Russia's technological policy and knowhow in a competitive global context

Santtu Lehtinen, Sinikukka Saari, Arho Suominen (Eds.)

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Abstract

The global science and technology (S&T) landscape is increasingly embedded in the intensifying great power competition. Significant global attention has been paid to the dynamics between China and the United States while Russia's notable S&T knowhow has been largely absent from the conversation. The ongoing war in Ukraine emphasizes the importance of S&T capabilities for Russia's power projection ability and its great power aspirations. This report examines Russia's current S&T knowhow and the trajectory of its technological edge. In addition, the report examines and evaluates the effectiveness of Russia's science, technology and innovation policies and strategies. Furthermore, the report analyses Russia's technological development in the context of its geopolitical implications, particularly with regards to the future of great power competition. The analysis of the future trajectories is based on Delphi -based foresight. Finally, the report highlights key implications for Europe and, in particular, Finland.

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Keywords research, research activities, Russia, international politics, technological development

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Tiivistelmä

Globaali tiede- ja teknologiajärjestelmä on yhä keskeisempi osa valtioiden välistä valtapolitiikkaa. Kiinan ja Yhdysvaltojen väliseen dynamiikkaan on kiinnitetty globaalisti paljon huomiota, samalla kun Venäjän tieteellinen ja teknologinen osaaminen on jäänyt vähemmälle huomiolle. Ukrainan sota on kuitenkin nostanut esiin tavan, jolla Venäjä on valjastanut maan teknologiset ja tieteelliset valmiudet osaksi sen voimapolitiikkaa ja kansainvälistä suurvaltakilpailua. Tässä raportissa tarkastellaan Venäjän teknologista osaamista, sen tulevaisuutta sekä innovaatiopolitiikan ja strategioiden tehokkuutta. Lisäksi raportissa analysoidaan Venäjän teknologista kehitystä sen geopoliittisten vaikutusten kautta, huomioiden erityisesti suurvaltojen välisen teknologisen valtakilpailun tulevaisuuden. Tulevien kehityskulkujen analyysi perustuu Delphi-pohjaiseen ennakointiin. Lopuksi raportissa nostetaan esiin keskeisiä vaikutuksia Eurooppaan ja erityisesti Suomeen.

Klausuuli Tämä julkaisu on toteutettu osana valtioneuvoston selvitys- ja tutkimussuunnitelman toimeenpanoa. (tietokayttoon.fi) Julkaisun sisällöstä vastaavat tiedon tuottajat, eikä tekstisisältö välttämättä edusta valtioneuvoston näkemystä.

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Rysslands teknikpolitik och kunnande vid åtdragning globala konkurrensen

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Det globala vetenskaps- och tekniklandskapet är alltmer blandad i den intensiven maktpolitiken. Kinas och Förenta staternas dynamik har uppmärksammats avsevärt, och analysen har i viss mån utelämnat Rysslands vetenskapliga och tekniska kunnande. Ryssland har betydande tekniskt kunnande och vetenskaplig potential i kombination med stora maktambitioner. Den senaste tidens händelser har också visat att vetenskaplig, teknisk och innovationsförmåga i Ryssland ses som viktiga verktyg för maktpolitik. I denna rapport undersöks Rysslands nuvarande tekniska kunnande och utvecklingen av dess tekniska försprång. Dessutom evaluerar effektiviteten i Rysslands politik och strategier för vetenskap, teknik och innovation. I övrigt analyseras Rysslands tekniska utveckling i betänkandet mot bakgrund av dess geopolitiska konsekvenser, särskilt stormaktskonkurrensen i dag och i framtiden. Analysen baseras på Delphi-metod. Slutligen rapport diskuterar viktiga konsekvenser för Europa och i synnerhet Finland.

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1 Introduction

"Artificial intelligence is the future, not only for Russia, but for all humankind. It comes with colossal opportunities but also threats that are difficult to predict. Whoever becomes the leader in this sphere will become the ruler of the world." [1]

Global technological competition is increasingly intertwined with intensifying great power competition. Thus far, the international debate has focused primarily on the competition dynamics and growing tension between the United States and China, with less attention being paid to Russia's scientific and technological knowhow. Despite this omission, Russia has significant technological knowhow and scientific potential, combined with the ambition to sustain and enhance its status as a great power. Indeed, scientific, technological, and innovation (STI) capabilities are seen as important tools in enabling Moscow to achieve its key domestic and foreign policy goals.

Vladimir Putin returned to presidency in 2012 with renewed determination to reassert Russia's great power status internationally. Part of regaining the great power status was the plan to restore Russia's scientific and technological prowess. Russia's technological competition strategy included an explicit plan to build its national long-term strategic planning and innovation system anew (Cooper 2012). Russia set up expert commissions and adopted a wealth of governmental strategies, programs, and plans for technological development[2]. As a result, renewed national STI infrastructure has been set up together with national funds for investment in STI as well as technology parks and business incubators for research and development (R&D) (Gokhberg & Kuznetsova 2010, 229; Gokhberg & Kuznetsova 2015).

1 President Vladimir Putin in an address to Russian school children, 1 September 2017.https://www.rt.com/news/401731-ai-rule-world-putin/ Accessed 19th December 2020.

2 These include Federal laws on Strategic Planning and Industrial Policy (2014), https://economy.gov.ru/material/directions/strateg_planirovanie/normativnoe_obespechenie_strategicheskogo_planirovaniya/ ; the Strategy of the Scientific and Technological Development of the Russian Federation (2016), http://kremlin.ru/acts/bank/41449; Digital Economy of the Russian Federation Programme (2017), http://government.ru/docs/28653/ ; and National Strategy for the Development of Artificial Strategy (2019), http://publication.pravo.gov.ru/Document/View/0001201910110003. The Energy Strategy (2020) is also relevant in this respect, http://static.government.ru/media/files/w4sigFOiDjGVDYT4IgsApssm6mZRb7wx.pdf. Accessed 19th December 2020.

However, simultaneously with Russia's progress, global technological competition has become increasingly fierce and geopolitical. It is therefore an appropriate time to evaluate the aims of Russia's technology policy, the competitiveness of Russian technology knowhow, and the geopolitical implications therein for both Europe and Finland.

Accordingly, this project report 1) maps Russia's current technological knowhow and the trajectory of its technological edge, 2) examines and evaluates the effectiveness of Russia's STI policies and strategies, and 3) analyses Russia's technological development in the context of its geopolitical implications, particularly with regards to the future of great power competition. By combining these approaches, the report produces knowledge and insight on Russia's current technological posture, its future trajectory and strategic objectives, and the mechanisms and policies by which it seeks to attain its stated aims. Moreover, the report analyses how these developments impact the broader international environment, the European Union (EU), and, specifically, Finland.

Instead of focusing on any particular industrial sector, this report takes a more holistic macro approach. Importantly, a specific in-depth analysis of military R&D, which is an important facet of the Russian STI context, was omitted from our report due to the existing volume and quality of novel analysis on the topic (e.g., Bendett et al. 2021; Engvall 2021; Zysk 2021a; Jankowski 2021). The references provided, among others, are excellent sources that can supplement the results of this study.

It should also be noted that the project has been completed at a significant juncture in history. As the project group finalized the writing of this report in February 2022, Russia invaded Ukraine. What followed was a significant transition in the dynamics between countries, at times a 180-degree change in the policy positions of countries. These decisions have had a significant impact on the results of the project. For example, in terms of the scenarios presented in the report, one of the more pessimistic scenarios became a reality. The project group has made an effort to complement the report with the possible implications of Russia's invasion. This has mostly impacted the discussion and conclusions sections of the report in the form of additions and footnotes.

Lastly, this report serves as the final outcome of the project and is preceded by three independent contributions from the project. First, Saari (2021) analyzed in detail the developments and geopolitics of technology around the Sputnik vaccine. Second, Suominen and Lehtinen (2021) analyzed the capabilities within the Russian science and technology (S&T) system. Third, Indukaev (2021), using the lens of digital competitiveness, analyzed the role of private businesses in Russia in securing their interests. These independent works are also briefly reviewed in this final report.

1.1 Background

With more than 140 million inhabitants, a higher education system that values scientific education in physics, mathematics, and chemistry (Chen et al. 2018), and good digital infrastructure and competitive domestic digital platforms, Russia has significant potential to succeed in international S&T competition. Russia is also performing relatively well in areas such as software development and computer science (Markotkin & Chernenko 2020). Furthermore, although Russia is not a global high-tech innovator or export powerhouse, it has succeeded in converting many new technologies to its own advantage and national ends (Saari & Secrieru 2020, 12).

Much of Russia's scientific edge is concentrated on the strategic industrial sectors, comprising of the defense, aerospace, nuclear, and hydrocarbon industries (Dezhina & Ponomarev 2016, 9). However, unlike in Israel and the US, innovations from national security sectors rarely transfer to other fields, although there are some limited exceptions, such as the Global Navigation Satellite System (GLONASS[3]). Due to factors such as low intellectual property rights (IPR) protection and weak incentives of the state-dominated National Innovation System (NIS), Russia's state led planning and innovation system has had a somewhat problematic relationship with the 'culture of innovation'. Even in fields of its traditional strengths, such as the space industry, new challengers are emerging, namely China and agile commercial operators, such as SpaceX[4].

3 'Globalnaya navigatsionnaya sputnikovaya sistema', global navigation satellite system, is a competitive Russian alternative to the American GPS system.

4 It is notable that Russia has historically struggled particularly with the commercialization of advanced technological capabilities such as computers (Graham 2013, 95-96).

SWOT on Russia's technological profile

The Russian S&T system has several identifiable strengths and weaknesses as well as opportunities and threats which are summarized in the table below. This SWOT analysis served as the starting point of the project on Russia's current S&T capability and its potential future.

Strengths	Weaknesses
• Solid educational and scientific base in mathematics and physics • Significant talent pool (population >140 million) • 4th largest R&D wokforce in the world • High-tech platforms in the nuclear, space, and software industries • Software industry and computer science based on STEM talent • Good digital infrastructure and a diverse e-commerce sector • High level of cyber security capability • Significant space (e.g., carrier rockets) and military technological knowhow • Competitive edge in oil, gas, and nuclear power production	• Research intensity and scholarly impact below global average • Low R&D spending by the industry and lack of available capital for new technologies • Decreasing foreign direct investments and collaborations in STI • Low number of internationally registered patents • Weak IPR protection and participation in global IPR markets • Low number of tech-oriented SMEs and start-ups • Low capacity for high-tech manufacturing and exports • Bureaucratization of the innovation process and top-down National Innovation System • One of the highest levels of corruption in the advanced world
Opportunities	**Threats**
• Commercializing military R&D and dual-use technologies • Developing excellence in energy, aerospace, and military technologies • Integration of global value chains in areas such as information and communication technology (ICT) and advanced materials • Increasing S&T collaboration with China and other non-Western powers	• Fast paced and intensifying global great power competition • Increasing dependency on imported technology, particularly Chinese • Stagnating scientific productivity • Western sanctions regime, including technology, trade, and scientific exchange • Unpredictable trajectory of the political regime

The SWOT analysis was used to guide the literature review that subsequently led to the development of future-gauging Delphi statements.

Currently, the Russian state is not only a policymaker but also the leading source of R&D funding and a major investor/owner in the Russian high-tech economy (Schiermeier 2020). Hence, it is crucial to understand the role, mechanisms, and drivers behind the Russian state and its policies in the field of technology. First, Russia tends to approach technological development primarily from the perspective of international competition. Being a sovereign actor—a great power—requires, first and foremost autonomous technological ability but also national economic growth and competitiveness in global markets. Second, Russia's National Innovation System is state-centric and characteristically top-down-oriented. This can be an advantage in high-priority national projects, such as setting up and developing a quantum computer or developing a vaccine against COVID-19, but it could also lead to a post-Soviet version of the "bureaucratization of the innovative process", similar to the Soviet system (CIA 1969).

In short, Russia's technological strategy—as its overall competitive strategy (Lavikainen et al. 2019)—aims to build on its relative strengths, that is, on strategic sectors such as its space, military, nuclear, and hydrocarbon sectors. These are all state-dominated fields, and together, they form the backbone of Russian geoeconomics, which flexibly combines political and commercial interests. In addition to its traditional fields of strength, where Russia competes at the very top globally, Russia has prioritized a few fields in which it aims to strengthen its global competitiveness. These include information and communication technology (ICT), artificial intelligence (AI), cyber security technology, and biomedicine. These fields are also essential assets for cutting-edge military technology development.

Russia's view of the global energy transition is conservative—instead of investing heavily on renewable sources, it has concentrated on competing in fields where it is already leading (Mitrova & Melnikov 2019). Russia aims to defend its position as one of world's top exporters of gas, oil, and nuclear products through digitalization and the development of new production technologies.[5] The only (potentially) green energy sector that has been the focus of political attention in Russia is hydrogen technology (CSIS 2021).

5 Based on 2020 data, Russia is the world's largest net exporter of oil and gas combined. Russia was the third largest producer and exporter of oil as well as the second largest producer of gas. Russia also has the lead in the export of nuclear power plants globally. "Country insight – Russia", BP, 2021. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/country-and-regional-insights/russia.html Accessed 19th April 2022.

POLICY BRIEF: Sputnik V case description

The project produced a policy brief (Saari 2021) that analyzed the Sputnik V vaccine development and its international rollout, as well as the collaboration between private actors and state actors at different stages of the process. The policy brief made the case that the Sputnik V vaccine case reflects the broader and more general tenets of Russia's current STI and illustrates both Russia's potential in producing world-class biotechnology products as well as the limits of its capabilities in global competition.

With regard to the reformulated STI strategy, the policy brief highlighted three features: state control, sovereignty, and self-sufficiency. These three S's indicate that commercial and strategic goals are closely intertwined at all stages of the research and innovation process. Although economic profitability is naturally a goal of technological innovations, it is not the only criterion against which potential success is evaluated. Other aspects include enhancement of Russia's national security and key foreign policy interests, such as the advancement of the country's great-power status or cementing its channels of influence in strategically important states. Nanotechnology and biotechnology are among the selected strategic fields in which Russia aims to compete globally. This paper described the different phases of COVID-19 vaccine development. For each of them, the role of the Russian state was significant. The whole process can be described as a major national project; the development was funded by the Russian Direct Investment Fund and carried out in several Russian laboratories. Furthermore, to win time in the global race, the authorities were willing to bend common scientific and ethical rules. The first two Russian vaccines both entered the market before completing Phase 3 trials.

In a similar vein, the global rollout of the Sputnik V was coordinated by the state-run Russian Direct Investment Fund. The marketing was also backed by Russian state-controlled media outlets and the social media machinery that fiercely defended Sputnik V and spread disinformation about foreign vaccines. The close state involvement throughput the process had a negative impact on the Western markets, but in other emerging markets, the campaign was more successful. The case study supported the conclusion that Russia aims to use its innovation capability as a geoeconomics tool to shape the international environment, and that there are close linkages between Russian innovation policies and its foreign, security, and military policies.

Even before the Russian invasion of Ukraine in February 2022, Western sanctions, implemented as a result of the annexation of Crimea in 2014 and other malign maneuvers (Kofman 2020), have had a negative impact on scientific collaboration and trade between Russian and Western organizations.[6] Moreover, Russia's repressive practices at home have also led to additional sanctions.[7]

However, Russia has simultaneously increased its STI cooperation with China in a variety of fields. The two sides have initiated projects (for instance, in 5G, AI, robotics, and cloud computing) between Chinese and Russian IT companies (Sinkkonen & Lassila 2020). The most dynamic field of the Sino-Russian 'digital partnership' has been the two countries' common actions in formulating norms and practices, such as 'internet sovereignty', in governing cyberspace (Ekman et al. 2020). Through this close collaboration, Russia is also seeking to learn from China's approach, for example, on the commercialization of scientific knowledge and innovations (Bendett & Kania 2020).

However, should Russia fall significantly behind in the global great power competition in the geoeconomic sphere, its economic and technological dependency on China could grow significantly. In that case, many of the decisions impacting Russia's future would be shaped directly or indirectly in Beijing, contrary to Russia's own strategic emphasis on its technological sovereignty (Saari & Secrieru 2020; Bendett & Kania 2020). Therefore, the asymmetry between Russian and Chinese technological power casts a long shadow on the future of STI collaboration. Russia's ongoing invasion of Ukraine only reinforces this dynamic of Moscow's dependence on Beijing.

Russian strategic documents consistently refer to technology as an important domain of the increasing global geopolitical struggle. Reflecting these sentiments, Russian leadership has stressed the critical role of S&T development, placing it on par with national security in terms of strategic importance (Chen et al. 2018, 95-96). However, in terms of S&T development, the emphasis on national security has also hampered the efforts of many scientific institutes and high-technology companies in Russia. To increase self-sufficiency and ensure security, the state plans to ban the use of foreign software and technical equipment by Russian firms working in the realm of critical infrastructure. Furthermore, Russian security services have tried to limit international science exchange and cooperation by opening a series of espionage prosecutions against individual researchers, accusing them of passing classified information to Western countries or China (Weiss 2021, 7; Bendett & Kania 2020).

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6 A case in point of is the US ban on the use of Kaspersky products by US authorities in 2017. Volz (2017).

7 As of May 2021, there were over 730 Russian individuals, companies and entities subjected to sanctions. See e.g. Parachini & Bauer 2021

Russia has a long tradition and ethos of "catching up" with the West in the fields of technological and economic development. Throughout the 20th century, Russia has tried to close this developmental gap by engaging in multiple programs of radical change to modernize the country through a "dialectic of autonomy and adaptation" (Sakwa 2019, 6-7). In the field of technology development, this tendency has historically manifested itself as a pattern of "fits and starts" (Graham 2013, 164). In other words, although Russia has been able to invent and develop various leading technologies, it has often failed to maintain and sustain its lead in the long term. According to Loren Graham, a leading historian of Russia's S&T development, this state of affairs results from multiple sources, such as the attitudinal environment, political order, economic system, and the weaknesses in legislation. (Graham 2013, 99-101)

Up to the present day, Russian attempts to generate innovations and modernize technology development have tended to focus on state-led technocratic instruments, with less attention paid to wider political and societal issues (Graham 2013). Importantly, this feature is a key factor contributing to the inherent tension between socioeconomic development and state sovereignty in Russia. Therefore, it is important to note that Russia's future STI trajectory is not solely affected by the development of its scientific and technological capabilities and knowhow but also by its societal and political development.

1.2 Objectives and methods

The project on Russia's technological policy and knowhow in a competitive global context had three principal objectives:

1. Novel insight into the status quo of Russia's STI system: The project created significant new knowledge and applied research on Russian technological knowhow and STI policies as well as their geopolitical implications for Europe and Finland. The results of this research, combining both quantitative and qualitative methods, are presented in this report and communicated to policymakers and a wider audience through media, public events, and closed-door briefings.

2. Russia's future trajectories and its geopolitical implications: The project engaged in a foresight process through the use of the Delphi method. Four different scenarios were drafted based on the Delphi survey and a literature review. These activities contribute to the preparedness of the Finnish authorities by creating insight into the possible future trajectories of Russian technology policy and knowhow.

3. Active stakeholder engagement and dissemination of knowledge: In addition to this final report, three policy briefs were published and disseminated actively through the international networks of consortium members and their organizations. Moreover, various stakeholders were consulted as part of the Delphi survey. Much of the engagement was done online due to the overall COVID-19 epidemiological situation in Finland. These activities and publications, together with engaging in social media presence, contribute toward the situational awareness of Finnish authorities and toward knowledge-based decision-making.

The project began with the task of mapping out Russia's scientific and technological capacity and abilities through a methodological process identifying major clusters of Russian STI development. The methodological approach was based on 1) analyzing STI documents by individuals affiliated with Russian organizations using bibliometric methods, followed by 2) a thematic analysis to highlight recent trends. The input data was based on scientific publications, journals, magazines, and patent documents.[8]

Mapping of Russia's STI capabilities

- Methods: Interviews/Stakeholder discussion, scientometrics, bibliometrics, natural language processing (NLP) based content analysis
- Data: patent registers, innovation indicators, scientific publications
- Research questions:
  - *In which high technologies is Russian knowhow at the top level globally?*
  - *What areas of technological knowhow are critical to Russia's development? In which high technologies is Russia lagging behind its own goals and international development, and how is the country responding to this challenge?*
  - *What is Russia's capability to respond to the development of artificial intelligence and other disruptive technologies (5G/6G, quantum computers etc.) and complex systems of systems?*
  - *How has the bond between Russia's technological knowhow and the country's military technology developed in recent years?*

8 Through global archiving & indexing databases such as Web of Science and Scopus, we were able to grasp the Russian federation activity on scientific publications. Clarivate Analytics's Web of Science (WoS) is nominated as the data source for comprehending scientific breadth and depth of Russia. We also cross checked our research results with Scopus data

Second, the project conducted an analysis of Russian technological strategy and its effectiveness through a qualitative analysis (content analysis) of Russian-language sources. The core data consisted of key national strategic and policy documents[9]. The assembled data were subjected to a comprehensive thematic analysis performed with the help of *ATLAS.ti* qualitative text analysis software.

Analysis of the Russian STI strategy and its effectiveness

- Methods: Qualitative content analysis
- Data: Key national strategic and policy documents, media sources
- Research questions:
  - *What is Russia's approach to governance and mode of operating in the context of global technology competition?*
  - *In which directions does Russia's STI policy steer the development of Russia's technological knowhow?*
  - *What limitations loom on Russia's attempts to implement its STI policy?*
  - *What could be the successes of Russia's STI policy?*

Third, the project engaged in qualitative analysis of the geopolitical implications of Russia's technological posture by utilizing foresight methods to systematically analyze the long-term developments, trends, and possibilities. An important part of the process was the interaction between different project partners and stakeholders.

As part of the foresight process, the Delphi method was utilized to test the conclusions of the research and tease out the policy implications of the Russian technological edge and policies for the EU and Finland. The Delphi method is a well-known participatory innovation research method that facilitates anonymous discussions among experts about the challenges of a selected problem field. In the Delphi survey, a wide array of carefully

9 Including but not limited to the Federal laws on Strategic Planning and Industrial Policy (2014), Government decrees on National Technological Initiative (launched in 2015), the Strategy of the Scientific and Technological Development of the Russian Federation (2016), Information Security Doctrine of the Russian Federation (2016), the presidential decrees on National Goals (2018, 2020 and Digital Economy of the Russian Federation Programme (2017).

selected[10] experts were presented with statements regarding the plausible trajectories of Russia's STI policy and their implications. The expert answers to the Delphi statements were synthesized by the moderators toward a shared view of the experts. Central to the Delphi method is that the respondents can anonymously present their own arguments, which allows for different viewpoints to be expressed. Moderators ensured that the experts involved in the discussion were relevant.

Finally, as part of the foresight work, four different scenarios were constructed by supplementing the output from the Delphi survey with an analysis of the relevant literature. The scenarios aim to systematically imagine what Russia's possible future trajectories might look like in the light of selected key uncertainties.

10 Selecting the experts was based on Neville et al. (2011). We focused on identifying different types of stakeholders based on their 1) ability to directly influence change or maintain current situation 2) legitimacy of being involved and 3) their familiarity and understanding of the topic. We also strove for balance in public and private organization representatives and for gender equality. The expert stakeholder identification was based on the networks of the project partners and the steering group.

Analysis of the future geopolitical implications of Russia's STI posture

- Methods: Interviews, Delphi method, Scenario analysis, workshop
- Data: open-source documents, policy-makers' public comments, expert interviews, Russian language and international media sources
- Research questions:
  - *How does Russia's level of technological knowhow affect its available resources and the realization of foreign and security policy goals?*
  - *How does Russia position itself in the technology competition between China and the United States?*
  - *How does great-power competition affect Russia's technology solutions, for example, with regard to 5G technology?*
  - *How will this bond, as well as the general blurring of the line between civilian and military technologies, affect other actors' technology cooperation with Russia?*
  - *At what level is technology cooperation between Russia and China? How does the potential technological cooperation between Russia and China affect global great power competition?*
  - *What is Russia's role in global technology standard-setting and the global management of technology use?*
  - *How does Russia's positioning in the great-power technology competition affect the security environment in Europe and Finland?*
  - *How do the status and goals of Russia's technological knowhow affect the conditions for cooperation between Finland and Russia, for example, in commercial, scientific, and technological cooperation? What risks and opportunities may be involved?*
  - *How do geopolitical tensions and Western sanctions policy affect Russia's technological knowhow, technology transfer, and the introduction of new technologies?*

2 Russia's science and technology policy

2.1 Background

Putin returned to the presidency in 2012 with renewed determination to assert Russia's geopolitical and geoeconomic power globally. Although during the Medvedev presidency, Russia still attempted to copy Western innovation models, Russia's current science, technology and innovation (STI) system draws boldly on the country's statist, dirigiste traditions. Whereas the dominance of the state was once considered a drawback, today, it is often seen as a relative advantage for Russia compared to its Western competitors.

Russia's STI increasingly relies on top-down planning and initiatives as well as state-generated investment. Part and parcel of the reformulated STI strategy are the three S's: state-control, sovereignty, and self-sufficiency. The commercial and strategic goals are closely intertwined—often even in the case of private companies, as they typically have very close informal relations with state representatives. Although economic profitability is naturally a goal of technological innovation, it is not the only criterion against which potential success is evaluated. Other aspects include enhancement of Russia's national security and key foreign policy interests, such as the advancement of the country's great-power status or cementing its channels of influence in strategically important states.

Russia's STI system focuses on selected fields where it has a comparative advantage, and which are linked to its national security and economic sovereignty. For example, in the energy industry, Russia has primarily concentrated on the hydrocarbon and nuclear industries, where it is already leading the pack, rather than exploring the potential of new renewable energy sources. Apart from energy, Russia has focused for the most part on the military, space, and IT industries—all of which are considered highly strategic realms. Russia has also selected several cutting-edge fields where it seeks to compete globally, such as AI, nanotechnology, and biotechnology (Saari 2021).

The other side of the 'sovereignty' coin is self-sufficiency, namely, decreasing Russia's dependency on other powers in strategic sectors. Self-sufficiency in strategic sectors and import substitution were major goals in the planning documents even before rifts with the United States (US) and the European Union (EU) deepened as a result of Russia's illegal annexation of Crimea and war in Donbas. After 2014, Western sanctions and decreasing foreign investments in Russia further highlighted the need to encourage domestic investment and import substitution. The ongoing Russian invasion of Ukraine in 2022 only serves to reinforce these dynamics, although the feasibility of the aforementioned domestic solutions and import substitution policies seems increasingly at odds with the realities of Western sanctions and the global value chains of S&T[11].

