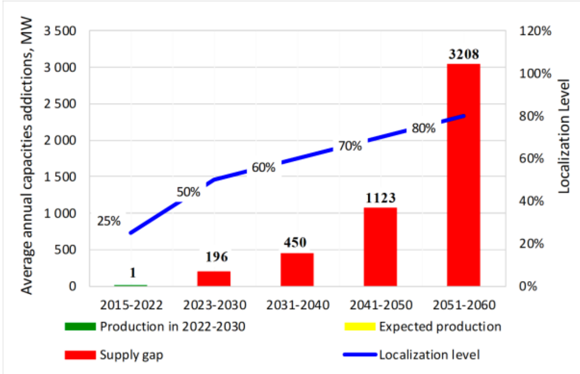
Automated heat supply stations: average annual output volumes and coverage sources

Solar water heaters (collectors). Technological gap: practically no production in Russia. Localization level will increase to 40% in 2030 and then to 70%. Supply gap will amount to 146 MW in 2030 and 1,800 MW in 2060.



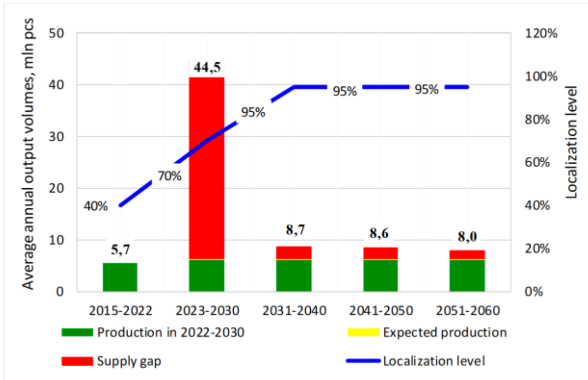
Solar water heaters: average annual capacities addictions and coverage sources

Heat pumps. Technological gap: practically no production in Russia. Localization level will increase to 50% in 2030 and then to 80%. Supply gap will be 196 MW in 2030 and 3,200 MW in 2060.



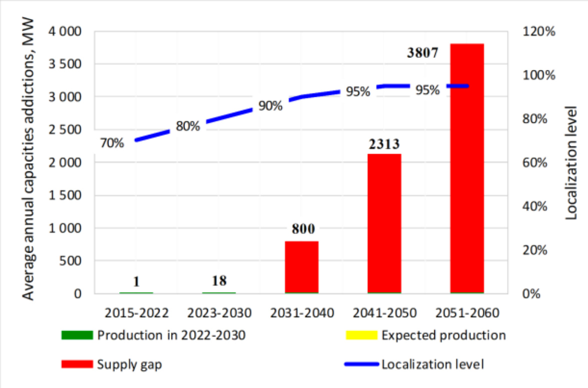
Heat pumps: average annual capacities addictions and coverage sources

"Smart" electricity meters. There is no technological gap, domestic production is established in Russia. Localization level is 40% and expected to increase to 85% in 2030 and then to 95%. Supply gap will be over 40 million units per year in 2030 and then will drop to 2-3 million units per year; it can be bridged through domestic production.



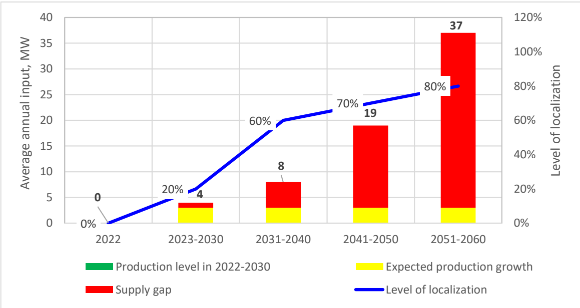
"Smart" electricity meters: supply gap

Photovoltaic panels. There is no technological gap, domestic production is established in Russia. Localization level is 70% and is expected to increase to 80% in 2030, and then further to 95%. Supply gap will be 3.8 GW in 2060. It is not clear though, to what extent it can be bridged through domestic production.



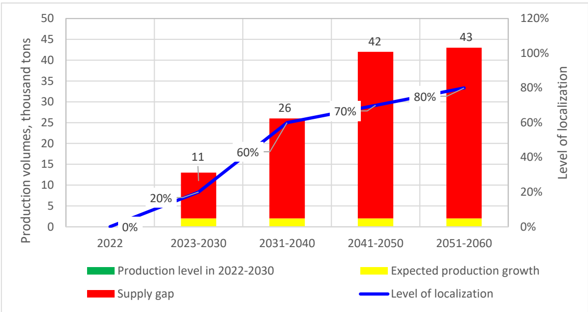
Photovoltaic panels for decentralized power supply: supply gap

Hydrogen electrolyzers. Technological gap: practically no production in Russia. Localization level will be 20% in 2030 and then will keep growing. Supply gap will be 4 MW in 2030 and 37 MW in 2060.