2.2 Review of the official Russian STI strategies

The threat perceptions of Russian strategic documents are based on views of accelerating international competition and the struggle for power. According to the National Security Strategy, the formulation of a multipolar international system is a primary source of regional and global instability. The struggle for power is concentrated around national development, resources, access to markets, and control of the vital arteries in the world economy. According to the strategy, competition between states increasingly expands to the areas of values and models of social and economic development, as well as human, scientific, and technological potential.[12]

The distribution of resources for STI development is becoming increasingly unequal due to the accelerating centralization of scientific and technological potential. Russia's strategic documents describe the growing role of international standards, leading to the formulation of a group of powerful countries that have a dominant position in the field of R&D. Simultaneously, a technological periphery is carved out of countries that are losing their capabilities for conducting independent STI and R&D activities. These countries are being positioned into the role of "donors" of qualified labor to advanced economies.[13]

Similarly, the possibilities for economic development are diminishing due to increasing tensions between the great powers in the international system. The international economy is increasingly under the influence of political factors due to the utilization of economic, financial, investment, and technological policies for the achievement of geopolitical goals, thus degrading international economic relations. Particularly in the field of AI, the leading actors in the international market are actively taking actions to secure their dominant position and to maintain a long-term competitive advantage by preventing new participants from gaining a position in the market.[14]

The strategic documents make the case that the primary factors behind the success of states in intensifying international competition are achievements in the field of S&T. Scientific and technological development are directly connected to economic

11 These developments are discussed more in detail in the Discussion section of the Report.

12 National Security Strategy 2015, paragraph 13. President of Russia 2015.

13 National Security Strategy 2015, paragraph 16. President of Russia 2015.

14 refer to e.g. the National Strategy for the Development of Artificial Intelligence 2019, paragraph 16. President of Russia 2019.

competitiveness as well as to national security. The Strategy of Scientific and Technological Development determines that primacy in the field of research and development, high rate in production of new knowledge, and creation of innovative products are the central factors determining the competitiveness of national economies and success of national security strategies among states in the international system.[15]

A key technology behind the competitiveness of national economies is the utilization of data processing. The Strategy for the Development of Information Society states that at the international level, those national economies in which key industries utilize big data have a significant competitive advantage. These technologies are utilized in Russia but their often foreign origin creates vulnerabilities for the state.[16]

According to Russian strategic documents, the development of information and communications technologies has created new types of threats that contest the sovereignty and territorial integrity of states. Moreover, the widespread utilization of information technologies in national economies and the public sector is creating new types of information threats due to information being instrumentalized to achieve geopolitical and military-political goals. For example, information-psychological means are utilized to destabilize domestic politics and undermine sovereignty.[17]

The National Security Strategy argues that confrontation in the information space is increasingly influencing the international situation. According to key strategic documents[18], "certain states" are attempting to use their technological superiority to dominate the global information space. Moreover, the uneven distribution of capabilities for ensuring the safe and sustainable operation of the internet prevents the creation of a stable information environment.[19]

The Russian National Security Strategy describes the long-term interests of the Russian Federation. The interests most relevant to S&T policy can be summarized as 1) strengthening sovereignty, independence, and self-sufficiency; 2) increasing the quality of life for citizens; 3) increasing the competitiveness of the national economy; and 4) maintaining Russia's status as one of the great powers in the international system. These

15 Strategy of Scientific and Technological Development 2016, paragraph 8. President of Russia 2016c.

16 The Strategy for the Development of Information Society 2017, paragraph 15. President of Russia 2017.

17 Doctrine of Information Security 2016, paragraph 10., 12., 15., 16. President of Russia 2016d.

18 National Security Strategy 2015. President of Russia 2015.; The Strategy for the Development of Information Society 2017. President of Russia 2017.

19 The Strategy for the Development of Information Society 2017, paragraph 19. President of Russia 2017.

long-term interests, defined in the National Security Strategy, form a basis for defining the strategic goals and strategic priorities in different fields of activities.[20]

The realization of long-term national interests is based on achieving certain strategic national priorities. The essential strategic national priorities in the context of S&T policy include sustainable economic growth, together with science, technology, and education. According to the National Security Strategy, the strategic national priority of economic growth is realized through a transformation of the national economy to a new level of technological development, and as a result, it should be possible for Russia to enter the group of leading countries in terms of GDP.[21]

The strategic national priority of science, technology, and education defines certain strategic goals that are prerequisites for its realization. The first strategic goal is defined broadly as modernization of the national system of S&T, modernization of the national economy, realization of national competitive advantages, ensuring national security, and creating a foundation for future development. The second strategic goal is defined as increasing social mobility as well as the quality of education and fundamental research.[22]

The Strategy of Scientific and Technological Development aims to change the role of S&T in Russian society, economy, and government and create a unified system that is integrated into the socioeconomic development of the country as well as securing the self-sufficiency (независимости) and competitiveness of Russia. The goals of scientific and technological development are defined as ensuring the self-sufficiency and competitiveness of the country through the build-up and complete utilization of Russia's intellectual potential.[23]

The Strategy of Scientific and Technological Development defines self-sufficiency as "achievement of a sufficient level of independence in critical spheres of life support as a result of high effectiveness in research and development as well as in the practical appliance of achieved scientific results." In this context, self-sufficiency and independence should be understood as core elements on which the concept of sovereignty is based. Competitiveness is defined as the development of clear advantages over other states in the fields of S&T and consequently in the social, cultural, educational, and economic spheres.[24]

20 National Security Strategy 2015, paragraph 30. President of Russia 2015.

21 National Security Strategy 2015, paragraph 31., paragraph 55. President of Russia 2015.

22 National Security Strategy 2015, paragraph 67. President of Russia 2015.

23 Strategy of Scientific and Technological Development 2016, paragraph 28., 36., 37. President of Russia 2016c.

24 Strategy of Scientific and Technological Development 2016, paragraph 4. President of Russia 2016c.

The Strategy of Scientific and Technological Development presents two scenarios of different developmental paths for Russia. The first scenario is characterized by stagnation in scientific and experimental activities, which would lead to a loss of technological self-sufficiency and competitiveness of Russia. The second scenario is based on the successful reversal of the prevailing negative trends through an effective restructuring of research, development, and innovation in the public and private sectors. The second scenario requires a significant increase in funding for research and development activities in relation to GDP to achieve a level comparable to the countries that are most developed in the field of S&T.[25]

2.3 Development of Russian STI policy toolbox

Russian STI policy is best interpreted as an accumulation of tools and approaches that were developed in a given political context and later repurposed once the context and strategic priorities changed. Russian STI policy toolbox consists of a combination of market oriented instruments and a "dirigiste" mindset. After 2012, the Russian government regained testing for a more hands-on approach while still actively using market tools. Although such ambiguity of policy approach is sometimes an asset, it also limits the efficiency of the Russian STI policy, reflecting the more general order limitations of Russian strategic choices and predominant approaches to governance.

Before 2000, research and development in Russia was put in crisis provoked by the end of the USSR; it suffices to mention that the overall state spending on R&D in Russia in 1994 was only one-fifth of that in 1991 (Graham & Dezhina 2008). STI domain was of marginal political importance for the political leadership, and while science reformers in government worked on making R&D activities in Russia more market oriented and introducing competition in research funding, that was not a high-profile initiative. In reality, the changes in science governance were as much motivated by reformist objectives as they were by the crisis (Saltykov 2006).

Putin's arrival to power marked the change in the STI sphere as the first elements of current policy started being built in the early 2000s. STI sector started being seen not as only one more burden on the state budget but also as an instrument in achieving the state's objectives. The 2000s can be seen as the time when the gradually increasing reliance on market-oriented approaches unfolded in parallel with the increase in the strategic importance of the STI domain. This trend could be exemplified by the

25 Strategy of Scientific and Technological Development 2016, paragraph 25., paragraph 26. President of Russia 2016c.

nanotechnology development program that was the highest-profile initiative in the STI domain in the late 2000s. Initially designed to be fulfilled via "federal targeted programs"—already a market-oriented instrument favoring competition for public procurement contracts—it ended up being funded, in large part, via Rusnano, an organization with operating mode close to that of a private investment fund.

In the 2000s, the use of market-oriented tools combined the desire to reinforce market mechanisms in the STI domain and stimulate high-tech entrepreneurial activities with typical prioritization of country's security and international standing. During Medvedev's presidency, the market instruments gained more importance. Economic and technological development was back then valued less for creating levers for power politics, but more as a strategic goal per se: joining the club of Western developed countries by integrating into the global economy thanks to innovation and technological progress was seen as a path to Russia's geopolitical success. Using market-oriented policy instruments was then seen as a form of institutional rapprochement with the West. Medvedev's modernization flagship project, Skolkovo, was also relying on market mechanisms—venture capital investment practices—and private actors. Skolkovo developed an infrastructure for start-ups attractive to venture capital and later featured a venture capital fund.

After Medvedev's departure from the presidency and the strengthened emphasis on Russian great power status and global geoeconomic and geopolitical competition, the leadership revised its approach to technological competition. The general approach to STI is now boldly top-down and state-led. In effect, the state selects winners instead of enabling the market to select the strongest. National programs stating explicit and detailed goals, protectionist measures, and governments actively enrolling economic actors in projects aiming at national technological self-sufficiency became frequent forms of policy action. However, the market mechanism is not, of course, totally absent from the system; rather, the market mechanism functions within and contributes to the state-dominated system.

The Russian confrontational stance in foreign policy has, however, reflected negatively on international collaboration with at least Western research institutions. Earlier, during the Medvedev era, research cooperation – epitomized for instance by the EU-Russia 'Partnership for Modernization' as well as on a smaller scale by the MIT-Skolkovo partnership – was considered one field where the Russian and Western interests were mutual and non-zero-sum logic prevailed. This approach was later marginalized in Russia's leadership and international partnering – at least with Western partners – lost its place among the privileged policy pathways.

2.4 Defence-led modernization of the National Innovation System

Currently, Russian leadership tends to perceive the technological competition among great powers as a global zero-sum game, which is why achieving success in this competition has been described as an "existential necessity" for Russia (Jankowski 2021). As a result, much of Russia's scientific and technological know-how is concentrated on the strategic sectors, consisting of defense, aerospace, nuclear and hydrocarbon industries (Dezhina & Ponomarev 2016, 9). These sectors are perceived as vital for Russia's sustained status as a great power.

According to analysts, Russia has by now largely spent its "knowhow" -inheritance from the Soviet military S&T (Engvall 2021, 31-32). Therefore, in addition to its traditional strengths, the Russian leadership has recognized the need for new innovation drivers in the field of emerging technologies. This has resulted in a two-pronged strategy to counter the looming technological supremacy of the US and China (Raska 2019, 72-74; Zysk 2021a; Zysk 2021b; Jankowski 2021):

1. *The emphasis on the modernization of existing strengths such as nuclear weapons in order to offset the conventional advantages of its adversaries.*

2. *Experimentation with selected "high-risk/high reward" emerging technologies such as hypersonic glide vehicles, in order to create asymmetric advantages.*

Russia's science, technology and innovation (STI) policy is characterized by the vertical orientation of its National Innovation System (NIS), which means that most of the instruments of STI are government controlled (Dezhina 2017, 8-9). According to scholar Katarzyna Zysk "Russia is an outlier among major powers with its traditional state-driven, top-down innovation model" (Zysk 2021b). Instead of dividing its limited resources across the board, Russia's approach is to "pool" its resources towards selected cost-effective and asymmetric strategic technology areas providing Russia with comparative advantages (Engvall 2021, 43-44), whereas in the broad range of R&D Russia has adopted a "good enough" approach (NATO 2020, 37).

Russia has also sought to complement its tradition of state-driven innovation by trying to create a more collaborative approach to R&D by developing linkages between the military, academia and the private sectors (Zysk 2021a, 2-3). In particular, the development of dual-use technologies has been seen as a way to increase synergies between the civil and military sectors as well as to boost economic growth and competitiveness of both sectors (Bendett & Kania 2018).

Russia is closely monitoring the technological development approaches and priorities of its great power rivals USA and China (Raska 2019). In so doing, Russia has also tried to study and emulate the successes of US approaches to dual-use technology led R&D as well as China's "civil-military fusion" (Zysk 2021a, 5-10; Zysk 2021b). Particularly notable in the approaches of the US and China has been the recognition of the growing global importance of basic and applied research (Engvall 2021, 32-33) conducted within the commercial and private sectors. The US Department of Defense is focused on close relations with the Silicon Valley while China is trying to reduce barriers between the private sector and its military industry through "civil-military fusion" (Laskai 2018).

The United States in particular has a long history of leveraging tight relationships between the Department of Defense, the academic community and the private sector (Bendett & Kania 2018), which is why the US model of public-private partnerships and civil-military synergies has been emulated in Russia (Zysk 2021a, 5-10). For example, Russia's Foundation for Advanced Research Projects (*Fond Perspektivnykh Issledovanii*, FPI) focusing on high-risk R&D has been modelled after the US example of DARPA (Schwartz 2019, 158-159), although its budget is nowhere near its US model.

Despite the willingness to emulate its successful rivals, Russia also has its own strategic approach and priorities to STI. Russia is seeking to utilize its S&T resources for the long-term modernization of its armed forces (Roffey 2013), but also as a "locomotive" for the broader technological and economic modernization of Russia (Bukkvoll et al. 2017). The rationale behind this approach is that the development of synergies between civilian and military R&D through dual-use technologies would thus help Russia to avoid making hard choices between the focus of investments on either civilian or military R&D (Schwartz 2019, 196-198).

The approach of defense-led modernization and innovation does make sense in terms of the centrality of the defense industry (OPK) for Russia's economy, high-tech production (Bukkvol et al. 2017) and R&D funding (Nato 2020, 45-46). Some Russian researchers even suggest that the military-industrial complex is a key component of the country economy's outside of commodities sector (e.g. Rassadin 2000; Yaremenko 2020). Moreover, Russia has made substantial investments to its defense sector through programs such as Armaments 2020 priority procurement program, thus benefitting many companies working within the national security sector (Gregova 2020).

However, the idea that specifically the defense sector would become "a launch pad" also for the development of breakthrough dual-use and civilian technologies (Akimkina et al. 2021), goes against the grain of global trends of the last three decades. During the Cold War, technological innovation often took place within the defense sector from which these innovations were transferred to the civilian sphere through "spin-offs". Nowadays, the direction of dual-use technology transfer has shifted to the opposite direction, whereby the most important innovations are often generated in the civilian sphere and later adapted to the military field (Cowan & Foray 1995). For example, most of the cutting-edge research related to emerging technology such as AI is currently driven by the private sector (Laskai 2018).

In light of these trends, Russia's attempt to specifically utilize its defense industry as a driver of innovations in Russia seems somewhat misguided. Nonetheless, Moscow has attempted to enforce cooperation between commercial civilian sectors and the defense sector by requiring the defense industry to increase its share of civilian and dual-use goods up to 30 percent by 2030 and 50 percent by 2050 (Engvall 2021, 31-32). Unsurprisingly, it has proved difficult for the defense companies to produce civilian commercial goods under market conditions (Shagina & Boulegue 2020).

Transforming Russia's military-industrial complex toward the modern dual-use and high-tech oriented defence industry has proved problematic. For one, Russia lacks a coherent and a systematic connection between civilian and military research (Roffey 2013). Globally, universities have an important role in the development of dual-use technology and military research. In Russia the level of university participation in dual-use R&D activities has been low, which has caused difficulties for technology commercialization (Carayannis et al. 2016, 1143-1145). In terms of spin-offs to the civilian markets, Russia has not been able to commercialize its defense related R&D very efficiently (Wang & Li 2021, 10-11).

Moreover, Russia lacks the basis for a knowledge economy to support the development of advance commercial dual-use technology. Russia does not have the type of tightly-knit network of competitive R&D actors that for example the US and Israel possess (Schwartz 2019, 170-177). A particular problem for the conversion of defense R&D towards dual-use technology and civilian spin-offs is that military R&D in Russia is not oriented towards the required IPR legislation and practices because the Russian defense industry is more concerned about protecting its technology from espionage (Bukkvoll et al. 2017).

All these aforementioned factors threaten the military modernization of Russia because of the overall conditions affecting the "defence complex" (Yaremenko 2020). The development of dual-use technology is perceived as a way to circumvent difficult choices between "guns and butter", between civilian and military R&D, by combining synergies from both civilian and military fields. However, it seems doubtful that the defence sector can act as a driver of economic growth and broader modernization of Russia, not least because of the blow dealt by Western sanctions on Russia's modernization programs.

2.5 Challenges faced by Russian STI policy

According to Russia's own national strategic documents, which were written before the imposition of the latest rounds of Western sanctions, the current stage of scientific and technological development in Russia is described as containing significant competitive advantages but also unresolved problems. According to these documents, the central problems in Russia are related to the centralization of quality research to only certain scientific organizations, inefficiency of scientific organizations, lack of mobility for Russian researchers, unattractiveness of Russia in attracting talent, disconnect of science and the real economy, insufficient funding for R&D in relation to Gross Domestic Product (GDP) and lack of coherence in supporting R&D in the federal, regional, industrial and private spheres.[26]

According to the Strategy of Scientific and Technological Development, the negative factors and tendencies in scientific and technological development are described as creating a risk for Russia of lagging behind the most advanced countries in technology, depreciation of domestic investments in science and technology as well as loss of self-sufficiency and competitiveness of Russia in the international system. These developments could create significant risks for Russia's national security.[27]

The National Security Strategy describes the threats to national security in the sphere of economic development as well as in the sphere of science, technology and education. The threats in the economic sphere are insufficient competitiveness, preservation of the export model based on raw materials and stagnation in developing and utilizing promising technologies. Factors that negatively influence national security in the sphere of science, technology and education are stagnation in developing advanced technologies, dependence on imports of scientific equipment, electronic components, software and computer systems as well as international sanctions directed against Russian scientific and educational organizations. Other factors include inefficient regulation, insufficient funding for research and development, insufficient qualified labour as well as low quality of professional and higher education.[28]

The Doctrine of Information Security describes the threats to information security in the different sectors of society. In the economic sphere the central factor influencing information security is the insufficient level of competitive information technologies and their utilization in producing products and services in Russia. The high level of

26 Strategy of Scientific and Technological Development 2016, paragraph 11. President of Russia 2016c.

27 Strategy of Scientific and Technological Development 2016, paragraph 12. President of Russia 2016c.

28 National Security Strategy 2015, paragraph 65., 68. President of Russia 2015.

dependency of domestic industries on foreign information technology especially in electronic components, software, processors and communications determines that the socioeconomic development of Russia is dependent on the geopolitical interests of foreign nations.[29] In the field of science, technology and education vital factors influencing information security negatively are ineffective scientific research focused on information technologies, insufficient level of domestic designs and qualified labour as well as the incoherent management and development of the information infrastructure.

This overall account of the Russian STI domain demonstrates a relatively optimistic outlook that the Russian government has of its STI policy capacity. In some regards Russia's policy capacity should not be underestimated. The active development of STI policy started in mid-2000's and the country accumulated significant experience in the domain. However, in the absence of systemic reforms of economy and governance, even a perfect execution of Russian STI policy would not be a game changer for Russia. The key limitations of STI domain are related to excessive presence of the state, the dirigiste approach, and the government determination to maintain its capacity to steer and coerce economic actors. This puts fundamentals limits on the growth potential of innovative technological and economic activities.

29 Doctrine of Information Security 2016, paragraph 17. President of Russia 2016d.

POLICY BRIEF: Russia's quest for digital competitiveness

The policy brief by Andrey Indukaev (2021) studied Russia's quest for digital competitiveness and its unique public-private partnership models. The policy brief was mildly optimistic about the the viability of the Russian 'hybrid' competitive model mixing geopolitical, technocratic and commercial goals.

The policy brief studied the public-private relationship through contemporary case studies, for instance through the collaboration between Moscow-based face recognition start-up NtechLab and local government in Moscow. The paper argued that while the state has an upper hand in the relationship, this does not exclude the possibility of mutually beneficial partnerships. In national markets the businesses often benefit from the close collaboration with state bodies but in export markets this can be a drawback, particularly in the Western markets.

The study concluded that Russia has managed to advance digital technology with sufficient potential in the private and public sectors, which are fexible and capable of combining a business orientation and technological capacity with an understanding of the state's priorities.

It is reasonable to expect that the capacity to balance and combine business and strategic interests, even more than the capacity to exert control over private and public actors in the digital economy, will determine the Russian state's potential in the development and strategic uses of digital technologies such as artificial intelligence. However, given the low investment in R&D and the fundamental limitations of the country's economy, one should not expect a radical change in the country's competitiveness thanks to digital technology.

3 Russia's science and technology capability

3.1 Background

The role of technology in great power competition cannot be understated. Technological innovation can create wide-ranging ramifications, both in terms of risks and benefits that can transform the whole international system, as was the case with nuclear power in the 20th Century (Weiss 2015, 414-418). Indeed, many Russian policy analysts perceive technology as the most critical sphere in the great power competition also in the 21st Century. Already during the Cold War, scientific and technological capabilities, especially in the form of nuclear and space power, were at the forefront of the competition between the Soviet Union and the United States (Bezrukov et al. 2021, 68-69).

In terms of technological development, Russia has experienced various cycles of modernization and development but also cycles of stagnation, decline and even collapse (Breedlove 2019). Historically, Europe has been the most important source of modernization for Russia from the Tsarist times, through the Soviet era, up to the present day (Kanevskiy 2014, 4-5). As a result, Russia has a long tradition of trying to imitate and catch up with the West. In the Soviet Union these policies were referred to as the "acceleration of scientific and technical progress" but in modern Russia these policies have become known as "the innovation and technological modernization of the economy" (Komkov 2019, 530).

The latest UNESCO Science Report (Gokhberg & Kuznetsova 2021) describes Russia as being at a "crossroads". Despite many efforts to the contrary, Russian economy remains reliant on hydrocarbons, especially in terms of federal revenue. Moreover, despite being one of the world leaders in physics, engineering, mathematics and chemistry, Russia is said to be "punching below its weight" in scientific research. (Gokhberg & Kuznetsova 2021, 347,355-356)

As a response to these challenges, Russia has sought a "transition to a new technological order" (Uskov 2020). In an attempt to close the gap between itself and the global STI leaders Russia aims to become a technological great power by transforming its economy from catch-up mode to a globally competitive innovation economy fit for the 4th industrial revolution (Gokhberg & Kuznetsova 2021, 347-348). In terms of policy, Russia's 2016 Strategy for the Development of Science and Technology to 2035 has seven mission-oriented priorities: digital manufacturing; clean energy; personalized medicine; sustainable agriculture; national security; infrastructure for transportation and telecommunications; and the readiness for the future (Gokhberg & Kuznetsova 2021, 352).

Accordingly, Russia has set out to become a global leader in emerging high-tech markets by 2035 in areas such as distributed energy systems, drones, transport systems, personalized health-care and cybersecurity (Gokhberg & Kuznetsova 2021, 352-353). In order to achieve this, Russia is developing its competitiveness, human capital and STI infrastructure (Gokhberg & Kuznetsova 2021, 347-348) in addition to modernizing its traditional sectors of strength such as the nuclear, energy, space and ICT sectors (Sokolov 2013, 188-189).

Despite these ambitions, Russia faces multiple challenges in its long-term technological development, including demographic problems, unfavorable business climate and paternalistic approaches to innovation (Sokolov 2013, 187-188). Moreover, Russia suffers from many "lows" in the field of STI: low global competitiveness, low level of innovation activities, low level of value added in technology exports, overall low level of high-tech and knowledge-intensive production as well as a low level of globally viable commercial patents (Uskov 2020). The private sector invests only modestly towards R&D (Gokhberg & Kuznetsova 2021, 355-356) and spends only a low proportion of these investments on acquiring new technologies, patents and licenses (Gokhberg et al. 2018, 119-121). Most of Russia's indigenous innovations are confined to domestic markets (Gokhberg & Kuznetsova 2015, 348). The recent withdrawal of Western companies from Russia due to Moscow's decision to invade Ukraine in February 2022 only serves to reinforce these existing problems further[30].

Thus far, Russian attempts to modernize and diversify its economy towards an innovation-led knowledge economy have not succeeded. According to the UNESCO report Russia suffers from export imbalance and a "persistent deficit in the balance of payments for trade in technology" (1.7 billion USD in 2018), which reflects Russia's "relatively poor global competitiveness in certain technological sectors, such as pharmaceuticals, electronics and computer hardware" (Gokhberg & Kuznetsova 2021, 357). Moreover, unlike other advanced OECD countries, Russia lacks a culture of SMEs that would generate innovations for the economy (Weiss 2021, 4). Russia's natural resource oriented and public sector dominated labour market is not attractive for skilled employees since its competitiveness has been traded for low unemployment in order to safeguard societal stability (Boutenko et al. 2017, 8-9, 26-27).

30 The effects of these developments are discussed more in detail in the Discussion section of the Report.

Perhaps most crucially, Russia's human capital has been under considerable strain since the 1990's. The dissolution of the Soviet Union in 1991 created a brain drain of scientific and technological talent that continues to this day (Dezhina 2017, 16-17). Russia has struggled to develop its ability to attract and retain highly-skilled and internationally oriented talent (Lassila 2019). The result has been the persistent emigration of STI expertise in the form of skilled engineers, scientists, IT specialists and software engineers (Zysk 2021b, 12), which has been described by the Russian security service FSB as a threat to national security (Weiss 2021, 5).

The security apparatus has argued for restrictions on international science cooperation, engagement and exchange, many of which have been approved and put into legislation. Russia's scientists have long worried about the stifling of Russian civil society and the possible impact of political interference to research (Schiermeier 2020). Legislation regulating "undesirable foreign organizations" (Dezhina 2017, 18-20) and a series of espionage prosecutions against academic researchers have negatively affected the academic community in Russia (Weiss 2021, 7).

Unsurprisingly, since 2012 the main reasons behind the decision to emigrate are related to the political climate, lack of civil liberties and lack of economic perspectives. Nonetheless, from the Kremlin's point of view, brain drain does have the upside of reducing political pressures in the short-term by getting rid of many of the regime's politically active critics (Lassila 2019). Nor is the regime without its own programs for talent. In order to combat the emigration of expertise, Russia has sought to attract Russian speaking researchers from the post-Soviet space as well as to "call back" the Russian diaspora of researchers (Dezhina 2017, 17-18). Despite these efforts, the Russian invasion of Ukraine has already increased the brain drain further, casting a shadow on the future of scientific and technological enterprise in Russia.

3.1.1 Russian STI capability: problems and possibilities

In September 2011, a group of expatriate Russian scientists working in leading research institutes in the West sent an open letter to the prime minister and the president to draw their attention to the 'catastrophic state' of Russian fundamental science. Much has happened since. At the time the letter was sent, the state had started a systematic effort to restructure the Russian STI system and improve Russia's STI capability to reach the global competition in select fields. Today, Russia has notable capabilities, particularly in fundamental science and education and within the innovation system (Gershman et al. 2018), but significant hurdles remain.

Some of the fundamental issues embedded in the Russian S&T system relate to a disconnect between the innovation system and private actors. Particularly striking is the fact that the innovation system lacks structures and mechanisms that link the innovation system and market actors together (Gokhberg et al. 2018) as well as foster entrepreneurial abilities (Bogoviz 2019). These structural challenges ultimately lead to the inability to create a broad socio-economic impact through R&D (Cervantes & Malkin 2001).

Toward the end of the first decade of the 2000s, Russia had actively implemented various innovation instruments to catalyze change in the National Innovation System. Often emulated from foreign models, the current Russian innovation system includes technology parks, strategic research centers, and other regional research and development clusters (van Someren & van Someren-Wang 2016, 22-24). An example of business linkage development is the Skolkovo Innovation Centre (announced in 2009), which has tried to create a supportive environment for entrepreneurship and S&T startups (Trelewicz 2012). Along with Skolkovo, there are several special economic zones in Russia that emphasize the creation of a high-technology industry tapping into the strong science and education foundation in Russia (Panfilova et al. 2019).

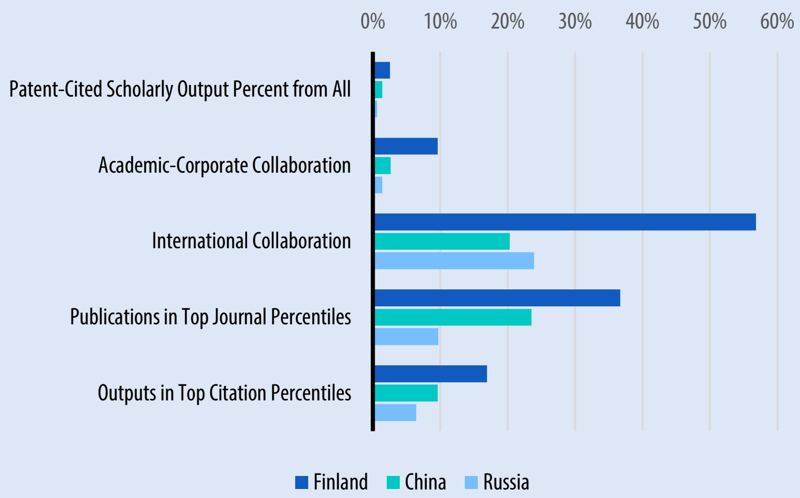
Overall, there has been a strong call for innovation policy instrumentation in Russia (Radosevic, 2003). However, we can question Russia's ability to further develop its innovation system due to the strong focus on technocratic instruments and a lack of attention in terms of broad societal implications (Graham 2013). Indeed, Russia has thus far been unable to solve the systemic weaknesses within its National Innovation System (Klochikhin 2012). Moreover, the work by Suominen and Lehtinen (2021) highlights the significant disparity, particularly when compared to the development of China, which has quickly emerged as an important global power in S&T, while Russia has remained stagnant.

POLICY BRIEF: Scientific and technological development of the Russian Federation

During the project, Suominen and Lehtinen (2021) published a policy brief titled "Scientific and Technological Development of the Russian Federation: Review of Current Status." The policy brief reflected on the differences between China, the European Union, Finland, the United States, and the Russian Federation. A secondary objective of this work was to identify significant case study technologies for more in-depth analysis.

The policy brief reported on the challenges of the Russian S&T system and the national innovation system more broadly, such as the "lack of entrepreneurial culture, market competition and private R&D investments" (Suominen & Lehtinen 2021). A particularly striking aspect of the analysis was the comparison between Russia and other global players. What emerges from the analysis is the notably low volume of Russian publications and patents, both in overall terms and in more specific areas. Russia is significantly behind China, the US, and the EU, as well as proportionally behind Finland. This can be attributed to a disconnect of Russian STI actors from the global mechanism of science and immaterial property rights, in which they are not visible through the data sources, or there is an absolute lack of activity. Neither of these possibilities is a good sign.

The report also reflects on comparisons with China. Whereas the data show the impact of Chinese policy measures on strengthening the innovation system, no similar impact is seen in the Russian data. This is clearly not due to a lack of policy measures, since the report also highlights the numerous different instruments put in place by Russia. This prompted us to look for a probable explanation from additional data. The figure below shows the comparison of Finland, China, and Russia in different S&T system indicators. Russia seems to be behind in science quality measures, such as publications in top journal percentiles and outputs in top citation percentiles. The differences compared to China are apparent, but they are also significant when compared to Finland.



The figure also highlights the lack of academic–corporate collaboration, an area in which Finland again has the highest, although there is a notable difference between China and Russia. In the economic impact measure, namely Patent-Cite Scholarly Output Percent for All, we observed similar behavior. Interestingly, in international collaboration, Russia is above China while trailing Finland.

Regardless of the measures taken, the quality of science, collaboration, or economic impact, Russia remains stagnated. The differences in comparison to China, which is deeply engaged with the global system, are striking. The important question is whether Russia is able to improve its S&T impact without similarly engaging with the global S&T system. We argue that this seems highly improbable.

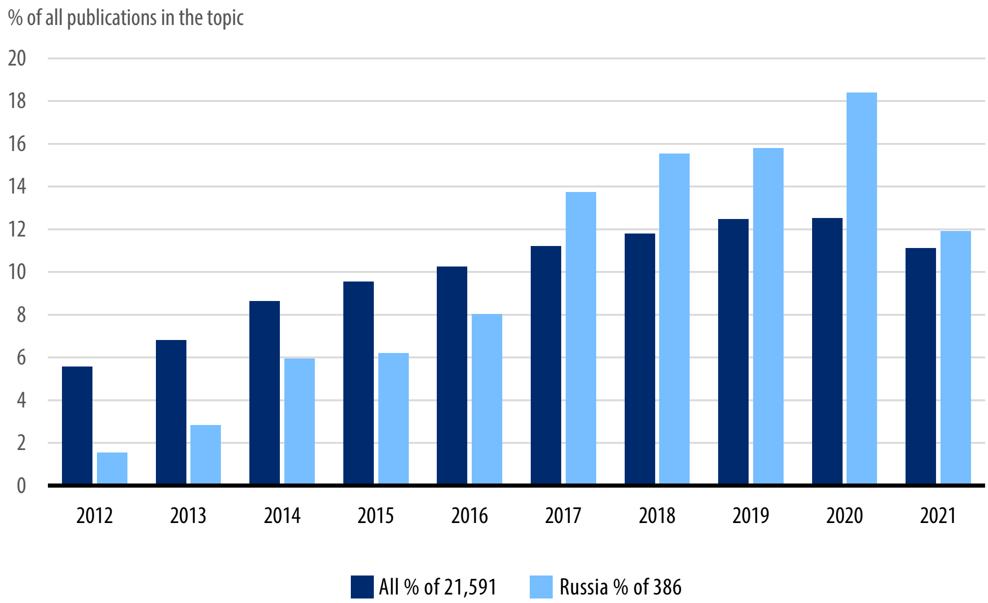
The following sections explore five case studies identified by Suominen and Lehtinen (2021) as relevant and topical to the Russian S&T system. These include cryptography, nanotechnology, nuclear science and technology (NST), artificial intelligence (AI), and quantum technology.

3.2 Case study: Cryptography

Cryptography was identified as one of the interesting case studies the analysis on Russia's S&T capabilities should particularly focus on. This stems from the long history of Russian science in physics and mathematics, which is also visible in the policy brief of Suominen and Lehtinen (2021). Suominen and Lehtinen (2021) found that, in comparison to China, the EU27, and the US, Russia's largest science subfields are more oriented toward the fundamentals of natural sciences. These include, for example, general physics and astronomy. Regarding the fields where the Russian science system has high capabilities, described by high volume and high growth, cryptography-related research was highlighted as one of the most important areas to follow.

We focus on cryptography using a bibliometrics approach developed by Devasena and Rao (2021). Their work developed a search strategy to highlight cryptography-related science literature, which we have employed in Web of Science and European Patent Office databases. Devasena and Rao (2021) highlighted the significant role of China and the US in cryptography-related research but also showed that research in the area had increased significantly. This can also be seen in our findings, where the share of scientific research has increased, whereas a plateau was observed since 2019 (**Figure 1**). Although the volume of Russian cryptography-related research has increased significantly, more so than the overall trend within the selected timespan, the overall volume of Russian research is low. Out of the overall 21 000 publications, there are only 386 Russian research publications indexed in Web of Science[31].

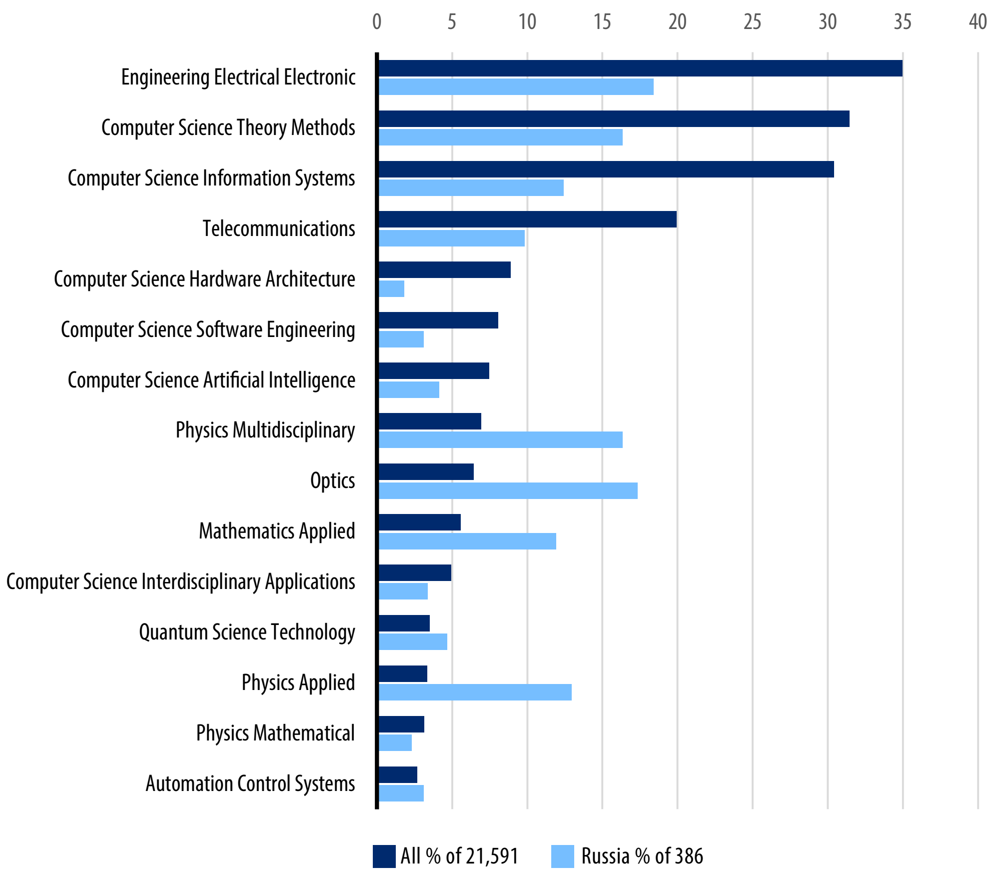
Figure 1. Publication volume yearly between 2012 - 2021 in Cryptography. The graph shows the percentage share of all publications between 2012 - 2021. Number of publications is seen in legend. Source: Web of Science.



31 However, it should be noted that the database might not contain all conference publications from 2021, and the volume for 2021 can increase as new publications are added to the database. Thus, strong analysis on the drop of publications in 2021 should not be made.

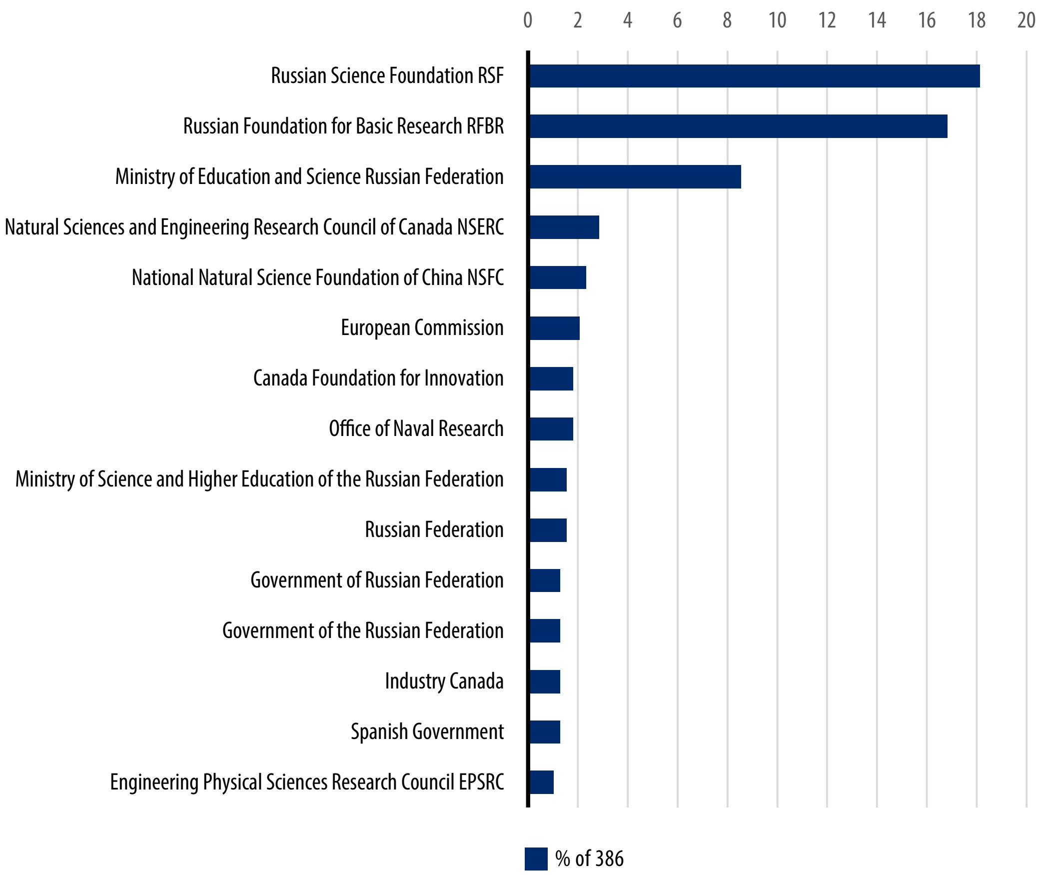
The profile differences between Russian science and that of the rest of the world are immediately apparent in **Figure 2**. The figure clearly shows how Russian research emphasizes different aspects of cryptography-related research. The main highlight is that while Russian research heavily emphasizes fundamental research on cryptography, such as physics-related research, global cryptography-related research heavily emphasizes applications, particularly in computer science. This comparison suggests that Russia is playing to its strengths, but it also reveals Russia's weaknesses in terms of broader innovations and applications.

Figure 2. Web of Science research categories of publications 2012 - 2021 in Cryptography.
Source: Web of Science



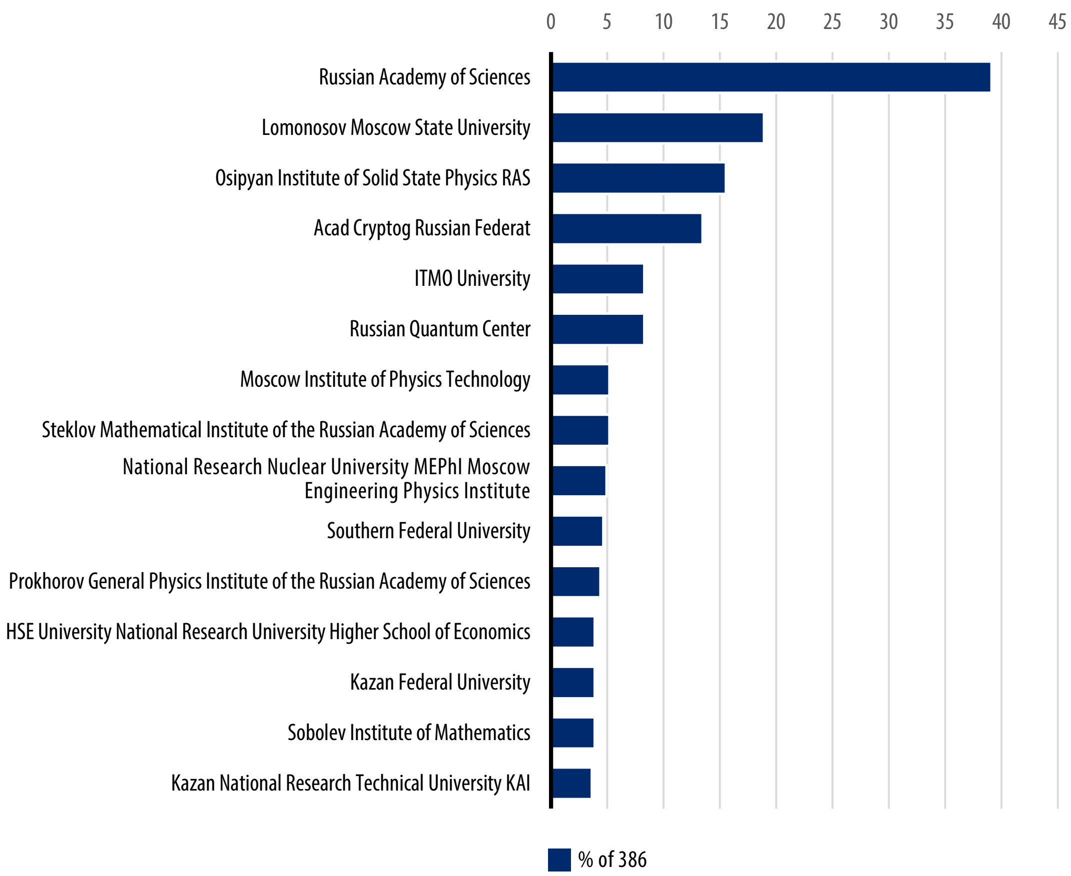
Reflecting on who funds the research, Russian cryptography research is mostly funded by the Russian Science Foundation and the Russian Foundation for Basic Research. The research funding acknowledgments also highlight international research collaboration, where research is funded by, for example, the European Commission, Canada Foundation for Innovation and the Office of Naval Research. The Office of Naval Research refers to the United States Office of Naval Research, which has funded larger Canadian, Brazilian, and Russian consortiums focusing on quantum cryptography (Pinheiro et al. 2018).

Figure 3. Research funding agencies 2012 - 2021 in Cryptography. Source: Web of Science



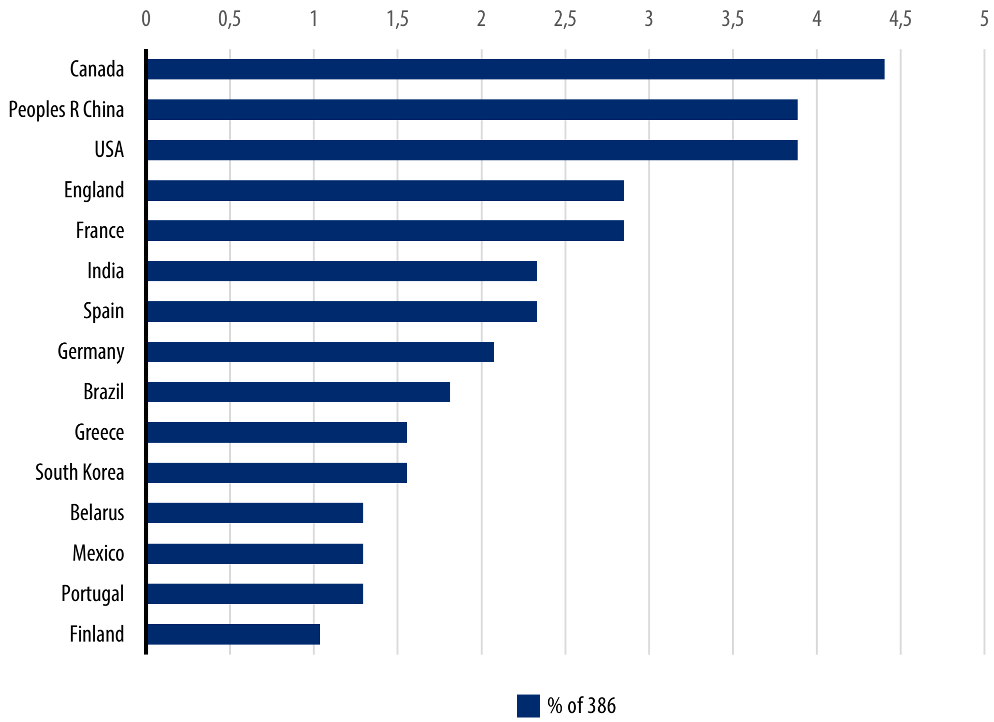
Focusing on the organizations conducting research on cryptography, we can see that the majority, close to 40 percent, of the research is done by the Russian Academy of Sciences (RAS). Most recently, a significant portion of publications have focused on quantum cryptography. This research is conducted at multiple RAS institutes, namely Steklov Mathematical Institute of the Russian Academy of Sciences, Federal Research Center "Computer Science & Control", Rzhanov Institute of Semiconductor Physics, Siberian Branch, Russian Academy of Sciences, and Osipyan Institute of Solid State Physics RAS. The different affiliations within RAS provide an indication of the overall diversity of research within cryptography. The focus of the research is on fundamental mathematics, applied physics, and computer science.

Figure 4. Organizations conducting research 2012 - 2021 in cryptography. The number of RAS publications is higher than shown, as institutes in RAS use either RAS as the institution's name or or the name of the specific institute. Source: Web of Science



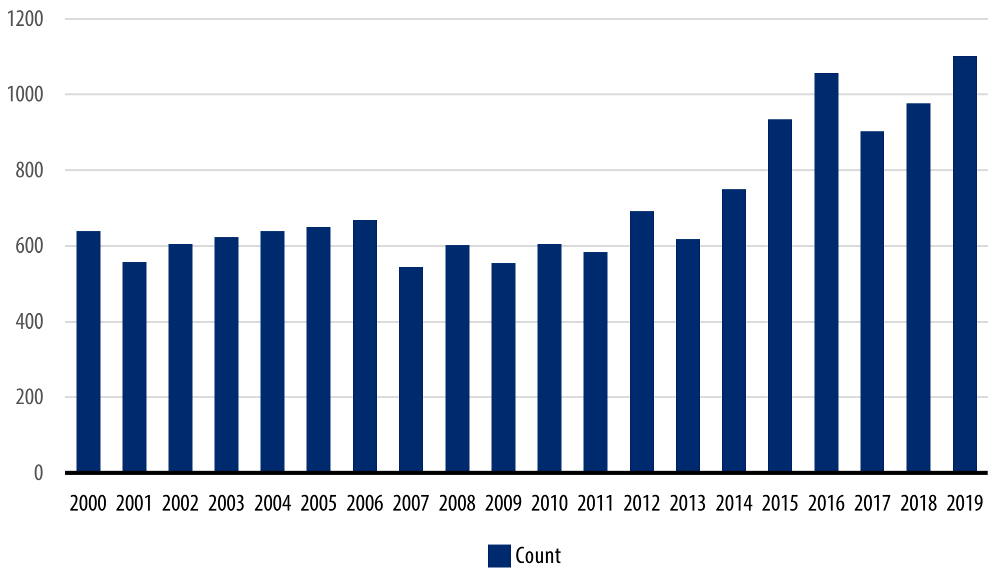
Interestingly, as we focus on international collaboration in science, Russia has the strongest linkages in cryptography with Canada. We can also see the usual suspects, China and the US, in addition to linkages to the European Research Area (ERA), India, Brazil, South Korea and Belarus. Overall, we should recognize that Russia's rate of collaborations at just above of four percent or lower is relatively low.

Figure 5. Countries Russia has been in research collaboration 2012 - 2021 in Cryptography. Source: Web of Science



Regarding the application of science, particularly protecting intellectual property, the search strategy was also implemented in the EPO full-text search database. Again, we observe an overall increase in cryptography-related patenting. For a long time, patenting in cryptography was at 600 patents a year, only to increase significantly from 2013 to reach a level of over 1000 patents yearly. Within this dataset, it is notable that only 38 patents have Russian inventors. The most significant patent assignee in the dataset is AO Kaspersky Lab, a prominent cybersecurity and antivirus company headquartered in Moscow, Russia.

Figure 6. Patent filings in EPO between 2000 and 2019 in Cryptography. Source: EPO



The overrepresentation of theoretical and fundamental research in cryptography and the low number of patents suggests that the activities in applied cryptography in Russia either do not abound, or they are, to a large measure, part of classified projects.

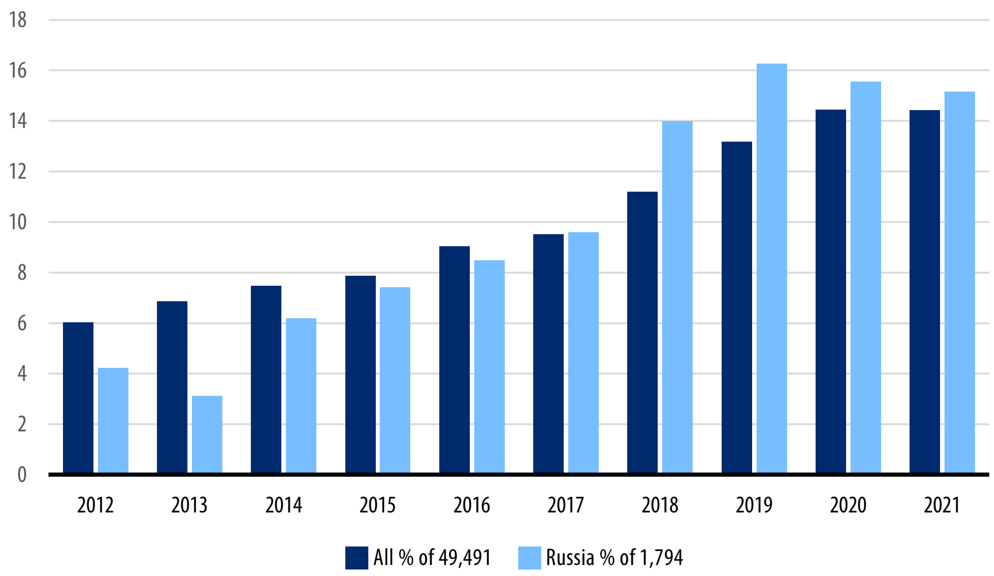
In recent years, cryptography has been featured in state policy actions aimed at economic and technological development. In particular, Information Security, one of six federal projects included in the national program Digital Economy of Russian Federation, featured goals and activities related to cryptography spanning across 2018–2021 (Matyukhin, D.V. 2019). These activities include those aiming at the integration of Russian cryptography experts in international organizations working on standards in cryptography and information security; the creation of national infrastructure for secure communication on the Russian segment of the Internet; and preparing legislation on state regulation of cryptography in Russia. The corresponding budget could be estimated at RUB 2.6 billion.

Not all the planned activities were accomplished within the planned framework. However, it seems that cryptography consolidated it place as one of the domains of state interest, as the 2021's revision of federal project Information Security (now spanning until 2024) added extra funding to the planned activities, including those related to cryptography (CNews, 2021). Additionally, some activities related to quantum cryptography are financed by the relatively generous funding that quantum technologies have received in recent years.

3.3 Case study: Quantum technology

In quantum technology, we follow the approach of Bornmann et al. (2019), who reviewed the global development in quantum technology (see Bornmann et al. 2019; Scheidsteger et al. 2021). In Scheidsteger et al. (2021), the authors highlighted the four main fields identified as quantum information science and quantum technology in general, quantum communication and cryptography, quantum computing and quantum metrology, sensing, imaging, and control. They calculated that between 1980 and 1999, quantum technology publications doubled every two to three years. This is in comparison to the overall doubling of publications indexed in Web of Science at seven to eight years. Although the doubling pace has reduced from 2011 to 2018 to four to five years, the field is still growing faster than science overall (Scheidsteger et al. 2021). This growth is also visible in **Figure 7**.