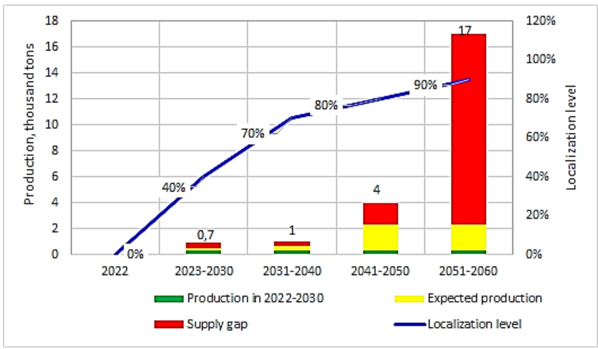
Hydrogen electrolyzers: supply gap

Blue hydrogen with CCUS. Technological gap: practically no production in Russia. Localization level will rise to 20% in 2030 and then to 80%. Supply gap will amount to 6,000 tons in 2030 and 30,000 tons in 2060.



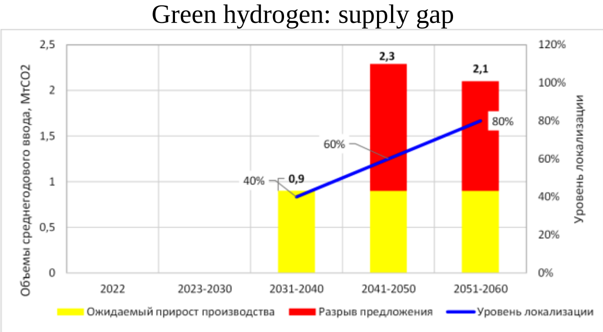
Blue hydrogen with CCUS: supply gap

Green hydrogen. Technological gap: practically no production in Russia. Localization level is expected to rise to 40% in 2030, and then to 90%. Supply gap will be 0.7 thousand tons in 2030 and 15 thousand tons in 2060.



Green hydrogen: supply gap

CCUS. Technological gap: practically no production in Russia. Localization level is expected to rise to 40% in 2030 and then further to 80%.
Supply gap will amount to 2.1-2.3 thousand tCO2 per year



CCUS: average annual capacity additions and coverage sources

1.9 Scale gap. Nothing-to-see view

Decoupling is lost.

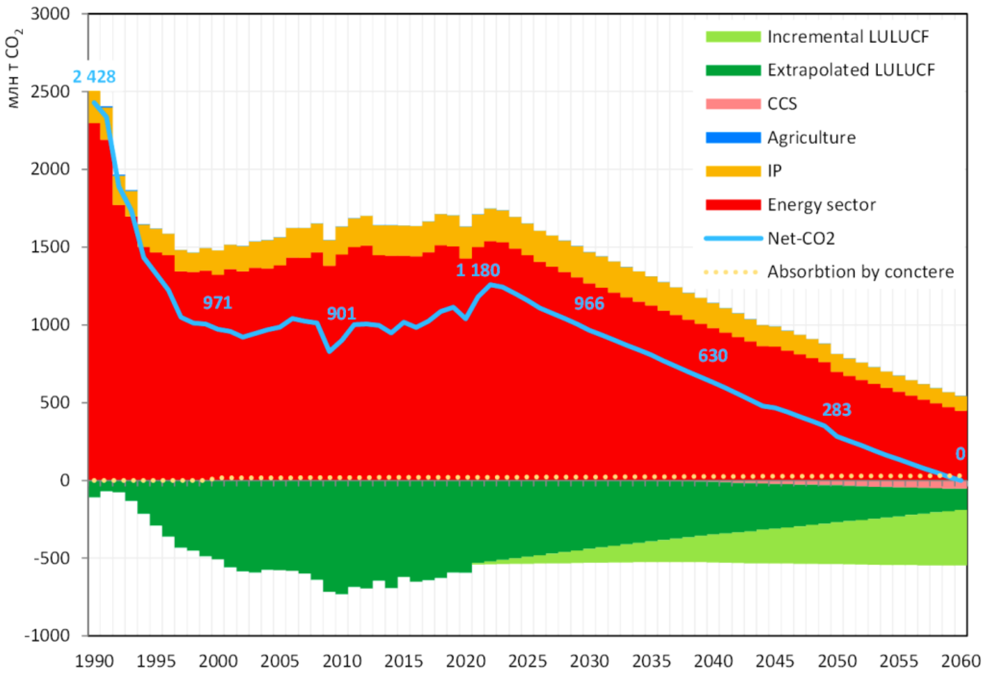
- Instead, super-coupling has been detected in Russia in the recent years:
  - in 2020 and 2021, GHG emissions were closely following GDP evolution;
  - increase in both GHG total net emission and energy related GHG emission has hit the record over the whole period from 1990 onwards.

Attaining carbon neutrality in 2060 is still feasible even without increasing net sinks in LULUCF (Fig. 1.1).

CENEf-XXI's research in 2022-2023 remains the only effort which tests this opportunity.

- Carbon neutrality pathways to 2060, as assessed in 2022, have somewhat changed.
- Low carbon technology access restrictions in the medium-term hamper technology uptake and maintain the higher levels of GHG emissions.
- Based on the low carbon technology uptake and revised estimates of Russia's economic development to 2060, GHG emission pathways to ensure the attainment of the carbon neutrality target by 2060 were developed.