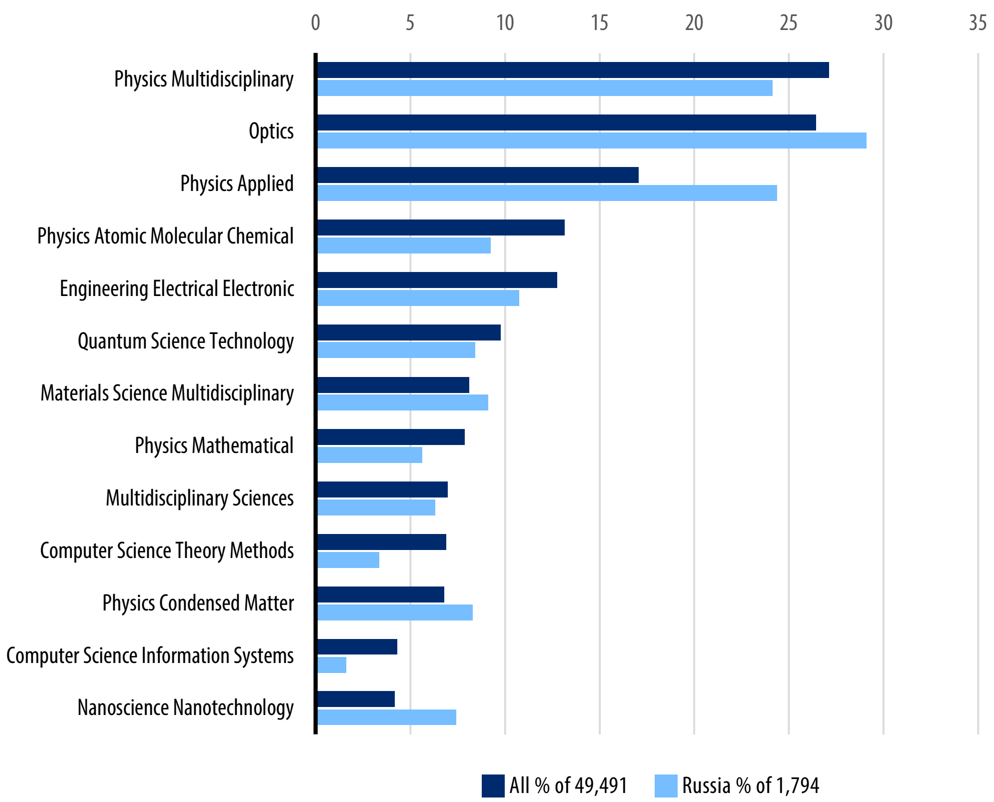
Figure 7. Publication volume yearly between 2012 - 2021 in quantum technology. The graph shows the percentage share of all publications between 2012 – 2021. Number of publications is seen in legend. Source: Web of Science.



As shown in **Figure 7**, Russian publication volume in quantum technologies is similar to the growth of publications overall. It should be noted that the publication volume since 2018 has increased significantly. Russian scholars have been a part of 3.6% of publications globally. Notably, this number exceeds the average Russian scientfic impact. Based on SciVal, Russia is involved in some 2.6 percent of global scientific production between 2011 and 2021.

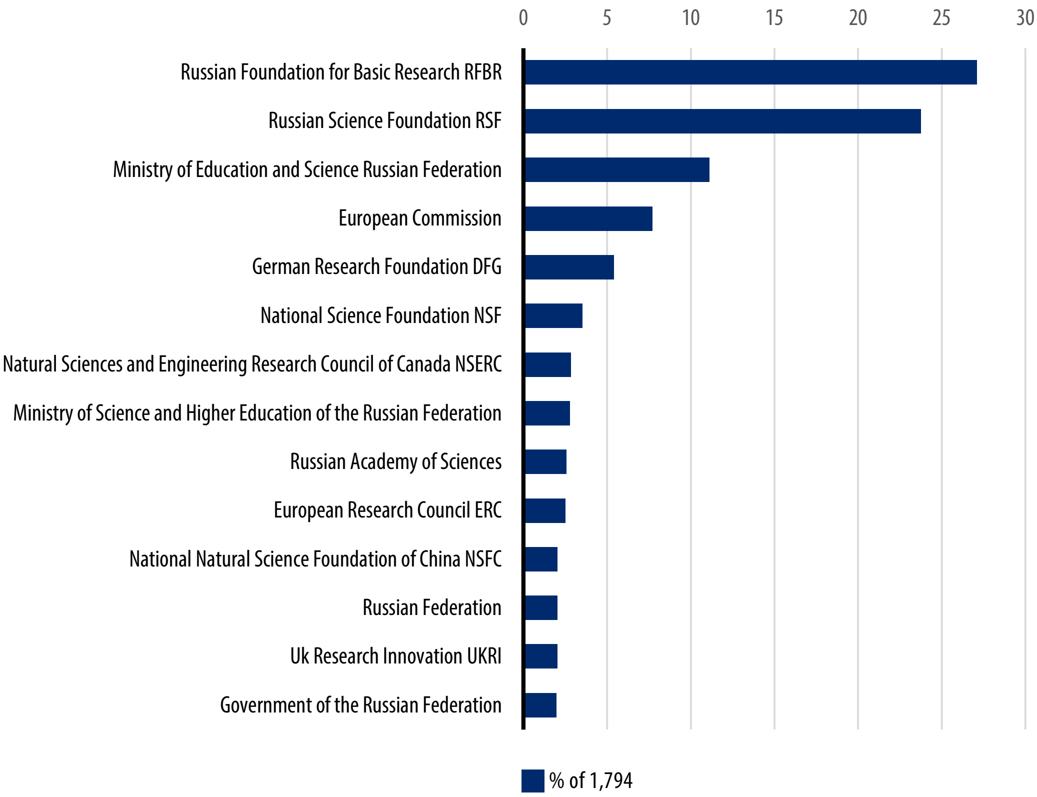
Considering the thematic orientation of publishing, Russian science clearly aligns with the global production of quantum technology research. As illustrated in **Figure 8**, there are no major differences in the thematic orientation of Russian research, with the slight exception of applied physics, nanotechnology, and information systems research. In the findings of Scheidsteger et al. (2021), Russia accounts for significant global contributions in quantum optics and quantum communication. Our results support the importance of Russian research in optics, but communication-related publications are embedded in physics-related publications.

Figure 8. Web of Science research categories of publications 2012 - 2021 in quantum technology. Source: Web of Science



Russian research funding in quantum research is based on funding from the major research funding agencies in Russia and, due to collaborative research, from European funding instruments. Particularly interesting is the role of the German Research Foundation. The German Research Foundation actively engages with Russian research organizations in quantum technology. For example, the German Research Foundation arranged a German Russian event for young researchers focusing on quantum physics held at Moscow State University[32].

Figure 9. Research funding agencies 2012 - 2021 in quantum technology. Source: Web of Science

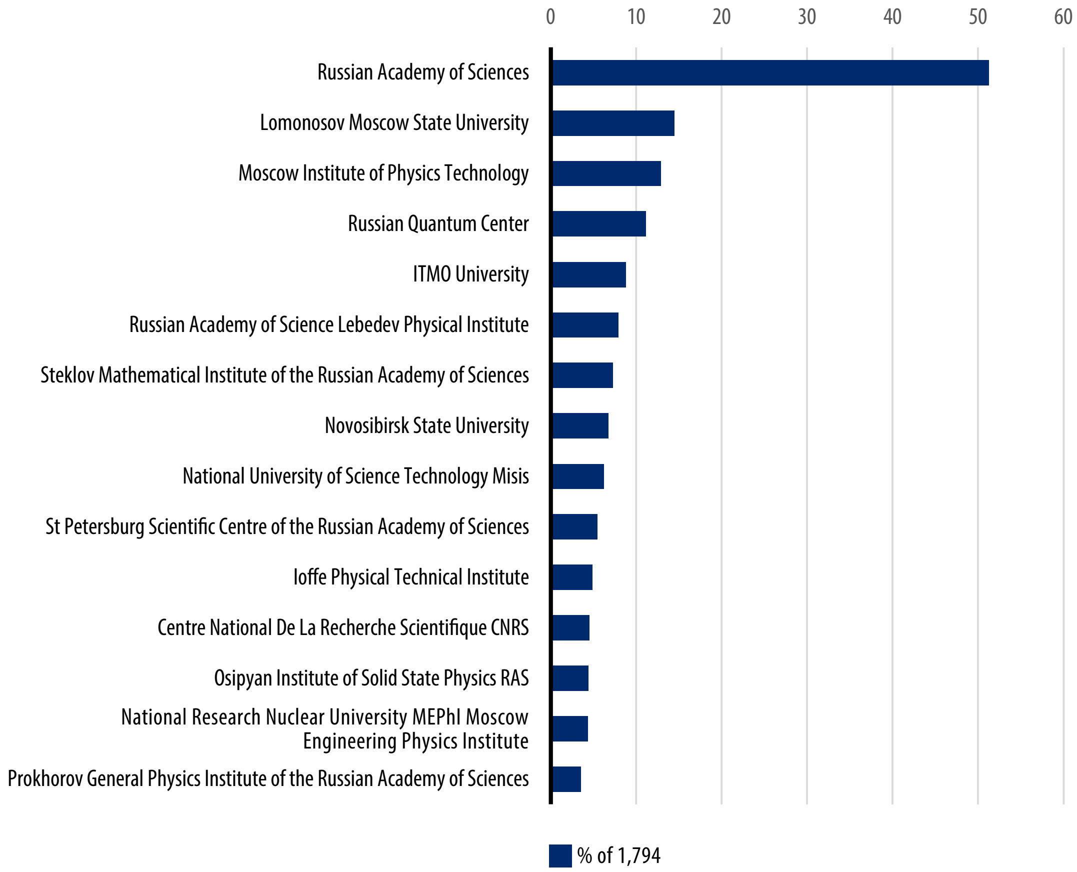


The RAS is the largest organization publishing research in quantum technology. This is not surprising, considering Russian science or the other case studies presented in this report. A notable organization on the list is the Russian Quantum Center, which is a non-profit S&T organization that focuses on quantum technology-based commercial products. The

32 see Ninth German-Russian Week of the Young Researcher at Moscow State University Focuses on Quantum Physics https://www.dfg.de/en/dfg_profile/head_office/dfg_abroad/russia/reports/2019/191009_quantum_physics/index.html Accessed 1.2.2020

organization was founded at the end of 2010 in Skolkovo.[33] From a research perspective, the Russian Quantum Center has rapidly risen to be a central element in the quantum technology science landscape. Overall, the Russian Quantum Center has been able to create an impact. In the impact report from 2012 to 2017, the organization highlighted several high-level scientific publications and five spin-offs.

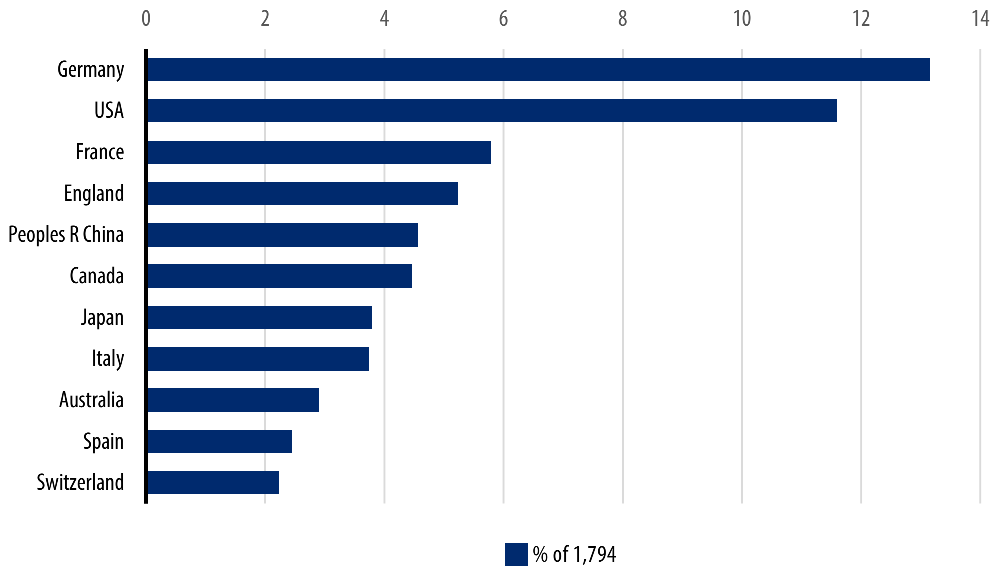
Figure 10. Research conducting organizations 2012–2021 in quantum technology. The number of RAS publications is higher than shown, as institutes in RAS use either RAS as the institution's name or or the name of the specific institute. Source: Web of Science



33 see Russian Quantum Center website https://rqc.ru/about Accessed 1.2.2022

In terms of the international links of collaborations, as shown **Figure 11**, Germany is the largest partner in quantum technology. This is visible in, for example, the report by the German Federal Government framework program in quantum technology that highlights the linkages between the Skolkovo Foundation and the Russian Quantum Center[34].

Figure 11. Countries Russia has been in research collaboration 2012 - 2021 in quantum technology. Source: Web of Science



Quantum technology is an important domain that has received substantial attention from the Russian government and is therefore entitled to priority funding. As stated earlier, the Russian Quantum Center, which was launched by Russian scientists in 2011 and became the early resident of Skolkovo, is a notable actor. Then President Dmitry Medvedev's project secured funding from a variety of sources for its establishment. In 2016, President Putin was personally pitched on the importance of quantum technologies, including quantum communication and quantum computing, by one of the researchers associated with the Center. In the same year, Putin mentioned quantum technology among other "cross-cutting technologies" that are to be developed in a priority manner in his address to the Federal Assembly (President of Russia 2016a, 2016b).

34 see Quantum technologies – from basic research to market A Federal Government Framework Programme https://www.quantentechnologien.de/fileadmin/public/Redaktion/Dokumente/PDF/Publikationen/Federal-Government-Framework-Programme-Quantum-technologies-2018-bf-C1.pdf Accessed 1.2.2022

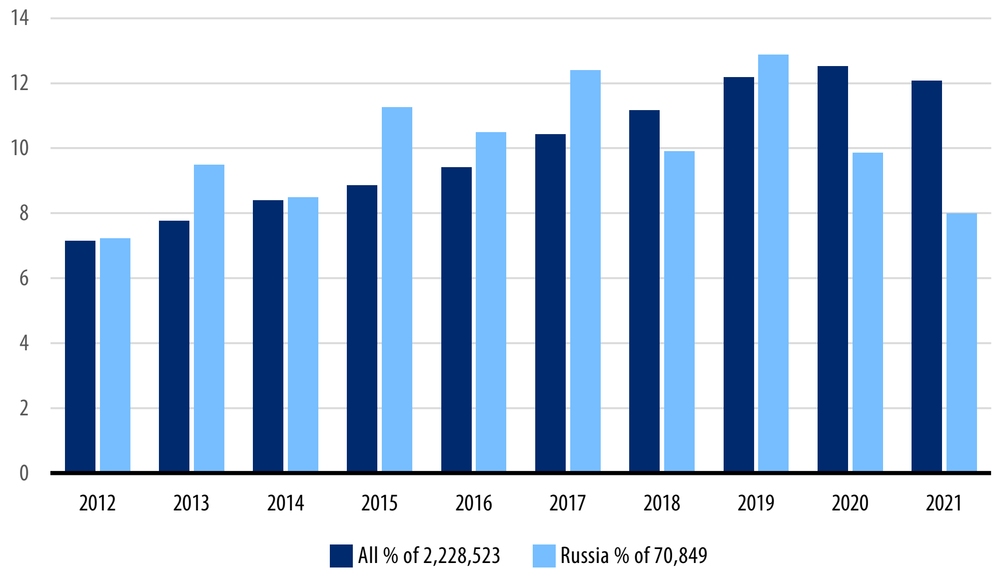
In government policy actions related to quantum technology, quantum computing occupies a visible role. The high profile "Digital Technology" federal project, the part of the Digital Economy national project, features three roadmaps of quantum technology development, focusing on quantum sensing (still in project and might be canceled), quantum communication, and quantum computing. These points align with the strengths of the Russian research highlighted in the analysis by Scheidsteger et al. (2021). By 2024, quantum computing development will receive RUB 13 billion of governmental funding, with state corporation specializing in nuclear technology, Rosatom, leading the project.

3.4 Case study: Nanotechnology

In the field of nanotechnology, there has been a previous case study by Karaulova et al. (2014) that highlighted the increasing focus in Russia on nanotechnology research. The report also revealed the dominance of RAS. However, the findings of the report also indicated stagnation, particularly in the "star" scientist outputs. Regarding collaboration, Karaulova et al. (2014) reported on the importance of Western Europe, former Soviet Union countries, Japan, and the US to the scientific work done in Russia. In terms of converting the research outputs to immaterial property, the report showed that Russian nanotechnology patenting was increasing but was led by public organizations, not private industry (Karaulova et al. 2014).

We replicated the approach used by Karaulova et al. (2014), which relied on nanotechnology analysis conducted at the Georgia Institute of Technology. In assessing the last 10 years of nanotechnology research, the global upward trend continues. The question we posed was: Is Russia following the global trend, or are we seeing early indications of decline? Particularly, the development from 2019, as shown in **Figure 7**, questions the development path of Russian nanotechnology research. Karaulova et al. (2014) discussed the possibility of stagnation in Russian efforts on nanotechnology, even though nanotechnology was still mentioned as a priority area.

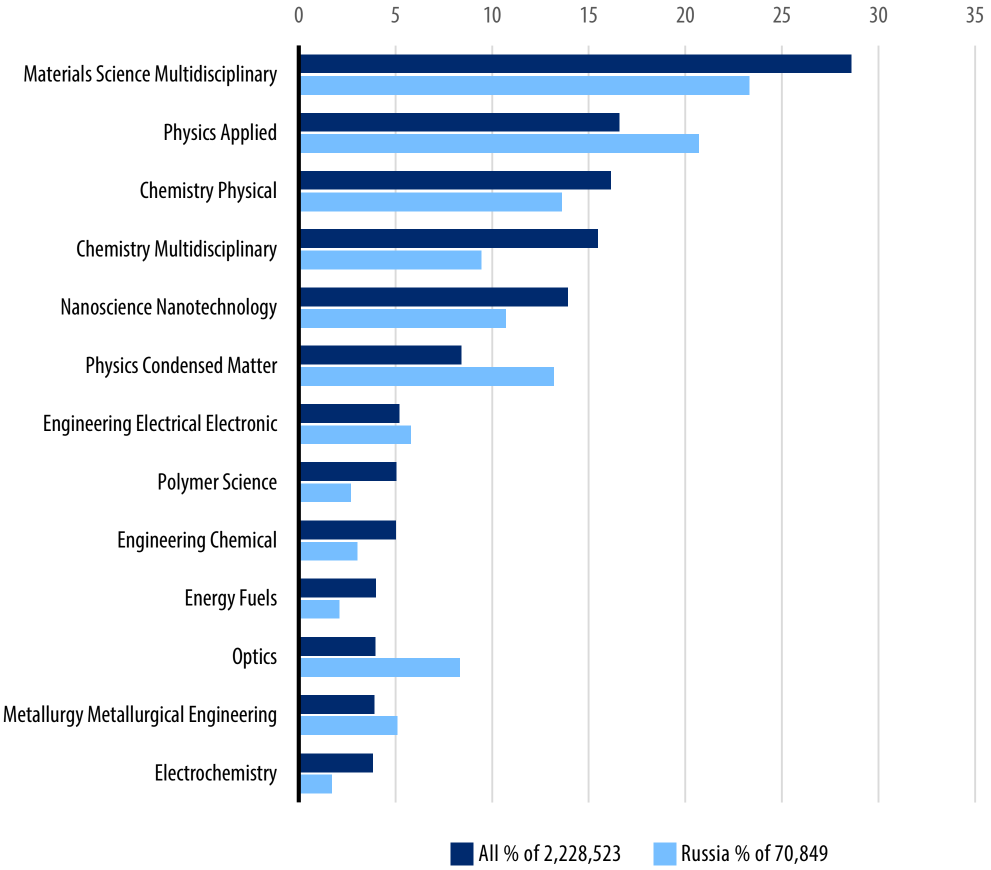
Figure 12. Publication volume yearly between 2012–2021 in nanotechnology. The graph shows the percentage share of all publications between 2012–2021. The number of publications is seen in the legends. Source: Web of Science



In nanotechnology research, the Russian research profile is relatively similar to that of global research. Nanotechnology research is materials science research, and the multidisciplinary aspect of this is the largest area of research globally and in Russia. Russia has, as in all of the other technology-specific case studies, a particular focus on fundamental physics. In the case of nanotechnology, research on optics is also a point of differentiation for Russian research. Within optical research, Russian researchers have published highly cited works on quantum dots and the optical properties of nanomaterials. Examples of this type of research are Yakubovsky et al. (2017) on the optical properties of thin gold films or photonic quantum technologies (Khasminskaya et al. 2016). It should be noted that the examples represented in this case study are not disconnected; rather, we should consider that they are highly overlapping.[35] In the Russian case, we see an example of the overlap of quantum technology and nanotechnology in optical research.

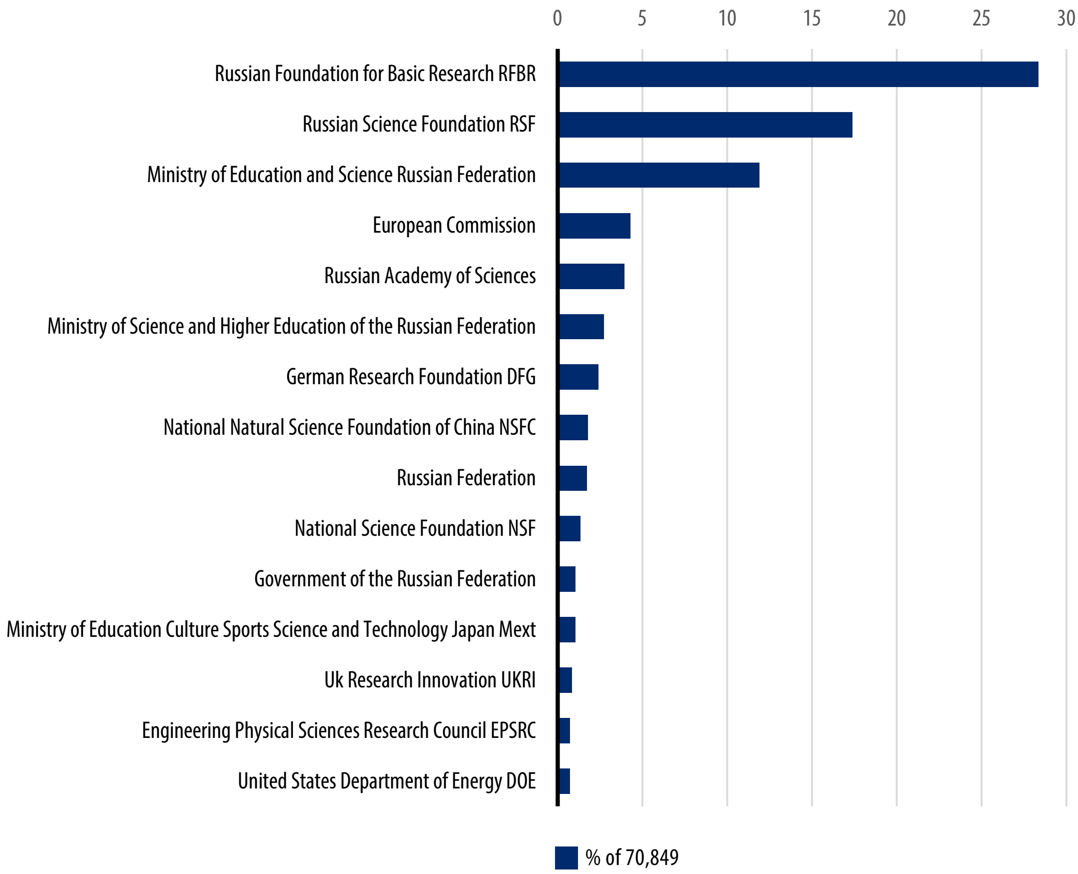
35 See for example the discussion on quantum nanotechnology Quantum nanoscience. Nat. Nanotechnol. 16, 1293 (2021). https://doi.org/10.1038/s41565-021-01058-0 Accessed 2.2.2022

Figure 13. Web of Science research categories of publications 2012–2021 in nanotechnology. Source: Web of Science



Organizations funding the research are similar to that of, for example, cryptography-related research. The largest nanotechnology funding organization, as shown in **Figure 9**, is the Russian Foundation for Basic Research[36]. The foundation, based on agreements with its partner organizations, particularly finances nanotechnology. Nanotechnology is designated by the foundation as a critical industrial technology that receives priority funding[37].

Figure 14. Research funding agencies 2012–2021 in nanotechnology. Source: Web of Science

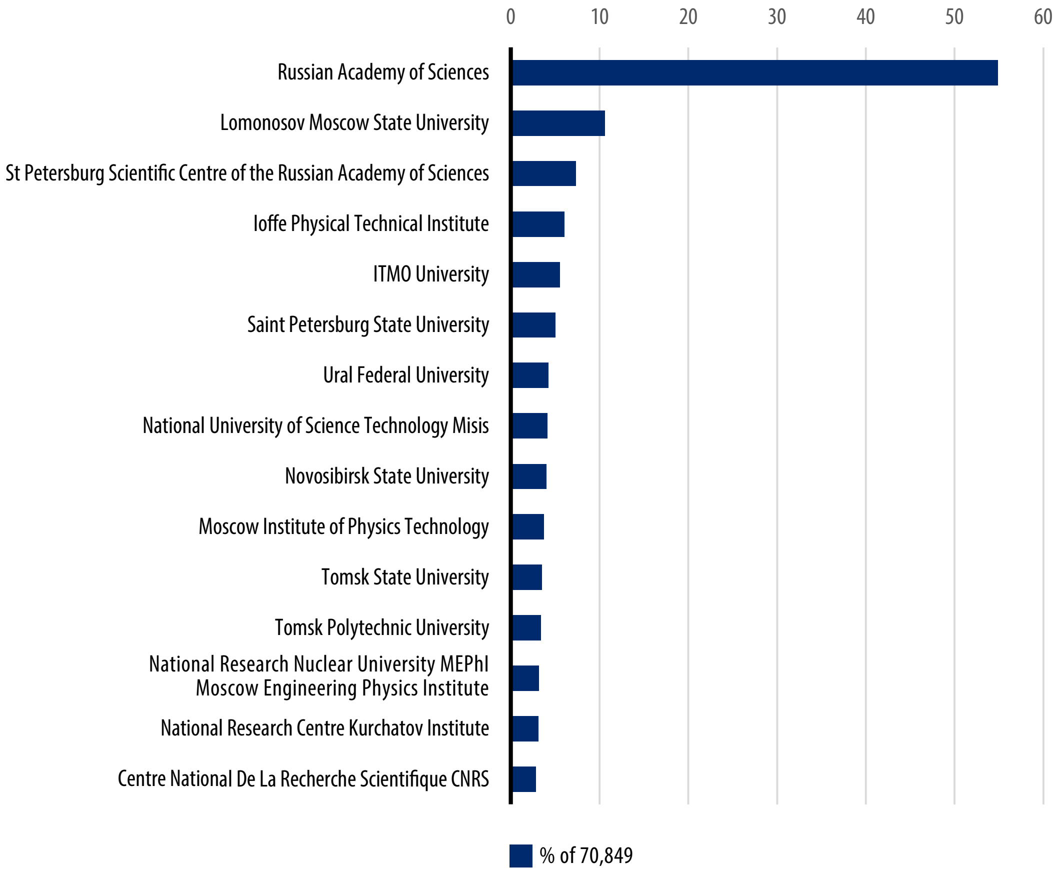


36 It should be noted that the Russian Foundation for Basic Research funds a significant volume of research, but with smaller grants. This can lead to it being mentioned in several publications, while the actual sum of funding is relatively small.

37 Refer to the general information available at the Russian Foundation for Basic Research (RFBR) website https://www.rfbr.ru/rffi/eng/info_eng Accessed 28.1.2022

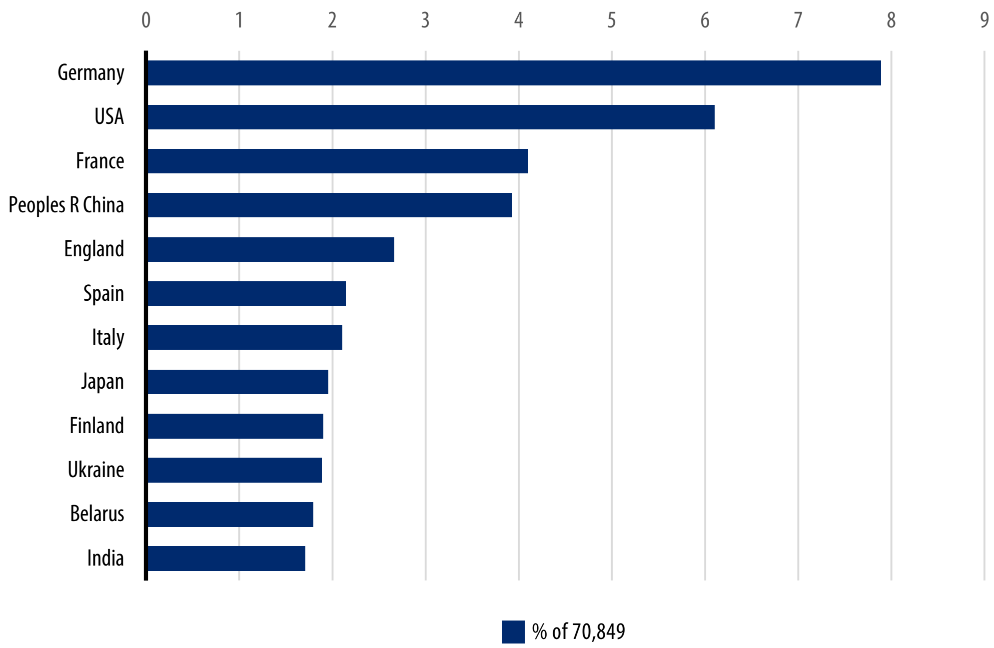
For nanotechnology, the significance of RAS is easily observed in **Figure 10**. In total, RAS accounts for over 50 percent of the research publications, with the second largest institute trailing at approximately 10 percent. Although RAS is important to Russia's overall science production, its importance in nanotechnology research is even more pronounced. In short, nanotechnology research in Russia is reliant on RAS's output.

Figure 15. Organizations conducting research 2012–2021 in nanotechnology. The number of RAS publications is higher than shown, as institutes in RAS use either RAS as the institution's name or or the name of the specific institute. Source: Web of Science



Regarding collaboration between countries, nanotechnology has been designated as a central aspect of research collaborations. This is visible in **Figure 9**, which mentions for example the European Commission. Concerning the relationship between the European research area and Russia, nanotechnology has been one of the central areas of collaboration. During the European Commission's 7th framework program, specific funding was allocated to support Russian and European Union collaboration[38]. The BILAT-RUS project highlighted the central element of nanotechnology research in European Union member states' collaboration with Russia[39]. However, the dynamics of the collaboration are such that mutual benefits are best produced if the collaboration focuses on Russian competencies in basic and theoretical research and the strengths of European actors in the field of innovation.[40]

Figure 16. Countries Russia has been in research collaboration 2012–2021 in nanotechnology. Source: Web of Science



38 Refer to for example BILAT-RUS project https://cordis.europa.eu/project/id/222618/reporting Accessed 28.1.2022

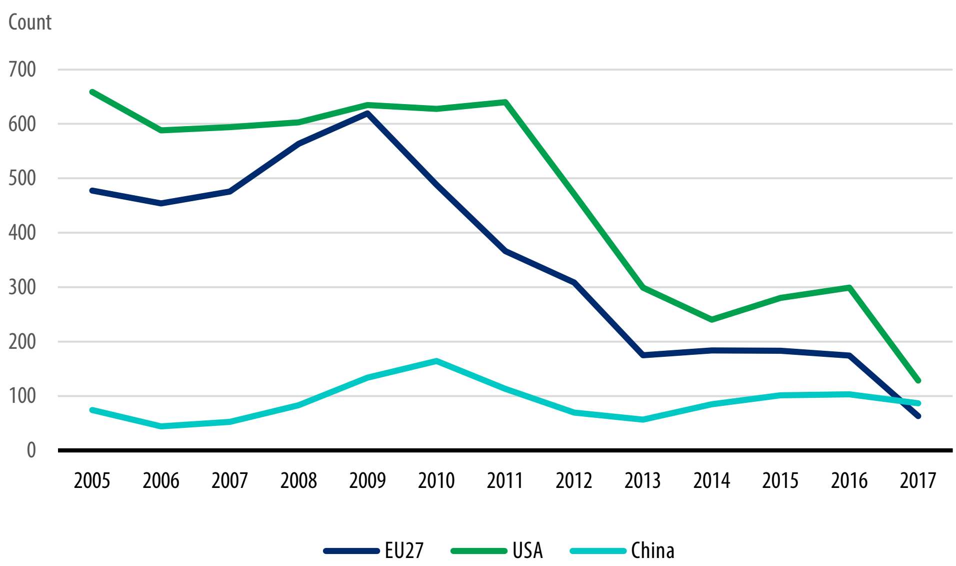
39 Refer to report on Good practice instruments and barriers for successful EU-Russia S&T cooperation https://www.eranet-rus.eu/_media/Overview_of_EU-Russia_RnD_and_Innovation_Cooperation.pdf Accessed 28.1.2022

40 Refer to the final report of NANORUCER project https://cordis.europa.eu/project/id/248178/reporting/es Accessed 28.1.2022

The dynamics between country-level collaborations with Russia are relatively stable across the case studies presented. The relative importance of Germany is high with the US and China, among other top collaborators. The reason for this is simply the high volume of nanotechnology publications produced by the US and China in particular. Overall, we see multiple ERA members and former Soviet countries among the most notable collaborative partners.

Globally, nanotechnology-related patenting in the US, the EU27, and China has been decreasing. Using the fractional count of IP5[41] patents in nanotechnology, we observe in **Figure 17** a clear decline in nanotechnology-related patents. This suggests, at least, stagnation in research translating to immaterial assets.

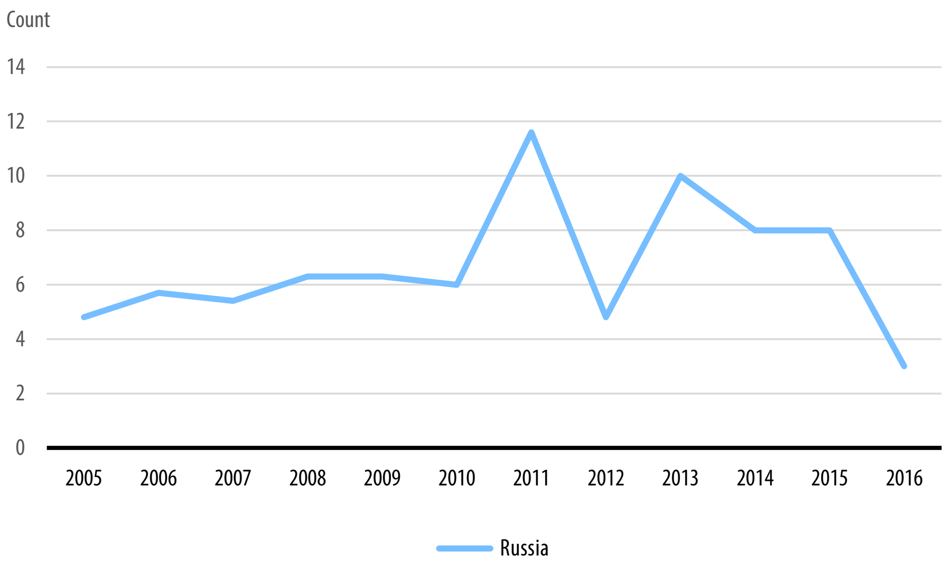
Figure 17. Patenting in nanotechnology measured using IP5 patents for the EU27, the US and China. Data from OECD and adopted from Suominen and Lehtinen (2021).



41 Patents are analyzed as IP5 patents, which refer to patents that have been filed in at least two IP offices worldwide, one of which among selected five IP offices. The five IP offices are the European Patent Office, the Japan Patent Office, the Korean Intellectual Property Office, the US Patent and Trademark Office and the State Intellectual Property Office of the People Republic of China.

When focusing on Russia, we do not observe the same behavior. As shown in **Figure 18**, Russia has only a few IP5 patents in nanotechnology, and, as pointed out by Suominen and Lehtinen (2021), even the much smaller country Finland has more nanotechnology patents. The negligible volume of nanotechnology patents can arguably be assigned to the broader Russian disconnect from the global immaterial property rights system. We should note that any commercially driven effort in this type of high-technology area beyond Russian borders would probably be reliant on having a strong and protected intellectual property portfolio.

Figure 18. Patenting in nanotechnology measured using IP5 patents for Russia. Data from OECD and adopted from Suominen and Lehtinen (2021).



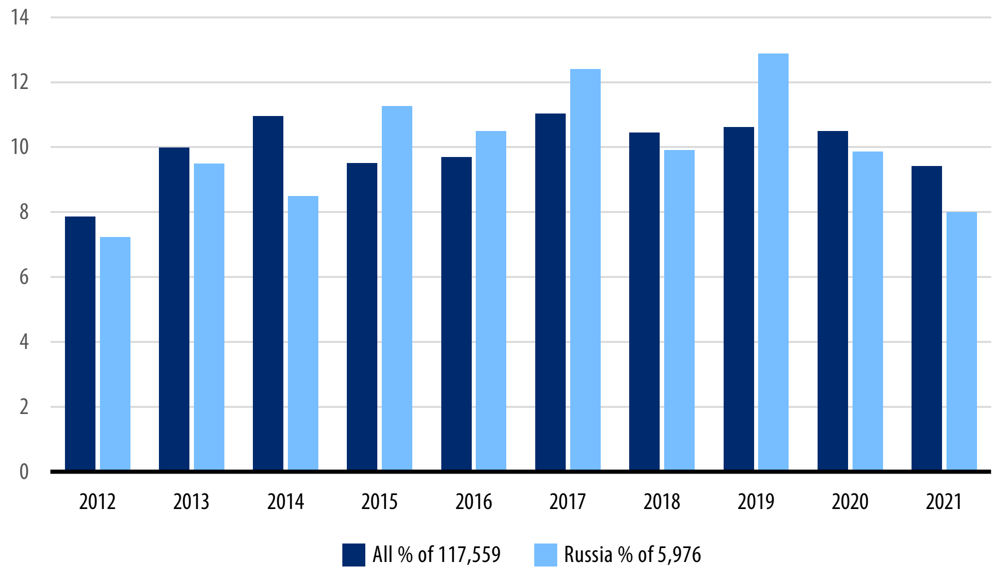
From a policy perspective, nanotechnology is a domain that the Russian government has been actively supporting since the late 2000s, not only as a fundamental and applied research area but also as an area of technological development and innovation. Nanotechnology is emblematic for the evolution of STI policy in the late 2000s and early 2010s, as nanotechnology development program development consolidated the importance of the expectation of both economic and strategic benefits from science for STI policy, and also set a path for using market-oriented instruments such as investment funds in STI policy. In the late 2000s, the nanotechnology development project was the most ambitious policy action in the STI domain, before being overshadowed by the more comprehensive project of the Skolkovo Innovation Centre. However, the significant funding that nanotechnology research has been receiving since the late 2000s, continued in the 2010s. Moreover, because of Rusnano, nanotechnology start-ups and growing businesses have access to priority funding. However, contrary to the technologies analyzed in the previous two cases, nanotechnology support is not increasing. Instead, it should be seen as an established domain with relatively stable (or slightly declining) funding and support available throughout the innovation pipeline.

3.5 Case study: Nuclear science and technology

To analyze the research on nuclear science and technology (NST) in the Russian context, we utilized the approach developed by Mardani and Abdiazar (2014). Using the classifications embedded in the Web of Science, the authors used the high-level Web of Science category of NST to take a holistic view of the research landscape. Mardani and Abdiazar (2014) highlighted Russia's strong engagement in the field of NST research. Ranking sixth in global publication volume, second only to the US, Japan, Germany, France, and Italy, Russia has a strong foothold in NST research. A particularly interesting finding from the researchers was that Russia has strong collaborative linkages in NST research. Mardani and Abdiazar indicated that "Russia contributes to 41.05 percent of internationally collaborative publication[s]" (Mardani & Abdiazar 2014).

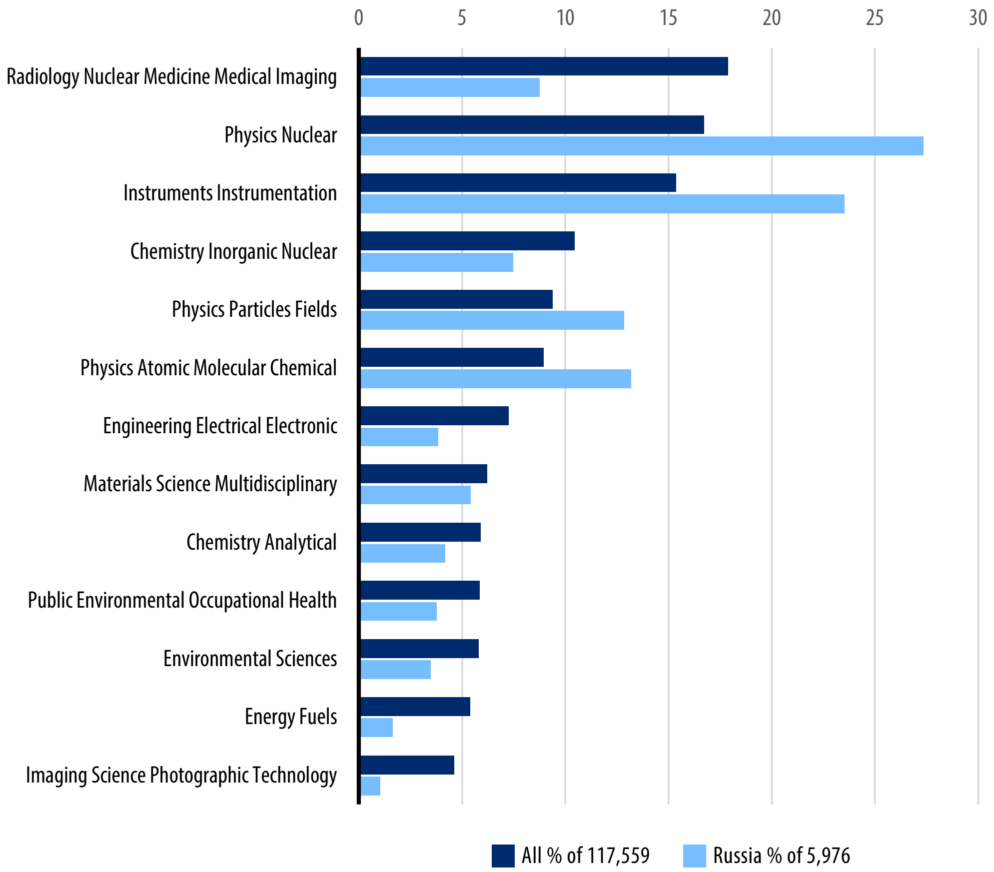
As shown in **Figure 7**, and in contrast to, for example, the cryptography case, research in NST is relatively stagnant by volume. Although visualized as percentages, the figure clearly shows how the publication volume has been relatively stable. The behavior is the same in research from Russia and overall. Although there is more fluctuation in Russian research output, the moving average across the years is relatively stable; thus, we should not make too strong implications from the yearly differences.

Figure 19. Publication volume yearly between 2012–2021 in the nuclear science and technology. The graph shows the percentage share of all publications between 2012–2021. The number of publications is seen in the legends. Source: Web of Science



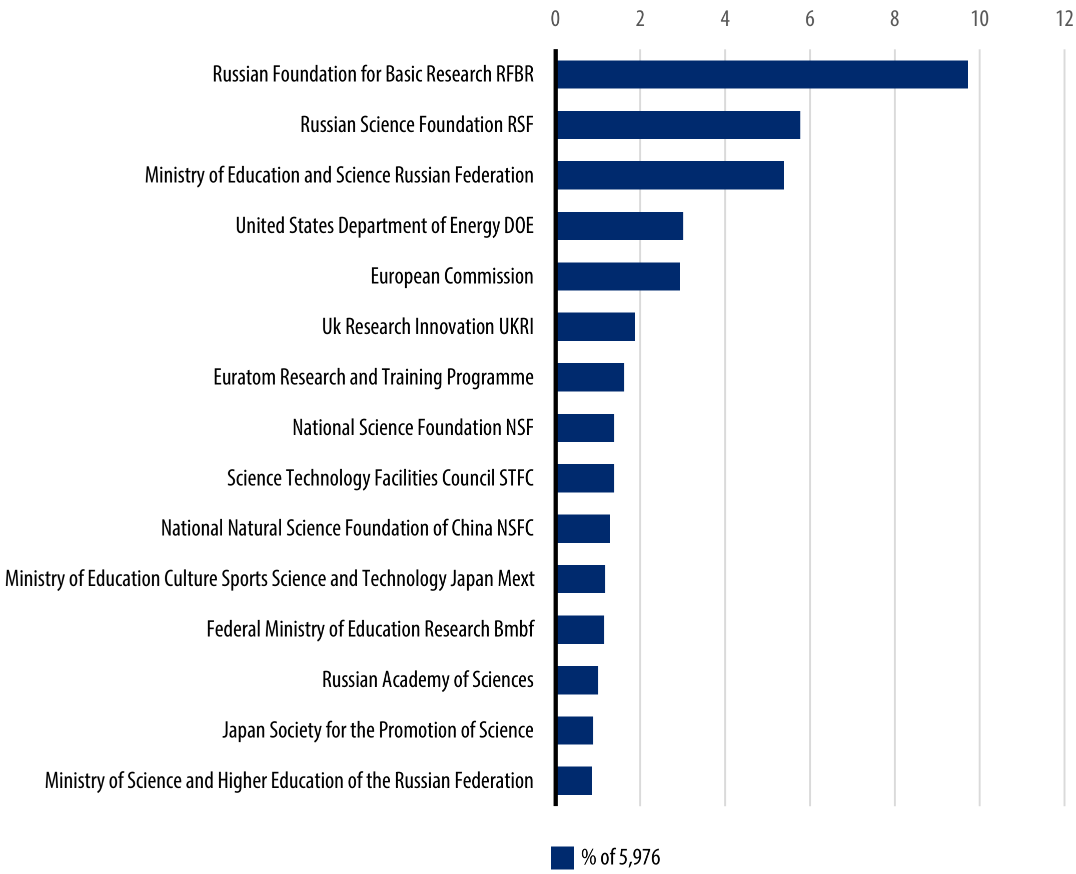
A focus on the science categories reveals that Russia's research profile differs from the global landscape. The graph in **Figure 8** highlights how global research emphasizes radiology nuclear medicine medical imaging, the largest category of scientific research globally. For Russia, research is much more focused on fundamental physics and instrumentation, whereas radiology nuclear medicine medical imaging is only the fifth largest research area in Russian NST research. This is a recurring theme in Russian research, where applied research seems to be at a disadvantage in comparison to fundamental research.

Figure 20. Web of Science research categories of publications 2012–2021 in the nuclear science and technology. Source: Web of Science



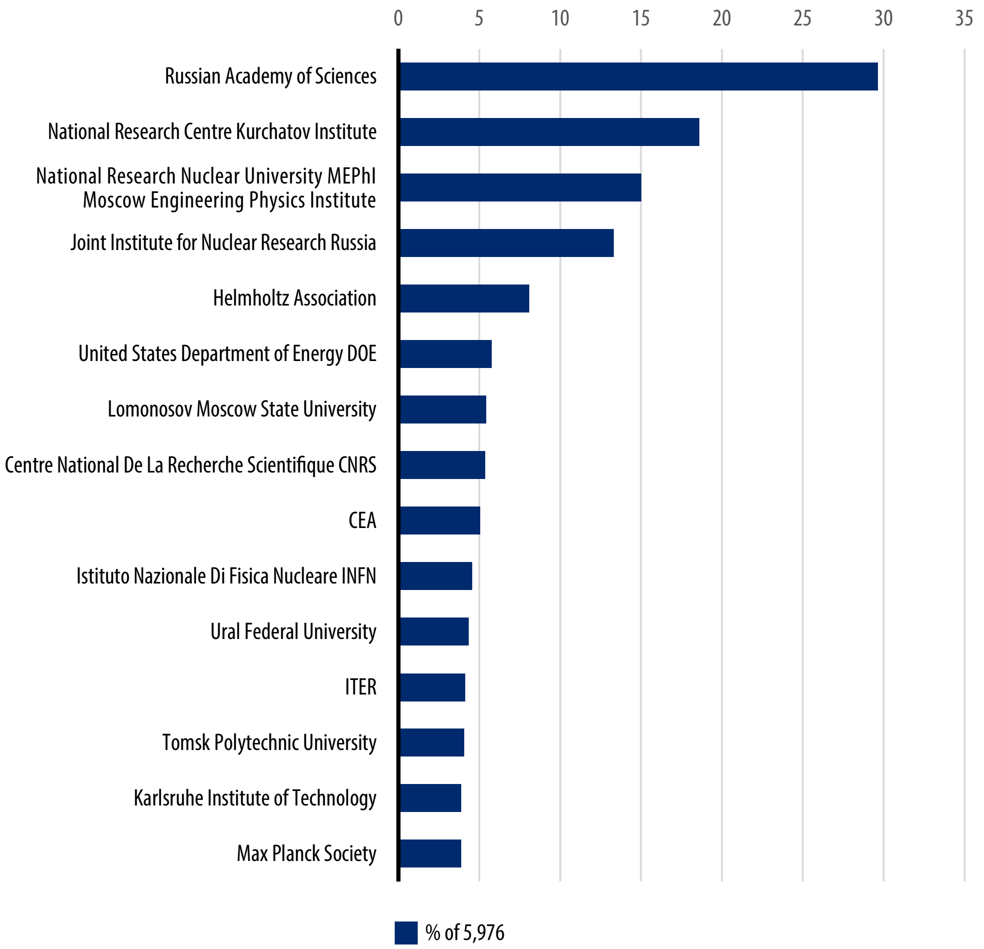
In light of the findings of Mardani and Abdiazar's (2014) study, we expect strong linkages between different funding agencies for research. By definition, much of the fundamental science in NST is "big science" building on large international collaboration networks. This is also visible in **Figure 9**, in which we can identify major research funders from the EU, the US and Japan.

Figure 21. Research funding agencies 2012–2021 in nuclear science and technology. Source: Web of Science



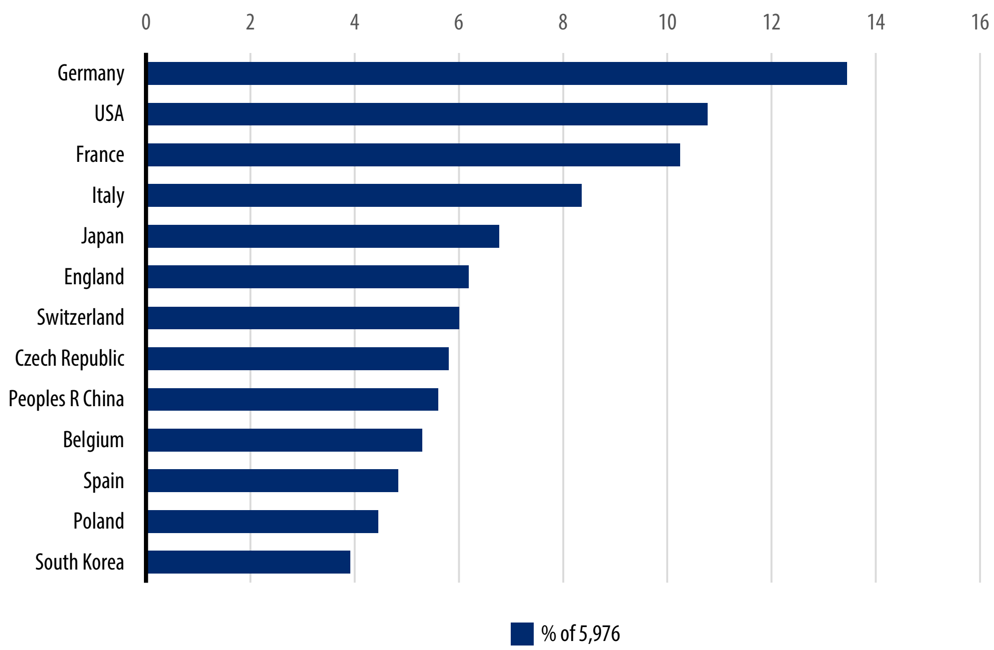
The "big science" nature of NST research is also visible in the organization conducting research. As seen in **Figure 10** the organization list contains several organizations outside of Russia as well as Russian organizations. Reflecting against for example **Figure 4** where the largest research conducting organizations were all Russian, NST research is significantly different in the sense that the collaborative nature of the field as well as the Russia's significant rate of collaboration brings foreign organizations to the table of largest research conducting organizations.

Figure 22. Organizations conducting research 2012–2021 in nuclear science and technology. Source: Web of Science



From a collaborative perspective, our findings are aligned with those of Mardani and Abdiazar (2014). As seen in **Figure 11** Russian, the five most significant collaboration partners for Russia are the countries with the highest number of publications in Mardani and Abdiazar (2014), but in a different order. The US and Japan, the highest publishing countries, can be found second and fifth, while Germany is the highest collaborative partner for NST research. In practice, the strong linkages between Russian and German research organizations are based on active collaboration between Russian organizations with the Karlsruhe Institute of Technology and the Helmholtz Association. These activities focus on fundamental physics and instrumentation. Many of these publications have been big science efforts, for example, in the context of ITER.

Figure 23. Countries Russia has been in research collaboration 2012–2021 in nuclear science and technology. Source: Web of Science

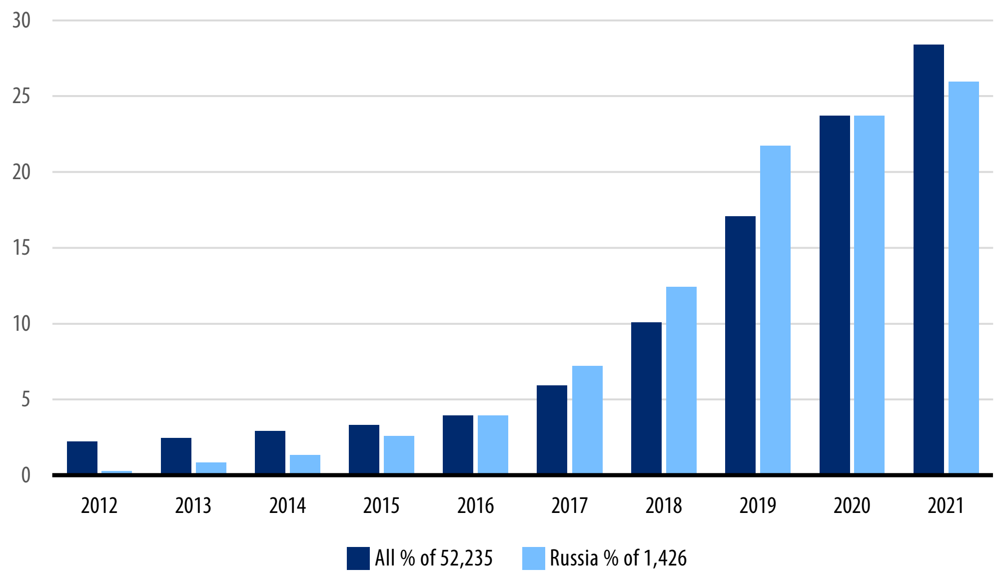


With NST being a paragon of big science, government policy action reflects the peculiarities of the domain. NST is funded primarily via large programs where most of the funding is dedicated to established big players in the field, with the National Research Center "Kurchatov Institute" being a central research organization and the state corporation Rosatom being a central, if not a unique, industrial player. The nuclear domain maintains its priority, as exemplified by a recent increase in funding for dedicated R&D activities (Interfax 2021). Although government policy action includes support for start-ups in the nuclear domain, for example via Skolkovo, the key ambitions in nuclear sphere are to be realized by the hands of Rosatom and its large academic partners, as in the case of the Breakthrough (Proryv) project aiming at the creation of a closed fuel cycle reactor.