Figure 1.1 **CO_2 emissions and sinks in the 4D scenario**



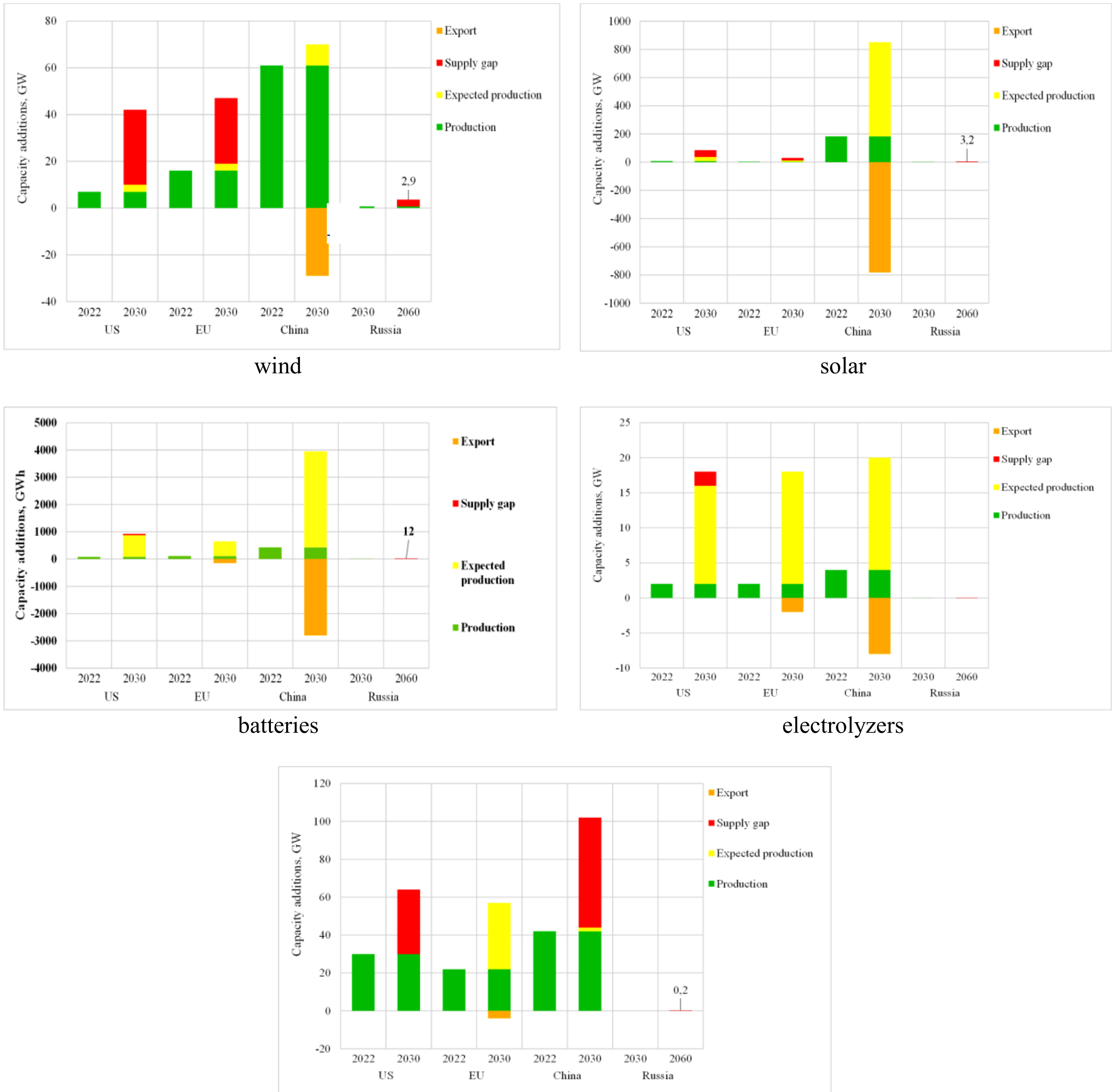
Source: CENEf-XXI.

Nothing-to-see view: the scale of low carbon technology production and uptake in Russia are extremely low compared to the global champions (Fig. 1.2).

The question is: how much is Russia willing to exacerbate its technological reliance on China and does it (or can it) have sufficient ability to reduce this reliance.

- In addition to the three gaps estimated above, one can notice a gap in the scale of the Russian market and other national or regional markets.
- Total technological sovereignty policy is a dead-end road, which incurs exorbitant costs with no guarantee of success. The efforts made by the USSR since the early 1930s didn't work out.
- Diverse and geographically balanced international cooperation in low carbon technologies is a sustainable and effective strategy for Russia, which is not a gigantic market.

Figure 1.2 **Nothing-to-see view: annual outputs of low carbon technologies in Russia against global champions**



Sources: CENEf-XXI and IEA. 2023. The State of Clean Technology Manufacturing. An Energy Technology Perspectives Special Briefing.