3.6 Case study: Artificial intelligence

In the case of artificial intelligence (AI), we follow the approach developed by Ho and Wang (2020). The work of Ho and Wang (2020) highlighted the importance of US research as well as the rise of China in AI research. In their work, based on data from 2018, countries were listed based on the number of publications that have been published. The list of the twenty largest publishing countries included the US, several European Research Area (ERA) countries, as well as Iran, Malaysia, and Singapore. Russia was not mentioned among the twenty largest countries publishing research. To focus on the intensity of Russian research, **Figure 12** shows the percentage of publications globally and from Russia as a percentage of publications throughout the time series.

Figure 24. Publication volume yearly between 2012–2021 in artificial intelligence. Source: Web of Science

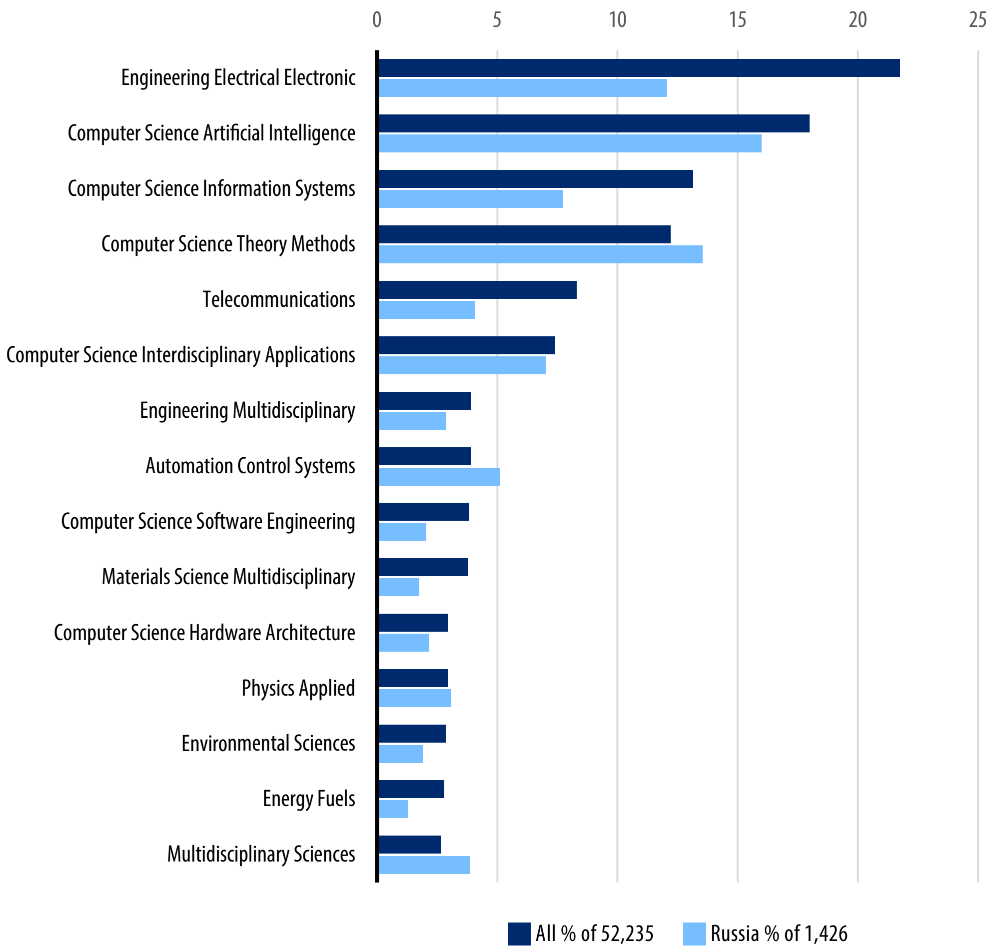


We can see that there has been a strong increase in global publishing, which is also reflected in Russian research. The growth of Russian research is similar to that of global research, but reflecting on Ho and Wang's (2020) findings, this would not mean that Russia is catching up on the global frontier but rather that it is trying to keep up with it. Moreover, keeping up should be contextualized with the high expectations set in the

Russian policy[42], which emphasize the objective to increase Russia's share of the global market through research.

Although Russia is keeping up with the increase in AI-related research, the differences between Russia and global research are visible in its thematic orientation. In **Figure 13** we can see that the largest thematic area of publishing is engineering electrical electronic, where Russia is significantly less active. Similarly, Russia is much less involved in telecommunications and information systems research. Aligned with other cases and the findings of Suominen and Lehtinen (2021), it can be noted that Russia is "overperforming" in computer science theory and methods.

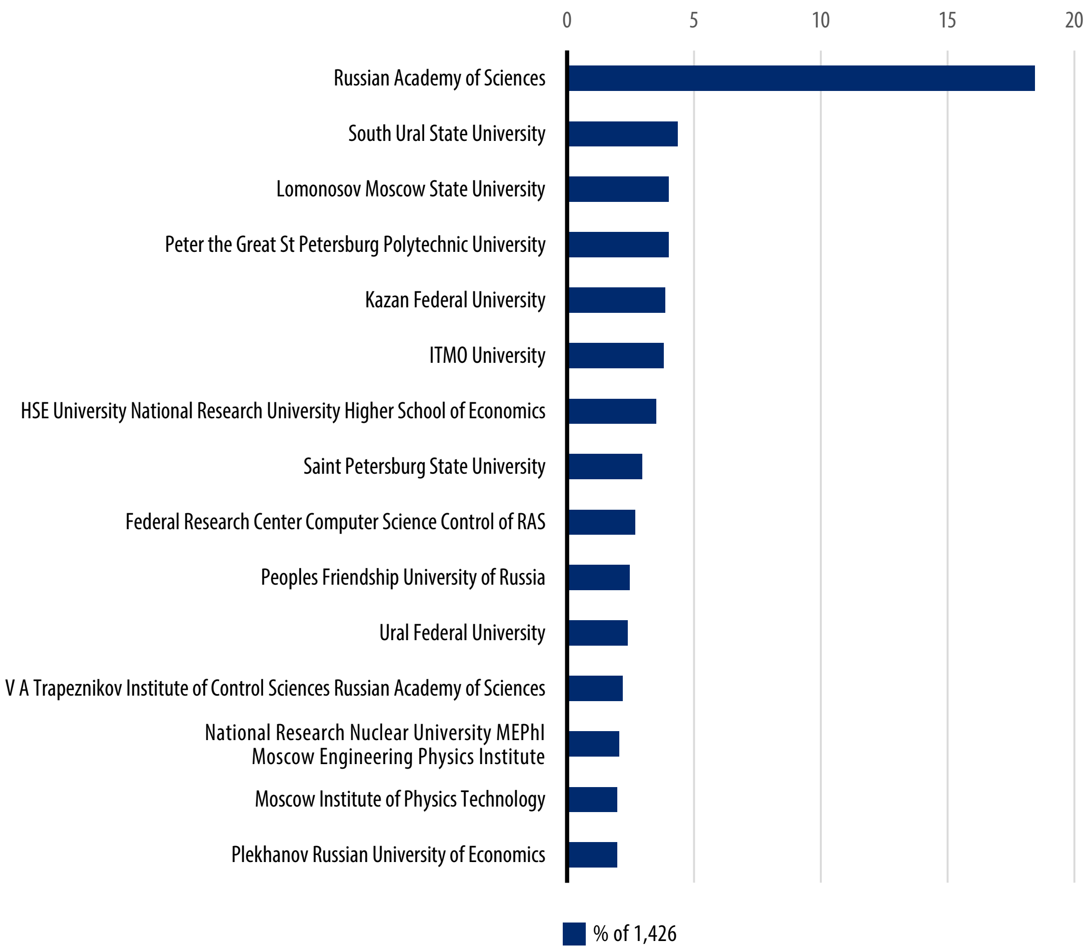
Figure 25. Web of Science research categories of publications 2012–2021 in artificial intelligence. Source: Web of Science



42 refer to "Decree of the President of the Russian Federation from October 10, 2019 No. 490 "On the development of artificial intelligence in the Russian Federation https://www.garant.ru/products/ipo/prime/doc/72738946/#1000 . Accessed 31.1.2022

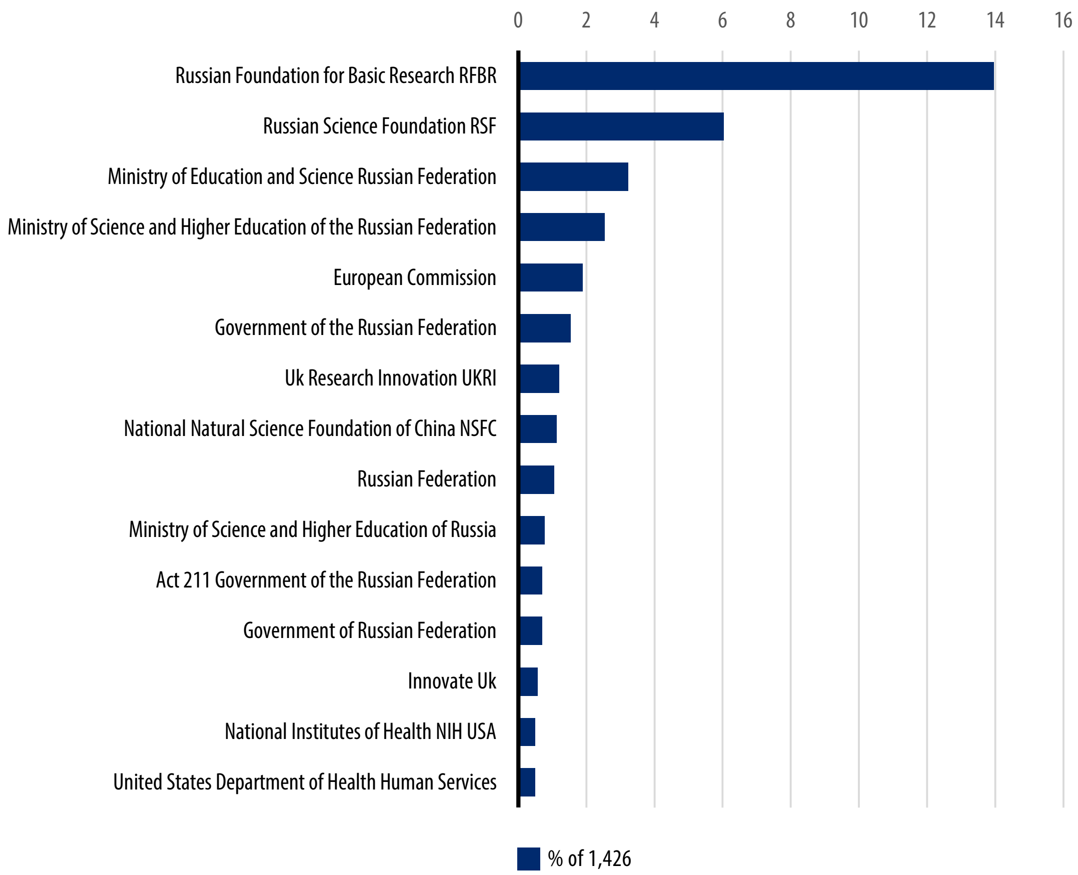
A deeper look into, for example, computer science theory and methods showed that research in Russia is theory-oriented. Looking deeper into the 193 publications in the computer science theory and methods category, health- and security-related research were identified as the only thematic application areas. Regarding research output by organization conducting research, we identified the usual suspects of Russia's scientific research. RAS is the largest publishing entity in AI-related research, as shown in **Figure 14**. However, compared to nanotechnology or NST research, the importance of RAS is much less significant. Given that the other organizations mentioned in the figure also have a relatively low number of publications, we can argue that AI-related research is highly spread across the Russian innovation system.

Figure 26. Organizations conducting research 2012–2021 in artificial intelligence The number of RAS publications is higher than shown, as institutes in RAS use either RAS as the institution's name or or the name of the specific institute. Source: Web of Science



As highlighted by Petrella et al. (2021), Russia's leading computer science university, Moscow State University, is on the list of the largest AI publishing institutes. However, the number of publications is low. Petrella et al. (2021) reviewed Moscow State University, which is "Russia's leading computer science research university, ranked 174th in the 2021 Times Higher Education World University Rankings." This ranking can be reflected in the publication volume. A key implication of low research intensity is the lack of high-quality research-based teaching (Petrella et al., 2021).

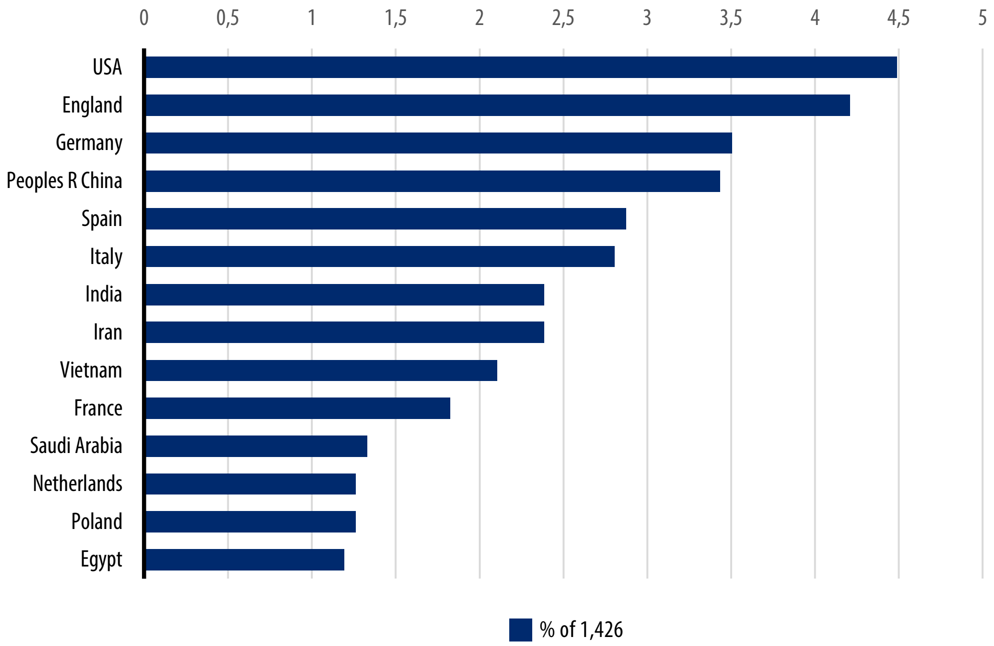
Figure 27. Research funding agencies 2012–2021 in artificial intelligence. Source: Web of Science



Focusing on funding, the majority of AI-related science is funded by the RFBR. Interestingly, the list also includes the "Act 211 Government of the Russian Federation", which corresponds to funding allocated within the framework of a program aiming at increasing the competitiveness of leading Russian universities, launched in 2013. Overall, it is noteworthy that the development of AI in Russia has been led by state-owned companies, such as Sberbank. The implication of this is the existence of substantial funding for AI, which is not visible in the acknowledgement sections of scientific publications. Among these, we can also include spending by the Russian Ministry of Defense (Petrella et al. 2021) on AI, which is estimated to be in the range of $12–$36 million. This can be seen as relatively modest in comparison to, for example, the US military spending on AI (Morgan et al. 2020).

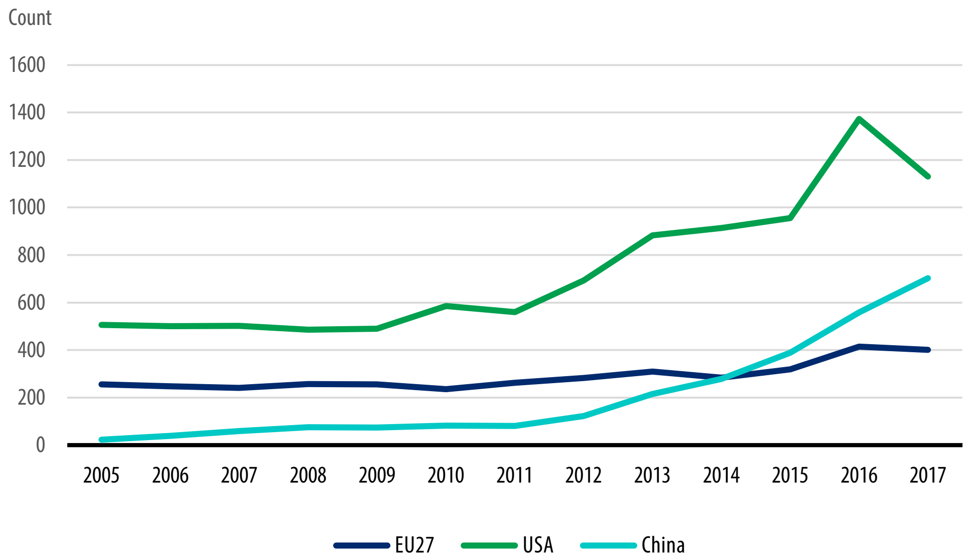
In **Figure 16**, we see that the US is the largest collaborative partner of Russia in AI. This is in contrast to, for example, NST or nanotechnology, where we were able to identify Germany as the main collaborative partner. However, we should note the scale on which the collaboration occurs: although in NST research, the largest collaborative partner shares close to 14 percent of the publications, in AI, US collaborates in approximately 4.5 percent of the publications.

Figure 28. Countries Russia has been in research collaboration 2012–2021 in artificial intelligence. Source: Web of Science



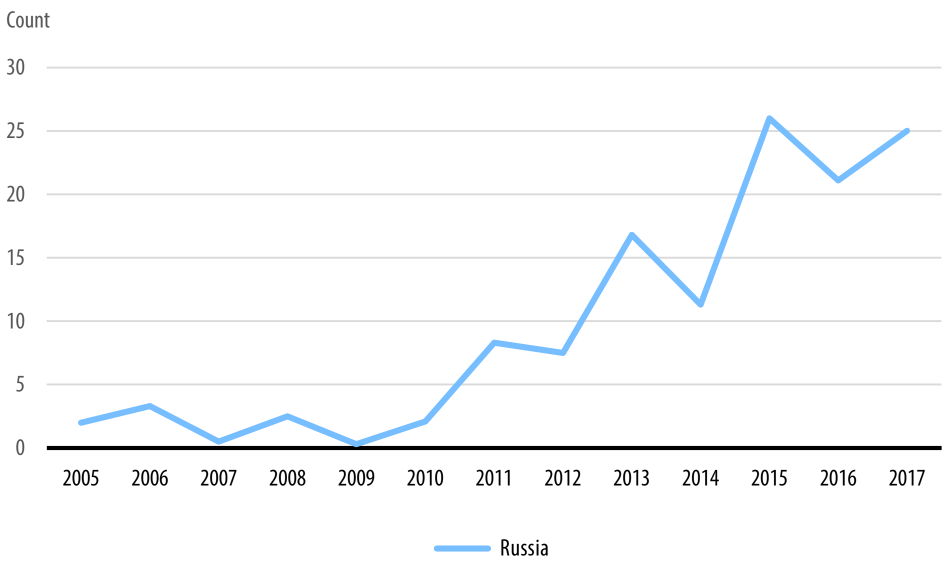
Globally, we can observe a strong increase in AI-related patenting. As shown in **Figure 29**, there has been a strong increase in patenting activities in the US, China, and the EU27. Although patenting in the US is significantly higher than in the EU27 and China, we should also note the substantial increase in China. Particularly interesting is the fact that China has overtaken the EU27 in AI-related patenting.

Figure 29. Patenting in artificial intelligence measured using IP5 patents for EU27, US and China. Data from OECD and adopted from Suominen and Lehtinen (2021).



Overall, China offers an interesting comparison to Russia. Although, as seen in **Figure 29**, Russian patenting in AI also has a strong upward trajectory, the absolute count is far from China's volume. This is an important observation when reflecting on the increasingly diverging development paths of China and Russia. Both countries see AI as a national priority, but only in China can we observe an integration into the immaterial property rights system that has resulted in a globally significant portfolio of assets.

Figure 30. Patenting in artificial intelligence measured using IP5 patents Russia. Data from OECD and adopted from Suominen and Lehtinen (2021)



Reflecting on the findings from S&T indicators with the policy relevance of AI creates an important context. AI is currently a top-priority S&T area for the Russian government. A dedicated national strategy for the development of AI appeared in 2019. It defines the goal of the development of AI as ensuring the growth of the quality of life of the citizenry, ensuring national security and the legal order, and accomplishing sufficient competitiveness for the national economy. The strategy for AI defines the implementation of the strategy as a prerequisite for entering the group of leading countries in the field of AI.

The National Strategy for the Development of Artificial Intelligence is based on six different spheres of activity. The strategy states that the primary tasks for the development of AI are providing sufficient funding for scientific research in the field of AI, developing domestic software based on AI, increasing the quality and availability of data for the development of AI, increasing the availability of hardware necessary for AI, ensuring the availability of a qualified workforce, and creating a favorable system of regulation for the development and introduction of AI in society and the economy. A significant task for strengthening technological sovereignty in the field of AI is the goal of developing Russian microprocessors by 2030, which should also be made available on international markets. (Eskonmaa 2021)

The Russian government has made a systematic effort to catch up in AI, and its policies reflect this. For example, it is working on AI regulation at the legislative level and setting up several regional 'regulatory sandboxes' to test innovations. It also encourages the administration to adopt AI technology by requesting that each ministry adopt a roadmap of AI development. Lastly, a large federal project on artificial intelligence (within the national program Digital Economy) features diverse forms of support for AI research, technology development, and marketization, as well as investment in education. AI policy development is an ongoing process that includes the active collaboration of private organizations and state-owned businesses. The state-owned Sberbank is a central actor in the AI development program (Edmonds et al. 2021). Importantly, Russia seeks to boost its AI development through its S&T partnership with China (President of Russia, 2022).

4 Prospects of S&T development in Russia

4.1 Delphi-survey: Selection of arguments

On the basis of the analysis and literature reviews conducted during the project, we selected 15 arguments for a Delphi-survey. The selection of the arguments was done in consultation with relevant partners, stakeholders and the steering group. The arguments can be found from the **Table 1**. The selection of the statements required prioritizing. Originally 20 statements drawn from the project analysis were eventually synthetized to 15 most relevant statements. This was done by merging similar statements and prioritizing the most important arguments for the project.

It is important to note that the selection and formulation of the Delphi statements was conducted before Russia's invasion of Ukraine in February 2022. Similarly, the survey respondents provided their answers before the aforementioned aggression. Thus, the Delphi-survey itself does not take into account the impacts and implications of Russia's invasion in February 2022. Because of these deficiencies, the outcomes of the survey are later contrasted with the potential impacts and implications of Russia's invasion in the Discussion section of the Report.

Table 1. Dephi statements selected based on the literature review.

#	Delphi statement	Reference
1	*The science and technology (S&T) collaboration between Russia and the EU continues to develop in a positive way through avenues such as science diplomacy and scientific cooperation.*	Kalinichenko, P. (2021)
2	*As a result of Russia's growing technological dependence on world leaders, the Kremlin will most likely intensify the strategic partnership with China in order to develop its S&T capabilities.*	Lavrikova, Y. et al. (2018)
3	*Because of federal budget constraints and the unwillingness of the private sector to invest in research, the overall funding and impact of R&D in Russia will not improve.*	Gershman, M. et al. (2018); Gershman, M., & Kuznetsova, T. (2016)
4	*Russia is unable to utilize the potential of ICT technologies for the improvement of labour productivity.*	Voskoboynikov, I. B. (2017)

#	Delphi statement	Reference
5	*Russia's historical inability to sustain and utilize its technological innovations for broad societal benefits stems from a technocratic approach to innovation policy and the resulting lack of entrepreneurial culture.*	Radosevic, S. (2003); Graham, L. (2013)
6	*Russia uses its innovation capability first and foremost as a geoeconomic tool in order to shape the international environment. Any other considerations, such as scientific impact or economic competitiveness are subordinated to this mode of governance.*	Saari, S. (2021); Nocetti, J. (2020)
7	*Russian efforts in R&D will continue to be significantly driven by national security considerations.*	NATO (2020)
8	*Russia will invest considerable resources and effort to the creation of its own technology-ecosystem and techno-economic bloc in order to preserve its technological sovereignty and great power status.*	Bezrukov, A. O., et al. (2021)
9	*Russia has the necessary science and technological know-how to create its own tech-ecosystems as well as converging physical, digital and biological capabilities to ensure its great power status.*	Diesen, G. (2021); Bezrukov, A. O., et al. (2021)
10	*The Kremlin will succeed in its drive to replace foreign technology with domestic technologies.*	Soldatov, A. (2021)
11	*Russia does not strive for technological superiority against USA, China or EU, but rather to have its own technology ecosystem that is "good enough" for its needs.*	NATO (2020)
12	*Because of sustained brain drain, Russia will continue to lose its science and technology talent to the benefit of USA, China and the EU.*	NATO (2020)
13	*Russia has been unable to utilize its relatively strong fundamental research capabilities and educational base, which means that it will continue to suffer from a "high-education, low human-capital paradox".*	Kotkin, S. (2018)
14	*The capacity of Russia to achieve its goals in the most advanced spheres of technology (ICT/digital/AI) depends on its ability to enlist the help of various private sector actors, start-ups and private-public partnerships.*	Indukaev, A. (2021)
15	*Russian priorities in the technological field largely mimic global trends, but with its own idiosyncratic interpretations of the most important issues associated with these technologies.*	Eskonmaa, J. (2021)

As seen in **Table 1**, each of statements is provided with a key reference to enable evaluation of the foundation of the statements. Overall, the statements selected cover the main thematic areas of Russian S&T development, namely S&T collaboration, private investment in R&D, benefits from R&D, and the geopolitics of technology.

The Delphi process was implemented as a two round survey focusing on the 15 statements identified during the previous stages of the research. In consultation with the project steering group, the project focused the survey to national experts on Russia, but it also included selected international experts to limit potential contextual biases. In total 46 experts were invited to participate in the Delphi process. Each expert was carefully selected so that they would possess clear expertise on Russia. Moreover, a selected number of experts was required to have agency in decisions implemented in Finland.[43]

In the first round, a total of 22 experts (47,8 percent) responded. In the second round, a total of 18 experts participated. Results from the first round of the analysis can be seen in Table 2. Round 2 results, which resulted in stronger cohesion between the answers, are shown in the Annex.

The following subsections after the Table, describe the synthetized consensus view of the expert opinion concerning the prospects of S&T development in Russia. The consensus view is clustered to the following four key thematic areas: *S&T collaboration*, *private investment in R&D*, *benefits from R&D*, and *the geopolitics of technology*.

43 A more detailed description of the Delphi process and methodology can be found in the Annex.

Table 2. Results from round 1 of the Delphi process.

	Stronly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree	N
The science and technology (S&T) collaboration between Russia and the EU continues to develop in a positive way through avenues such as science diplomacy and scientific cooperation.	9 %	55 %	14 %	18 %	5 %	22
As a result of Russia's growing technological dependence on world leaders, the Kremlin will most likely intensify the strategic partnership with China in order to develop its S&T capabilities.	0 %	9 %	23 %	55 %	14 %	22
Because of federal budget constraints and the unwillingness of the private sector to invest in research, the overall funding and impact of R&D in Russia will not improve.	5 %	18 %	32 %	27 %	18 %	22
Russia is unable to utilize the potential of ICT technologies for the improvement of labour productivity.	0 %	41 %	27 %	27 %	5 %	22
Russia's historical inability to sustain and utilize its technological innovations for broad societal benefits stems from a technocratic approach to innovation policy and the resulting lack of entrepreneurial culture.	9 %	32 %	5 %	27 %	27 %	22
Russia uses its innovation capability first and foremost as a geoeconomic tool in order to shape the international environment. Any other considerations, such as scientific impact or economic competitiveness are subordinated to this mode of governance.	9 %	27 %	23 %	32 %	9 %	22
Russian efforts in R&D will continue to be significantly driven by national security considerations.	5 %	0 %	14 %	41 %	41 %	22
Russia will invest considerable resources and effort to the creation of its own technology-ecosystem and techno-economic bloc in order to preserve its technological sovereignty and great power status.	5 %	5 %	9 %	45 %	36 %	22
Russia has the necessary science and technological know-how to create its own tech-ecosystems as well as converging physical, digital and biological capabilities to ensure its great power status.	18 %	23 %	18 %	41 %	0 %	22
The Kremlin will succeed in its drive to replace foreign technology with domestic technologies.	5 %	59 %	18 %	14 %	5 %	22
Russia does not strive for technological superiority against USA, China or EU, but rather to have its own technology ecosystem that is "good enough" for its needs.	0 %	27 %	9 %	41 %	23 %	22
Because of sustained Brain Drain, Russia will continue to lose its science and technology talent to the benefit of USA, China and the EU.	0 %	5 %	18 %	68 %	9 %	22
Russia has been unable to utilize its relatively strong fundamental research capabilities and educational base, which means that it will continue to suffer from a "high-education, low human-capital paradox".	0 %	14 %	18 %	64 %	5 %	22
The capacity of Russia to achieve its goals in the most advanced spheres of technology (ICT/digital/AI) depends on its ability to enlist the help of various private sector actors, start-ups and private-public partnerships.	0 %	14 %	9 %	41 %	36 %	22
Russian priorities in the technological field largely mimic global trends, but with its own ideosyncratic interpretations of the most important issues associated with these technologies.	0 %	5 %	27 %	45 %	23 %	22

4.2 Delphi results

The following sections describe the synthetized consensus view of the expert opinion of the Delphi-respondents regarding the prospects of Russian S&T development.

4.2.1 Science and technology collaboration

> ***The science and technology (S&T) collaboration between Russia and the EU continues to develop in a positive way through avenues such as science diplomacy and scientific cooperation.***

According to the majority of the respondents, S&T cooperation between the EU and Russia will continue on a declining trajectory, apart from a few selected positive areas of collaboration. In particular, the broader pattern of increasing tensions between the EU and Russia after 2014 has put a stop to any cooperation in the field of military and dual-use technology and research.

More broadly speaking, S&T have been politicized and securitized in Russia. Instead of an open S&T collaboration, Russia aims for competitive autonomy and sovereignty in S&T development. International cooperation in S&T is restricted by various laws that pose requirements and limitations for cooperation. For Russian researchers, international funding and collaboration can result in a "foreign agent" designation or in a treason charge.

Despite these challenges, the EU and Russia will nonetheless continue to seek cooperation in unrestricted technologies due to business, technology, and scientific interest on both sides. The continuing elements of S&T cooperation, through programs, such EURUCAS[44], CREMLIN[45], CREMLINplus[46], and Horizon 2020[47], have played an important role in facilitating EU–Russia cooperation. In the field of science, exchange programs are a particularly important facet of continuing people-to-people contact between the EU and Russian citizens.

44 European-Russian Centre for cooperation in the Arctic and Sub-Arctic environmental and climate research. https://cordis.europa.eu/project/id/295068/reporting. Accessed 19th April 2022.

45 CREMLIN aims to improve and strengthen the relations and networks between European and Russian research infrastructures both at a scientific level and at a research policy level. https://www.cremlin.eu/. Accessed 19th April 2022.

46 CREMLINplus is an EU project fostering European-Russian S&T collaboration in the field of research infrastructures. https://www.cremlinplus.eu/. Accessed 19th April 2022.

47 Horizon 2020 was the EU's research and innovation funding programme from 2014-2020 with a budget of nearly €80 billion. https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en Accessed 19th April 2022.

As a result of Russia's growing technological dependence on world leaders, the Kremlin will most likely intensify the strategic partnership with China in order to develop its S&T capabilities.

The majority of the respondents agreed that key trends point toward intensifying cooperation between Russia and China. Due to its tensions with the West, Russia looks to China, particularly for investments, markets, and technological expertise. Moreover, at least on a rhetorical level, the emerging Sino–Russian partnership includes increasing cooperation in dual-use high-tech areas, such as AI and ICT.

Nonetheless, the overall depth and strength of the Sino–Russian partnership can be questioned. The Sino–Russian relationship consists of a combination of cooperation and competition, which functions on a case-by-case basis, focusing on issues with mutual benefits. China is a partner but also a strategic competitor for Russia. Therefore, the growing reliance on China is a concern in Russia, although the extent of Russian dependence on China varies from one sector to another. For example, in military hardware, China has been dependent on Russia and not vice versa. However, apart from selected military technologies and human capital, Russia cannot offer much to China.

Overall, many of the experts noted that the benefits of the partnership with China can be assessed with a certain degree of skepticism. Many of the expected benefits for Russia, such as technology transfers and foreign direct investments, have not materialized. Moreover, on a grassroots societal level, a degree of mutual distrust exists between China and Russia. As a result, Russia seeks to limit its dependency on China by balancing its partnerships with Beijing through other international partners, such as India, as well as through its own domestic efforts.

Due to sustained brain drain, Russia will continue to lose its S&T talent to the benefit of the US, China, and the EU.

Global competition for talent has become an integral part of the great power competition. It was strongly agreed that Russia is likely to continue to lose its S&T talent due to "brain drain." Many educated young people in Russia are seeking new and improved opportunities abroad. The increasing limitations, restrictions, and repression in the Russian system will increasingly drive out talented, individualist, and creative minds. Reasons for emigration include corruption, the lack of financial and scientific opportunities, low living standards, political atmosphere, and restrictions such as the foreign agent law. Moreover, many foreign high-tech companies, such as Huawei, operate in Russia to capture their talent. In short, the brain drain will continue to pose a persistent problem for Russia.

Nonetheless, the specific volume and intensity of the brain drain remains an open question. Russia will most likely seek new ways to stem this tide through various carrots and sticks. Russia will probably be able to retain talent through various means, such as financial rewards and with the help of increased patriotic sentiments. The state has drafted a program to invite expatriate experts back into STEM fields, which has been promoted by Putin. Furthermore, Russia might be able to attract new talent from the Global South and post-Soviet countries.

> ***Russia has been unable to utilize its relatively strong fundamental re-search capabilities and educational base, which means that it will continue to suffer from a "high-education, low human-capital paradox."***

There was broad agreement on the statement that Russia has been unable to utilize its relatively strong fundamental research capabilities and educational base. One of the main reasons for this state of affairs is the weak link between fundamental research and the commercialization of innovations. Unlike in the US or China, there are only a few connections between scientists and the private sector in Russia.

Moreover, even the much-vaunted strength of the Russian education system can be at least partially questioned, especially in its ability to adapt to modern challenges. Whereas elementary school children fare well in PISA studies, the relative quality of students tends to drop in higher levels of education. Overall, the Russian education system is geared toward prestigious institutions that receive resources and donations for development. Despite this, many highly educated people do not find enough opportunities in Russia because of the relatively weak business environment, the lack of institutional support for innovations, and the utilization of human capital. Education as such is not enough if the societal environment does not support flourishing human capital.

Many of these problems are recognized in the Russian leadership. Human capital is identified as one of the most significant drivers of economic progress in the new Russian National Security Strategy. Moreover, multiple efforts and reforms to improve the situation have been undertaken, but with ambiguous results. The Russian Academy of Sciences (RAS) had undergone reforms, and Russia's STEM workforce has been the objective of a massive government investment program related to ICT.

4.2.2 Private investment in research and development

> ***Due to federal budget constraints and the unwillingness of the private sector to invest in research, the overall funding and impact of R&D in Russia will not improve.***

In terms of overall funding, Russian R&D and STI are heavily state-led and financed. There are no indicators that point toward major changes in this respect. Fundamental issues, such as systematic corruption, will slow down any potential attempts toward large-scale reforms in the field of R&D. Despite these issues, the stable macroeconomic conditions and the resources provided by the National Wealth Fund provide viable opportunities for an increase in the share of R&D funding.

However, instead of an overall improvement in R&D spending, Russia will probably focus its R&D efforts on selected key sectors, such as energy, space, and military, to have a more substantial impact. Regarding purchasing power parity (PPP), Russia has increasingly invested in military technology-related R&D. State priorities in terms of R&D funding continue to be oriented toward the needs of the national security and military sectors.

In the civilian realm, R&D funding is having major problems. The private sector has been relatively unwilling to invest in R&D due to perceived risks in the business environment and the investment climate. Indeed, the overall viability of tech businesses is often affected by the interests of the state. Despite these problems, there are efforts to increase the impact of R&D by increasing the involvement of state-owned companies as well as the R&D centers owned by foreign companies. Russian companies with global ties will increasingly invest in R&D and ESG requirements[48].

> ***Russia's capacity to achieve its goals in the most advanced spheres of technology (ICT/digital/AI) depends on its ability to enlist the help of various private sector actors, start-ups, and private–public partnerships.***

On a global level, all states are increasingly dependent on the cutting edge of technological innovations that originate increasingly from private-sector actors. The Russian leadership recognizes this, and it seeks to create a strong partnership with the private sector. The government is eager to provide funding for exceptional talents to study and develop technologies that align with state interests. However, one of the problems has been that spin-offs and collaboration between the military and civilian sectors have been difficult. Despite these problems, the Russian state has been able to develop

48 ESG refers to increasingly important Environmental, Social, and Governance factors in the field of finance, e.g. https://www.cfainstitute.org/en/research/esg-investing Accessed 19th April 2022

significant innovations for its own purposes, such as cyber capabilities, which might not be commercially relevant but are crucial for national security interests.

The state often has an important key role to play in managing, funding, and facilitating the private technology sector. In Russia, digitalization is directed immensely in a top-down orientation, even though start-ups and tech companies have an important role to play. Public–private partnerships are often state-driven or managed, and the private sector is highly interlinked with the government. As a result, successful corporations are "strongly persuaded" to take part in government projects, whether or not they are commercially viable. However, in addition to public-private partnerships, the in-house R&D activities of major companies have become an increasingly important facet of technology development.

4.2.3 Benefits from research and development

> ***Russia is unable to utilize the potential of ICT technologies to improve labor productivity.***

The majority of the respondents argued that contrary to the statement, Russia is in fact able to utilize the potential of ICT technologies for the improvement of labor productivity. The question of how much and to what extent productivity will improve depends on the sector. For example, in state-owned companies and in the oil industry, ICT is widely implemented to improve productivity. Furthermore, public services have also improved through the implementation of ICT.

Some analysts argue that domestic ICT solutions are already improving labor productivity and will continue to do so slowly in the future. Especially in consumer-oriented markets, there is evidence of improved productivity. Russia has a fairly well-developed domestic digital platform, internet, and software industry that includes successful companies such as Yandex, mail.ru, VKontakte, and Kaspersky.

Despite the existing potential, low labor productivity continues to be one of Russia's main economic problems. The current demographic crisis and labor shortages only increase the need to find solutions to the problem of labor productivity. Nonetheless, Russian problems in labor productivity are not unique, as most advanced nations face somewhat similar problems. In fact, Russia has some "low-hanging fruits" in terms of potential catch-up growth in the application of ICT to various sectors of the economy. ICT is partially underutilized in Russia, not least because the government seeks to develop its own domestic alternatives, often for reasons linked to security or autonomy.

> ***Russia's historical inability to sustain and utilize its technological innovations for broad societal benefits stems from a technocratic approach to innovation policy and the resulting lack of entrepreneurial culture.***

The respondents were somewhat conflicted in their views on the statement above. The majority agreed that although the current Russian state cannot be compared to Tsarist Russia or the Soviet Union, the legacies of state-led technology development have left an enduring effect on the current R&D system. For example, technological innovations in Russia have traditionally been geared toward the needs of the state and the security apparatus. Even today, major innovations are focused on the national security and military sectors, with only limited commercial potential.

The problems in Russian technology development stem from various sources. First, there is a recognized lack of cooperation between universities and the private sector. Second, developers and innovators continue to suffer from weak rule of law and a lack of sufficient property rights. Third, the developing culture of entrepreneurialism suffers from constraints of state intervention and forms of corruption. Lastly, overall weak societal trust forms a key obstacle to the development of an innovation-based economy.

Recognizing the problems of the current model, the state has been trying to provide a more meaningful role for the private sector in R&D. More importantly, despite inadequate financial instruments and difficulties in market entry and exit conditions, younger generations have found ways to create entrepreneurial opportunities through the digital platform economy. Indeed, younger generations perceive entrepreneurship in a more positive light, whereas older generations tend not to trust entrepreneurs, start-ups, and SMEs in general.

4.2.4 Geopolitics of technology

> ***Russia uses its innovation capability first and foremost as a geoeconomic tool to shape the international environment. Any other considerations, such as scientific impact or economic competitiveness, are subordinated to this mode of governance.***

The answer regarding the above statement were distributed relatively along a Likert scale. It was widely recognized that the question is not as clear-cut either/or dichotomy as presented. For one, Russian leaders are acutely aware of their country's economic limitations, and this is exactly the reason for its catch-up ethos. Russia was seen to be in the middle of the ongoing global struggle for markets in which it has to improve its competitiveness even to maintain its current position, let alone win access to new markets.

Russia was believed to seek economic growth as an objective, as with any other state. In Russia, innovation was seen as a driver of growth in the domestic economy. In addition to this, however, the government was seen to utilize innovations such as surveillance technology as a tool for social control domestically, as well as a tool for international power projection. Overall, it was believed that Russia has more limited capabilities to use its innovations as a geoeconomic tool than countries such as China or the US.

In summary, geoeconomic viewpoints emphasizing security and sovereignty are more prevalent in some areas of the economy, whereas competitiveness in a global economy is more important in others. In many fields, they overlap without clear-cut boundaries between the goals.

> ***Russian efforts in R&D will continue to be significantly driven by national security considerations.***

The importance of national security as a driver for Russian R&D and STI is widely recognized among the respondents. That Russia's actions are driven by national security considerations is explicitly stated in the 2021 Russian National Security Strategy. Russia's self-declared perception of itself as a state "under siege" is mirrored in the significant share of R&D funding directed toward the national security sector. Due to the increasingly contested international environment as well as domestic tensions, R&D will be increasingly applied for the purposes of power projection, both domestic and foreign, to minimize the state's vulnerability in various scenarios. Moreover, this emphasis on national security will most likely stretch beyond the current regime.

However, despite the prominence of national security, the issue of R&D drivers was not seen in such a black-and-white manner. Perceived in a broader international context, the Russian emphasis on national security is not an anomaly; rather, it applies to most great power actors, at least to a degree. Moreover, apart from national security, new drivers such as "green transition" need to be considered as well. Indeed, understood broadly, national security has many linkages to many other issues that are not contradictory to the goal of national security. For example, Russia is also seeking to utilize its military–industrial sector as a driver for the broader economy.

Indeed, the driver of national security was seen to consist of a two-pronged approach: from a more traditional strategic culture that perceives Russia as a "besieged fortress", but also from the increasing emphasis and recognition of the need to remain connected internationally to sustain technological and economic relevance in the global technology competition.

> ***Russia will invest considerable resources and effort in the creation of its own technology-ecosystem and techno-economic bloc to preserve its technological sovereignty and great power status.***

There was a relatively shared understanding among the respondents that Russia would try to create its own technology-ecosystem and techno-economic bloc to preserve its technological sovereignty and great power status. Many recent state strategies, statements, programs, and legal initiatives point to this direction. The rationale for this approach originates from an analysis of the global situation. Russian leadership is believed to perceive ICT broadly as the determining basis for a country's sovereignty. In this sense, the global technological race is a crucial part of the ongoing great power competition in which Russia is aiming for an autonomous approach vis-à-vis the other great powers.

The Kremlin sees domestic alternatives in sectors such as ICT, data, and the internet as crucial for maintaining Russia's national security, because foreign technologies can always be sanctioned. A comparison can be made to the early 2000s, when the Russian state took control over "strategic" energy resources. According to this logic, Russia is now seeking to control new strategic assets, one of which is the high-tech industry. Digital technology is seen as a means to secure the regime's political power as well as a way to project power in the rapidly changing geopolitical environment.

Investments will be made according to this vision, but the results will inevitably be mixed. Russia has its own ecosystems and standards in many areas, for instance, even internationally competitive GLONASS satellite navigation system. However, despite the considerable push toward technological sovereignty, economic realities were seen to place limits on the implementation of these policies and Russia's freedom to maneuver. For one, Russia is already dependent on its partnership with China and, more broadly, on the import of semiconductors. As a result, Russia was believed to focus its technology investments on sectors that matter most in terms of national security.

> ***Russia has the necessary science and technological knowhow to create its own technology ecosystems as well as converging physical, digital, and biological capabilities to ensure its great power status.***

It was generally agreed that Russia had many of the elements needed to create its own technology ecosystem, such as scientific and technological expertise. However, the creation of a diverse technological ecosystem with global significance seems to be out Russia's reach. As it stands, it is more likely that Russia can achieve break-throughs and competitive advantages only in limited technological areas.

It was noted that Russian companies are having trouble trying to keep up with the developments of US and Chinese private companies. Russia does not possess the knowhow required to create conversions, spin-offs, and synergies between various sectors, as seen in the US and China. Moreover, the global market is dominated by competitive firms, while the Russian tech industry operates mostly in a catch-up mode. It is unlikely that Russia will sustain its great power status in multiple technology fields.

The backbone of the great power status of Russia continues to be its military might, in particular its nuclear arsenal. However, in terms of economic power, Russia is not in the same league as the US, the EU, and China. Russia is constrained by its political system, economic resources, and dependency on foreign technology. A true (super)great power status would require a stronger economy built on diverse foundations. In short, Russia will have its domestic technology ecosystem to a degree, but its quality and influence, especially in global terms, will be limited.

> ***The Kremlin will succeed in its drive to replace foreign technology with domestic technology.***

It was agreed that the Kremlin would in fact not succeed in its drive to replace foreign technology with domestic alternatives, even though it’s currently an official state policy. This policy reflects the long-term ambition of the Kremlin to increase its technological sovereignty. The impact of this policy will be most significant in the security and military sectors, where Russia has been able to find domestic alternatives for critical sectors, such as the nuclear industry and cybersecurity.

It is important to note that policies favoring domestic tech have costs in terms of the economy and the quality of technology, which will most likely inhibit the scale of these policies. Russia does not have the required industrial and technological base to conduct this policy on a wide scale, since the mere labor unit costs would be too high. Furthermore, the volume of the Russian market is not sufficient to support all technologies, and the competitiveness of most Russian companies is not strong enough for global export markets. More importantly, the broader society still prefers imported high-quality commercial technologies, such as iPhones, over any Russian alternatives.

It was pointed out that in a globalized world, no country has complete self-sufficiency in terms of technology and resources. Russia does not have the resources or capabilities to replace foreign technology universally and effectively. Russia will continue to be dependent on semiconductors as well as on 5G and oil drilling technology, for example. As a key characteristic of global tech development, the degree of cooperation and interdependence will inevitably remain. Nonetheless, Russia will increasingly continue to try and develop "good enough" domestic technology solutions tailored to its needs in terms of sovereignty and security, even though their quality might be weaker.

> ***Russia does not strive for technological superiority against the US, China, or EU, but rather to have its own technology ecosystem that is "good enough" for its needs.***

Russian leadership seems to understand the crucial role of technological capabilities in the unfolding great power competition. Rhetorically, Russia will continue the emphasis on Russia's status as a technological great power. However, despite this bombastic rhetoric, the Russian leadership knows that full technological supremacy is unattainable with the resources at their disposal. Russia needs foreign markets, as the Russian market is too small for an independent technological ecosystem.

In short, it was believed that Russian leadership has a relatively realistic assessment of its abilities and weaknesses. One of the main objectives of leadership is to control the degree of dependence on foreign technology in strategic sectors. Indeed, the ambition for an independent Russian technology ecosystem serves the objective of regime security and survival rather than achieving broad commercial influence on a global scale.

As a result, Russian R&D as a whole most likely aims for the logic of "good enough." Nonetheless, achieving and sustaining internationally recognized leading positions in selected technological sectors is an important objective for Russia. These include various military technologies related to competition with the US and China. Moreover, Russia will seek to gain asymmetric advantages in cost-effective fields, such as cybersecurity. Indeed, the current unfolding high-tech competition is best understood as a long-term process in which Russia is seeking to improve its performance relative to its competitors in selected technology areas while maintaining a "good enough" approach to R&D as a whole.

> ***Russian priorities in the technological field largely mimic global trends but with their own idiosyncratic interpretations of the most important issues associated with these technologies.***

It was agreed that the pattern of adapting global trends to local realities is common. Innovations, in general, are copied and modified to fit into new contexts. Indeed, Russians follow global trends very attentively and act in response to them. As an example, unlike most countries, Russia has a domestically dominating internet search engine, social media, and multi-domain digital platforms such as Yandex, Mail.ru Group, and Ozon.

It was pointed out that Russia's history, culture and geography shape the way in which it perceives and responds to global trends. Despite certain shifts in interpretation and policies, there is continuity in Russia's strategic culture, whereby Russian leadership has tended to interpret technology trends mainly from the point of view of security. Overall, Russia's current technological priorities emphasize sovereignty and autonomy, often at the cost of other perspectives.

The respondents agreed that the state will continue to play an important role in setting strategic technology priorities in the future. Russia focuses on the ability to exploit R&D to create asymmetric enablers and force multipliers to contest and disrupt Western and Chinese supremacy in global technology competition, both in civilian and military fields. In particular, Russia was believed to seek to maintain its leading position in traditional fields, such as nuclear and military technology. For example, Russia's hypersonic weapons program, which was revived in 2002, has produced advanced nuclear weapons, such as Avangard, that have dominated headlines around the world.

5 Scenarios for Russia's S&T development

The scenario analysis done for this study was founded on the Delphi expert analysis findings, previous steps of the analysis as well as on a literature review assessing various foresight source material related to Russia and global trends in general (e.g. National Intelligence Council 2021; Kragh 2020; Saari & Secrieru 2020; NATO 2020; Sakwa 2019; Lavikainen et al. 2019; Zheltikova & Khokhlova 2019; Smith & Bacon 2014). The scenario work builds on the previous analysis done in the report by factoring in identified key uncertainties related to S&T development and systematically imagining how Russia's geopolitical futures might look in the light of these uncertainties. An important part of the foresight process was the interaction between different project partners, in particular through an online consultation with key stakeholders.

It is important to note that the scenarios for this project were drafted around December 2021 and January 2022. Since then, Russia's invasion of Ukraine has cast a new light on the scenarios. In a matter of days, the seemingly most realistic scenario of *Stagnant & statist Russia*, depicting current realities, had morphed into the scenario of an *Isolated & fortified Russia* that was previously seen as a relatively pessimistic scenario. In short, the war in Ukraine has become a key driver of Russia's future development trajectory.

Scenario analysis has long been a popular way of analysing Russia's future development trajectories, particularly in the West (Bacon 2012), but increasingly so also in Russia (Monaghan 2021). Scenario work focuses on identifying emerging trends, core drivers and key dynamics as well as on the potential pathways and trajectories created by various combinations of these factors.

Scenarios are particularly helpful way of assessing the potential impacts of various critical uncertainties by imagining their possible permutations in the form of different scenarios. (Saari & Secrieru 2020, 98-100) Because of systemic complexity and inherent unpredictability of the future, the emphasis of the scenario work is not on predictive accuracy, but rather on the anticipation of and preparedness for various plausible alternative futures (Bacon 2012). Indeed, it is important to remember that "scenarios are reductions that will never as such become reality" (Kuusi et al., 2007, 81). Scenarios are a heuristic tool to better understand the whole spectrum of plausible futures as well as their potential implications.

5.1 Key drivers and critical uncertainties

The scenario analysis was based on the application of key drivers and critical uncertainties identified in the Delphi survey and literature review. The four identified key drivers were political situation, status in the great power competition, economy, and the global energy transition. In the second phase, the four drivers and related uncertainties were modified, applied, and analyzed using the futures table method.

Political situation

Putin's regime has created a stability system in Russia, favoring technocratic leadership, statism, and economic nationalism. The stability system seeks to balance the main interest groups in society to guarantee societal coherence and stability. More recently, the stability system has been affected by the perception of Russia "under siege", which has limited Russia's openness and enhanced the role of the security apparatus. Moreover, the stability system is undermined by demographic issues, such as an aging population, decreasing workforce, and increasing brain drain. (Sakwa 2019, 172,208-213; NATO 2020, 61-64)

In terms of political economy, Russia can be analyzed through the "limited access order" -framework (North, Wallis & Weingast 2009, 30), which refers to the elite consensus and stability based on lucrative privileges originating from rent extraction. Conversely, economic problems can also destabilize the elite consensus. (Kluge 2021, 490-491)

Critical uncertainties: What will be the future development trajectory of Russia's societal environment and political system?

- What will Russia's political development look like in the future?
- What will the future be like in terms of elite conflict versus coherence?
- What will be the volume and intensity of the brain drain from Russia?

Status in the Great Power Competition

Great power competition is an important driver of Russia's grand strategy. In the current constellation of global politics, Russia has emerged as a challenger (Sakwa 2019, 208). Due to limitations in terms of resources compared to US and China, Russia seeks to secure its great power status by focusing on cost-effective asymmetric tactics, military power, and selected technological strengths. However, despite Russia's emphasis on national security and sovereignty, its scientific and technological development is significantly dependent on its international partners. In terms of international partnerships, Russia has increasingly disengaged from the West and pivoted toward China. (Sakwa 2019 184-190; Stanoyava 2020, 20-25; Kaczmarski 2020, 85-93; NATO 2020, 62-64)

Critical uncertainties: What will be the impact of the intensifying great power competition and the resulting shifts in global power for Russia?

- How does Russia navigate its confrontation with the West?
- What is the overall depth and strength of the Sino-Russian partnership?
- Will the emphasis be on isolating from or integrating to global systems and developments?

Economy

The long-term outlook and sustainability of Russia’s economic model based on rent extraction places constraints on Russia’s ability to achieve both its global ambitions and the safeguarding of its domestic stability. In particular, Russia’s dependence on the export revenues of hydrocarbons creates vulnerabilities for market fluctuations. As the relative gap between the Russian economy and the economies of other great powers increases, Russia’s reliance on its traditional strengths, such as energy and military sectors, will grow. Consequently, a substantial share of national resources in technology development is directed towards the “national security sector”. (Kluge 2020, 43,51-55; Sakwa 2019, 95,172; Kragh 2020, 18)

Critical uncertainties: What will be the impact of the shifts in the global economy for Russia’s policy and strategy?

- Will Russia reform its economic model or continue on its current path?
- Is Russia able to utilize its military-industrial sector as a driver for the economy and S&T development?
- What will be the extent, costs and eventual success of Russia’s drive to replace foreign tech with domestic alternatives and import substitution policies?

Global energy transition

The relative importance of hydrocarbons in the energy constellations of many advanced nations is declining because of advances in renewable energy. However, global energy consumption is projected to grow until around 2050, and the transition to renewable energy is likely to be geographically uneven. Hence, although Russian energy products may have smaller markets in Europe, there could still be profitable markets for Russia’s products elsewhere for years to come. Nevertheless, the energy transition threatens Russia’s economic model in the long term. Russia’s ability to spend on STI development is partially dependent on the fortunes of its energy export revenues. (Saari & Secrieru 2020, 16-20; Kluge 2020, 51; NATO 2020, 64-65; Kragh 2020, 18)

In short, the Green transition will have significant long-term geopolitical consequences, especially for fossil fuel producers that do not adapt to a decarbonizing world (Siddi 2021).

Critical uncertainties: What will be the long-term impact of emerging drivers in the field of energy such as the global green transition?

- What is Russia's willingness and/or ability to adapt, modernize and diversify the energy sector?
- Will the energy transition increase dependency on China?
- Will the green transition lead to increasingly aggressive foreign policy?

5.2 Futures table

The following futures table and the resulting scenarios are based on the four aforementioned key drivers of Russia's developmental trajectory. On the basis of these four drivers, we identified three key dimensions for our futures table: S&T, strategic orientation in the ongoing great power competition, and systemic choices. In terms of S&T, the key factors identified were brain drain and the specific focus of STI/R&D policy. In the dimension of great power competition, we identified the partnership with China and the relationship with the West as key factors. In terms of systemic choices, the political system and economic model were identified as key factors.

Table 3. Futures table

Scenario #	Impact of brain drain	Partnership with China	Relationship with the West	Political system	Economic model	Focus of R&D and STI-policy
5.3	Substantial	Partnership	Limited cooperation	Continuation and preservation of current regime	Slow decline of the statist model	Oriented towards the needs of the state
5.4	Small	Non-existent	Rapprochement	Constitutional reforms towards parliamentary politics	Structural reforms towards innovation economy	Oriented towards the needs of the civil-society
5.5	Massive	Pragmatic	Conflict	Isolation and repression of the civil society	Fast decline of the hydrocarbon-economy	Oriented towards military technology
5.6	Limited	Selective	Challenging the liberal order	Authoritarian reform & agile repression	Neo-liberal reforms	Oriented towards dual-use technology

5.3 Stagnant & statist Russia 2030

Realist scenario of continuation and decline

Scenario is characterized by the preservation of the current political regime and the continuation of the statist economic model (Sakwa 2019, 172; Kragh 2020, 5-6,8-11).

The state controls the strategic heights of high-tech enterprises and has a key role in managing funding and facilitating the private technology sector. The interference of the state in tech development continues to stifle economic dynamism and social innovativeness, which helps to increase the flow of emigrating scientists and entrepreneurs toward the West. Moreover, Russia's economic model is increasingly threatened by the global green transition. In particular, the decreasing federal revenues from hydrocarbons expose Russia to more dependence on Chinese investments.

In the intensifying global setting, Russia strives to sustain its great power status by challenging the West, thereby limiting the EU–Russia relationship to a few non-political issues. Russia is increasingly characterized by anti-Western sentiments, which increases the importance of the Sino–Russian partnership. (Saari & Secrieru 2020, 97)

The Russian economy is increasingly structured to withstand Western sanctions by reorienting trade and STI cooperation toward Asia. Russia focuses on partnerships with non-Western countries, such as India and China, to secure financing, investments, and cooperation. Despite these benefits, Moscow is troubled by the increasing economic and technological power of China, which makes Russia increasingly susceptible to Beijing's influence and even coercion.

Due to the increasingly contested international environment, combined with the limited availability of resources, Russia's R&D is geared toward the needs of the state and the security apparatus. Russia focuses its R&D efforts on fields with national security relevance, such as energy, space, and the military. However, global market conditions and other economic realities place strict limits on Russian ability to keep up with the pace of the global development of technology. Moreover, despite sporadic efforts at reform, Russia continues to suffer from "a high education and low human-capital paradox" (Kotkin 2018).

Despite the strong demand for R&D funding due to the increased cost of research and the ambitious nature of mission-oriented research, Russia suffers from an overall stagnation in R&D spending. As a result, Russia is increasingly drawn to collaborate with China, since Beijing is willing to invest in joint Sino–Russian projects. However, in contrast to the highly successful Chinese policy of engaging with global scientific and intellectual property regimes, Russia remains sidelined from these systems.

The implications of this scenario for Europe are driven by the increased importance of China in the scientific and technological development of Russia. The deepening relationship between China and Russia, for example, in the form of Chinese investments in Russia's research infrastructure, decreases the relative importance of the EU to Russia as a partner in S&T development.

A particular case in point is a Big Science project, the construction of Russia's Nuclotron-based Ion Collider Facility (NICA)[49], which was a central element in the recent China-Russia "Year of Scientific and Technological Innovation." China's participation in the project was highlighted as one of the main outcomes of the Sino–Russian collaboration[50].

49 see details on NICA https://nica.jinr.ru/physics.php Accessed 10.2.2022 Accessed 19th April 2022. Notably, the development of the NICA research facility has leveraged previous EU-Russia collaboration. An example of this is the international FAIR particle accelerator facility built in Darmstadt Germany, which is a collaboration between Germany, Finland, France, India, Poland, Romania, Sweden, Slovenia, United Kingdom, Czechia and Russia. Importantly, Russian research institutions and the State Atomic Energy Corporation Rosatom have had a important role in this large research mission in Europe.

50 Refer to press release by Ministry of Foreign Affairs, the People's Republic of China https://www.fmprc.gov.cn/mfa_eng/zxxx_662805/202111/t20211128_10454394.html Accessed 9.2.2022

Due to the rising influence and importance of China as well as the broad securitization of the EU-Russia S&T cooperation, the EU is slowly but steadily marginalized to the periphery of Russia's S&T partnerships. For the EU, the impact of these developments will be reduced access to the substantial fundamental knowledge of Russia, particularly in the natural sciences.

Nonetheless, the steady emigration of a talented workforce away from Russia creates increasing opportunities for European countries and companies to attract top Russian S&T talent. Simultaneously, due to increasing tensions between the West and Russia, the relative attractiveness of Russia as a destination and a partner in science, technology, innovation, and business collaboration decreases.

5.4 Smart & open Russia 2030

Optimistic scenario of reform and modernization

The scenario is characterized by societal reforms, restoration of the constitutional order, and the emphasis on parliamentary politics (Sakwa 2019, 187-188; Kragh 2020, 6-7,11-12).

The premise of this scenario is the reform of Russia's political system and the total reorientation of its foreign policy towards the West. After a radical change in policy, Russia steers clear from authoritarian autarchy toward openness, international cooperation, and a partnership with the West. Russia embarks on a path of societal and economic reforms that helps connect it to the global value chains of technology development. In particular, the Russian leadership recognizes that the rise of renewable energy is imperative for Russia to diversify away from a hydrocarbon-based economy.

Key institutions in the political and economic spheres have been reformed. Russia focuses on structural reforms that improve property rights, the cultivation of entrepreneurialism, and the development of the education system (Sakwa 2019, 187-188). Because of the reforms and the subsequent improvement of societal conditions, Russia is better able to retain its most valued scientific and technological talent.

In the international realm, Russia seeks rapprochement with the West to balance and hedge against the rising influence of China (Kaczmarski 2020, 85-90). The partnership between EU and Russia is transformed by the resolution of the broader confrontation between the West and Russia. Russia's new alignment with the West helps Russia to diversify its economy by attracting various technology and foreign direct investments (NATO 2020, 63-64). In particular, the improved political relationship with the West provides an opportunity for Russia to focus on a broad range of STI cooperation with the EU.

The successful utilization of ICT technology helps to improve the labor productivity of the Russian economy, whereas the resulting benefits are directed toward the development of civil society and public services. Russia is able to develop its technology companies to a globally competitive status and to increase its international influence. Innovations of Russian origin function as drivers of the domestic economy.

The scientific and technological basis of this scenario is the modernization and diversification of Russia's energy sector and its military-industrial complex, which helps Russia reap societal benefits from S&T development. In particular, much of Russia's "national security sector" is successfully directed toward the development of dual-use technologies with an increasing focus on civil applications and commercial solutions.

In strategic terms, the intensifying geoeconomics competition between the US and China provides an opportunity for the positive development of EU–Russia relations in STI and beyond. From the European perspective, Russia's increasing connectivity to global value chains of technology development, scientific engagement, and IPR increases the attractiveness of Russia as a partner in S&T collaboration. A more open and diversified Russia creates engagement opportunities between the EU and Russia in Big Science projects but also in a range of broader innovation-related activities, for example, in collaboration with the European Innovation Council[51].

In this scenario, science diplomacy is successfully utilized for the articulation of mutual concerns in the field of grand challenges. A joint EU-Russia research fund helps the parties to increase cooperation in the field of grand challenges, such as climate change and food security. Visa liberalization between the EU and Russia increases STI cooperation and deepens ties in education and scientific exchange. (Sokolov 2014) Moreover, in the field of energy, Russia successfully transforms to a leading global hydrogen producer. Cooperation in green hydrogen functions as a bridge between EU and Russia, aligning Moscow with the agenda of green transition. (Zabanova & Westphal 2021)

The increased predictability and stability in EU–Russia relations helps to enhance the collaboration and investments between Finnish institutions and companies in the field of S&T. The opening of the Russian S&T system provides opportunities for foreign direct investments in sectors where Russia has comparative advantages and strong capabilities.

51 Currently the EU-Russia S&T cooperation focuses on large-scale research facilities, such as EU X-ray Free-Electron Laser, European Organisation for Nuclear Research, International Thermonuclear Experimental Reactor, Facility for Antiproton and Ion Research and European Synchrotron Radiation Facility. For more information refer to European Commission website https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/europe-world/international-cooperation/russia_en Accessed on 15.2.2022

This combination of increased scientific and technological opportunities also provides new avenues for increasing trade between the EU and Russia.

Overall, the increased opening up of Russia politically, diversification of its S&T, and broad engagement with the global systems of S&T, as well as rapprochement with the West, leads to increased engagement and exchange between the European and Russian actors in the field of STI.

5.5 Isolated & fortified Russia 2030

Pessimistic scenario of aggressive autonomy

The scenario is characterized by the imperative of state sovereignty amid a turbulent external environment and disrupted societal stability (Sakwa 2019, 188-189; Kragh 2020, 7-8,12).

In the economic realm, the fast-paced global green energy transition leads to a steep decline in the federal hydrocarbon revenues (Stanovaya 2020, 25). The combination of Western sanctions and the high cost of Russia's import substitution policies leads to a socioeconomic disruption that undermines Russia's economic model and threatens the stability of the society (Saari & Secrieru 2020, 97-98). As a result, Russian leadership embarks on a path of self-sufficiency along with tightening control of the economy and repressive governance of civil society to maintain the stability of the society (Sakwa 2019, 189). Geopolitical tensions help the regime to create a "rally around the flag" -effect in the society and to strengthen elite coherence. However, the increasing restrictions imposed on the civil society drive critically important scientific and technological talent out of the country, which stifles Russia's ability to compete technologically.

Because of turbulent power shifts (NATO 2020, 62) in global politics, economy and technology development, Russia's relative status in the world decreases, leading Russia to emphasize its security and sovereignty. To safeguard its global influence, Russia's foreign policy becomes more aggressive and unpredictable, which intensifies Russia's conflict with the West. To balance the conflict with the West, Russia forges a partnership with China based on pragmatic complementarity: Russia has natural resources, while China has technology and capital. Nonetheless, the strength of the Sino–Russian partnership is limited by the increasingly asymmetric relationship; Russia's growing reliance on China increases the leverage of Beijing in its relationship with Moscow.

As Russia becomes increasingly isolated from the West, both economically and politically, its great power status becomes more reliant on its ability to project power militarily. As a result, Russia gears its R&D efforts toward the security apparatus. However, because of the lack of linkages between fundamental research and commercial actors, as well as the military and civilian sectors, Russia is unable to utilize its R&D for societal or economic gain. Instead, Russia seeks to safeguard what is left of its autonomy by replacing foreign tech with domestic technology, despite problems with quality and costs.

Russia's ability to increase or even sustain governmental R&D spending and investments of state-owned companies is reduced by the steep decline of federal revenues. Furthermore, Russia remains sidelined by global science and IPR regimes.

The mission orientation of Russian innovation policy aligns with the interests of the regime and the security apparatus. Russian efforts increasingly focus on military projects, such as the development of hypersonic missiles and anti-satellite weaponry[52]. Russia will increasingly compensate its weaknesses in other fields of great power competition by focusing on S&T directly related to existing strengths and military capabilities in particular.

In this scenario, the main impacts for the EU and Finland result from Russia's focus on developing and leveraging its technological sovereignty, despite the resulting costs for Russia in terms of economic impact and reduced innovation outcomes. Moreover, due to various import substitution policies resulting from Western technology sanctions, Russia increasingly resorts to import restrictions. Similarly, the EU and the US will further sanction Russia with technology import bans. These sanctions, counter-sanctions, and other restrictions lead to increased geoeconomic tensions both with the EU and Western states as well as with China.

Russia's isolation and STI decoupling from the West leads to a reliance on an assertive and aggressive international posture. From the point of view of Western countries, the EU and Finland, the attractiveness of Russia as a partner in terms of scientific, technological, and innovation exchange plummets. Importantly, Russia's isolation from the West leads to a significant increase in the brain drain to the West and elsewhere, thus benefitting the EU.

52 Refer to National Geographic story on anti-satellite system https://www.nationalgeographic.com/science/article/russia-just-blew-up-a-satellite-heres-why-that-spells-trouble-for-spaceflight and Deutsche Welle on hypersonic missile https://www.dw.com/en/russias-hypersonic-missiles-what-you-need-to-know/a-61204404 Accessed on 15.2.2022

5.6 Agile & authoritarian Russia 2030

Wild card scenario of authoritarian modernization

The scenario is characterized by the successful authoritarian modernization of the Russian state with a focus on competitive autonomy. (Kluge 2020, 43-44; Saari & Secrieru 2020, 98)

In the economic realm, Russia adapts ito global market conditions through "authoritarian shock-therapy", prudent macroeconomic policies and the successful utilization of its military-technological sector as a driver for economic development (Rácz 2020, 65-67). Through various collaborative dual-use policies, Russia is able to create spin-offs and synergies between the military and civilian sectors. Russia also finds new ways to exploit its vast hydrocarbon and mineral resources by adapting, modernizing and diversifying these sectors. Particularly important factor is the development of domestic green hydrogen production, which provides a hedge against global decarbonisation. More importantly, through improved economic and scientific opportunities as well as selective and agile repression tactics, the Russian state manages to limit brain-drain to a minimum.

The landscape of global politics is increasingly fragmented to various regional techno-economic blocs. Along with the US, EU and China, Russia controls its own regional bloc. (National Intelligence Council 2021, 8-9) In terms of alliances, Russia is engaged in a selective strategic partnership with China. Through subversive tactics and hybrid operations combined with traditional diplomatic efforts, Russia successfully leverages geopolitical concessions and sustains its status as a global great power.

Given the excellent conditions of the Russian state budget and the National Wealth Fund, Russia is able to increase its share of R&D in the federal budget. Russia focuses these funds on the creation of substantial new cyber capabilities and the development of selected dual-use technologies. Moreover, Russia develops its education system as well as programs for acquiring and retaining scientific and technological talent.

Indeed, a central element of this scenario is the "call back" of talented Russians. Modeling the approach taken by China (Cao et al. 2020), Russia actively seeks to attract Russians abroad with various attractive programs, and by successfully utilizing and exploiting rising patriotic sentiments affiliated with the intensifying great power competition. These successful talent programs help Russia meet the emerging skills gap, particularly in more innovation-oriented areas of R&D.

From the European point of view, the implication of Russia's successful talent acquisition and retainment programs would be the lack of available S&T-related talent emigrating to the EU from Russia and wider post-Soviet space. As a result, Russia is better positioned to shape the conditions of STI cooperation with Europe according to its interests.

In this scenario, Russia follows the Chinese model of setting ambitious targets for S&T development. In particular, Russia takes heed from the Chinese model of developing and securing its IPR system through approaches resembling protectionism (Schotter & Teagarden 2014). These aspects, especially when producing similar outcomes as seen in China[53], would nonetheless decrease Russia's status as an attractive collaborative partner, especially from a Western point of view. Instead, Russia seeks increasingly to cooperate complementarily with selected like-minded partners such as China, utilizing Russia's strengths in STEM-related capabilities such as cyber power and cryptography.

This scenario is based on a successful development of Russia dual-use policy focusing on synergies between high-tech military and civilian technologies. Russia finds a way to create its own brand of STI strategy by successfully emulating and synthetizing the dual-use policies of the US as well as the Chinese strategy of "military-civil fusion" (Laskai 2018). Russia also intensifies its strategy of acquiring attractive dual-use technologies from the EU, either through trade, cooperation or espionage[54].

A dual-use driven STI strategy helps Russia to commercialize its leading innovations, thus providing funds for its continued military modernization, technological sovereignty, and economic competitiveness.

53 Refer to for example the case of unethical behavior in Chinese science system https://www.science.org/content/article/china-cracks-down-after-investigation-finds-massive-peer-review-fraud Accessed 15.2.2022

54 Refer to for example a recent example on German companies https://www.welt.de/politik/deutschland/article236869121/Umstrittene-Exporte-Deutsche-Unternehmen-lieferten-militaerisch-nutzbare-Gueter-fuer-Russland.html Accessed 15.2.2022

6 Discussion

This section of the report contrasts and compares our assessments of Russia's S&T prospects prior to the Russian invasion of Ukraine in February 2022 to the impacts and potential S&T implications of the invasion.

6.1 Sanctions and international developments

6.1.1 The impact of sanctions on EU-Russia STI cooperation

Already before Russia's invasion of Ukraine in 2022, the respondents of the Delphi-survey argued that the STI cooperation between EU and Russia will continue on a declining trajectory. As a result of the Russian invasion of Ukraine, it now seems that the cooperation could cease almost altogether. Even the few areas of positive collaboration are increasingly under pressure to be torn apart. These include fields such as science collaboration and exchange programs which have formed an important part of people-to-people contacts between European and Russian researchers and students.

Despite the fact that Russia has been waging a war in Ukraine since 2014, EU-Russia relations in science and education continued relatively robustly up until Russia's direct invasion of Ukraine in 2022. With active engagement on both sides of civil society and academia (Sokolov et al. 2014), EU-Russia cooperation in the field of higher education was often described as the "least conflictual" among the fields of collaboration (Deriglazova & Mäkinen 2019) and the scientific cooperation was hailed as "one of the few islands of positive cooperation in an ocean of negative relations" (Kelly 2019). Taking into account the impact of the current war in Ukraine, the continuation of these assessments does not seem realistic.

Since the Western sanctions in 2014 did not directly target scientific and educational cooperation (excluding some dual-use technology, military and energy applications) EU's policy of selective engagement with Russia focused on people-to-people contacts through education programs such as Erasmus+ as well as on supporting the Russian civil society (European Commission 2018). The logic behind these policies is the belief that scientific and educational cooperation can bring people together by engaging people and encouraging the movement of ideas (Kanevskiy 2014).

Fundamental science has been at the heart of EU-Russia cooperation in STI, especially in areas such as physics (Kanevskiy 2014, 10-11), whereas thematically EU-Russia initiatives have focused on research areas such aeronautics and health. EU-Russia cooperation has been particularly intensive in the field of research infrastructures, with examples including the EU X-ray Free-Electron Laser (XFEL) in Germany; the Facility for Antiproton and Ion Research (FAIR); the European Synchrotron Radiation Facility in France; the International Thermonuclear Experimental Reactor (ITER), and the European Organization for Nuclear Research (CERN). (European Commission 2018)

All the way up to the present war with Ukraine, Russian science continued to depend on cooperation with the West. Even after the 2014 sanctions, 24 percent of Russian scientific papers from 2017 to 2018 were co-authored with international partners, in particular with Americans and Germans, with the USA being Russia's largest collaborator in terms of co-authored papers and Germany the second biggest (Gokhberg & Kuznetsova 2021, 360).

Against this background, the speed and decisiveness of EU's scientific decoupling from Russia has been notable and even somewhat unprecedented. The EU Commission has suspended cooperation with "Russian entities in research, science and innovation", which means that no new contracts or agreements will be signed with Russian organizations and payments under existing contracts are suspended (European Commission 2022). Russia is thus not able to participate to Horizon Europe or Horizon 2020 programs. Moreover, Europe's largest university association has also decided to "cease contact and collaboration" with Russian governmental agencies (European University Association 2022).

These actions are notable, because many European countries such as Germany, France, Italy and Finland have a history of substantial scientific engagement with Russia (Kanevskiy 2014, 10-11). The effects have been particularly striking for Russo-German relations in science and technology, since the two countries share various joint research centers and labs. Germany, Russia's second largest research collaborator, has led the way by cutting almost all scientific ties to Russia. Germany has suspended all bilateral research projects, programs, partnerships and collaborations that involve the Russian government or technology transfers to Russia (Matthews 2022a).

Nonetheless, even before the ongoing 2022 war in Ukraine, sanctions and the broader geopolitical tensions since 2014 have already had a negative effect on the exchange of scientific knowledge, researcher mobility and collaborations between EU and Russia (Makkonen & Mitze 2021, 2-4). Since 2014, many western NGOs in the field of research have had to close their operations in Russia, while sanctions have made many equipment related to scientific research increasingly scarce in Russia (Dezhina 2017, 18-20). With the recent rounds of sanctions, the shortage of advanced scientific equipment has become even more acute (Matthews 2022b).

The long-term consequences and impacts of scientific decoupling and Russia's isolation will remain to be seen. Notably, even during the Cold War scientific exchange between the East and the West continued to a degree and even acted as a "back channel" for diplomacy between the blocs (Corvoisier 2022). Indeed, some have argued (Moran 2022) that STI-decoupling might actually lead to the strengthening of the Putin regime instead of providing an impetus for a change in Russia, whereas scientific engagement could act as a conduit for diplomacy. Therefore, even though it is important to choke Russia's ability to wage war, some have argued that the scientific decoupling between the West and Russia should be conducted in a nuanced manner, which would enable the continuation on the level of people-to-people contacts, especially since the institutional links between EU and Russia are currently being cut off (Corvoisier 2022).

6.1.2 Western sanctions and Russia's import substitution policy

Before 2022, we estimated that Russia would focus on a two-pronged approach whereby the traditional strategic culture that tends to perceive Russia as a "besieged fortress", would be complemented with selected connections to global value chains in order to sustain technological and economic relevance in the great power competition. As a result of the war and Western sanctions, the emphasis has clearly shifted towards the "Fortress Russia" approach that emphasizes technological sovereignty and security.

As a response to Russia's invasion of Ukraine in 2022, Western countries have decided to inflict costs to the Russian economy through the nodes of the international economy (Shagina 2020) by seeking to restrict Russia's access to global electronics supplies and to Western financial markets (Strohecker 2022). The US together with the EU and countries such as South Korea, Japan and Taiwan, have implemented coordinated export controls that aim to target Russia's vulnerabilities related to its high dependence on advanced Western goods and technology (Nakashima & Whalen 2022). Export and import bans have been put in place for defence-related equipment in addition to restrictions for dual-use goods that can be used for military purposes[55].

55 Sanctions include restrictions on dual-use goods and technology among other specific categories of goods such as technology and goods related to aviation, maritime or space industry as well as semiconductors and microchips. Included are also technologies that can contribute to Russia's military capability. Fernandez, M. P. & Stinebower C. N. (2022). Summary of EU Sanctions Targeting Russia. Winston & Strawn. https://www.winston.com/en/global-trade-and-foreign-policy-insights/summary-of-eu-sanctions-targeting-russia.html Accessed 19th April 2022.

The Delphi-survey recognized Kremlin's long-term ambition to increase its technological sovereignty. Since 2014, the Russian leadership has sought to limit and mitigate the effects of Western sanctions through import substitution policies. In effect, Russia has sought to safeguard its economic and technological sovereignty by supporting the creation of domestic alternatives for Western high-tech products and components (Shagina & Boulegue 2020). As an example, Russia has sought to mandate state-owned corporations and governmental agencies to switch to domestic software and hardware (Soldatov & Borogan 2022).

Despite the considerable push towards technological sovereignty, economic and technological realities place limits on the implementation of these policies and Russia's freedom to maneuver. For one, Russia is already dependent on its partnership with China and more broadly on the import of semiconductors. In short, because of the limited size of the Russian economy, low labor productivity and limited available capital, the strategy of import substitution has thus far produced only mixed success (Gontmakher 2021).

As a result, Russia has also applied "localization" as a part of its import substitution strategy. The government has invited and pressured foreign companies to localize their production in Russia, in order to preserve their market share in Russia. Moreover, the requirements related to domestic products in the IT sector have been softened, because Russian alternatives have failed to meet quality standards. However, because of the war, Russia's import substitution policies will be increasingly framed through security imperatives instead of economic objectives. This "securitization" of the economy through import substitution will only increase the problems related to Russia's rent-seeking economic model. (Shagina 2020)

Indeed, even before the ongoing war and the subsequent sanctions, the Delphi-respondents agreed that the Kremlin will in fact not succeed in its drive to replace foreign technology with domestic alternatives. Russia's import substitution policies favoring domestic tech have significant costs in terms of the economy and quality of technology, which will most likely inhibit the success and scale of these policies. Since Russia has only limited economic and technological capacity to sustain its great power status (Fortescue 2017), the combination of financial sanctions, export controls and scientific decoupling will have a substantial cumulative effect on Russia's long term S&T ambitions, not least because it cannot "replicate the capabilities of the global network" on its own (Grzegorczyk et al. 2022).

Despite Russia's bombastic rhetoric about technological sovereignty and military capabilities, Russia will continue to be dependent on foreign markets, technology and knowhow in order to sustain its limited technological ecosystem. The war in Ukraine only serves to reinforce the fact that Russia does not possess the resources or markets for an independent technological ecosystem. Therefore, Russia's remaining global links to non-Western world, especially to China and India, will become increasingly critical for Russia and its STI development.

6.1.3 Sino-Russian partnership

The Delphi-survey noted increasing cooperation between Russia and China in the field of STI, but it also highlighted many uncertainties related to Sino-Russian cooperation, especially in the fields of sensitive technologies. Because of the increasingly far-reaching Western sanctions regime, it would seem that Russia will become increasingly dependent on China, despite Russia's domestic and diplomatic efforts to limit these dependencies.

During the last decade, the combination of Western sanctions and Moscow's strategic considerations have led Russia to pivot towards China in the international realm. One of the main drivers behind Sino-Russian technological partnership is the complementary nature of the two countries: China has markets and resources while Russia has certain expertise that China needs (Gabuev 2021). As a result, Russia and China have intensified their STI cooperation which has led to Chinese companies replacing many Western ones in Russian markets since 2014 and Russia becoming increasingly reliant on Chinese high-tech, dual-use technology, machine tools and electronics (Schwartz 2021). However, it seems that China is not able, or willing, to fully replace components previously acquired from the West and Ukraine (Grzegorczyk et al. 2022). One reason for this is that Chinese companies fear the far-reaching extraterritorial US export controls and secondary sanctions (Huang & Lardy 2022). Chinese banks and companies are not willing to risk their valued relations to the West because of Russia's war in Ukraine (Economist 2022).

The scenarios that were drafted for this Report before Russia's invasion of Ukraine in 2022 already emphasized the centrality of China in terms of Russia's STI futures. Russia's war in Ukraine has made Beijing's choices and actions vis-à-vis Moscow even more crucial. As a result, the western world is increasingly trying to decipher China's stance towards Russia beyond the rhetoric of Sino-Russian partnership and cooperation. In the light of Russia's invasion of Ukraine, the important question is to what extent Russia's pivot to China and to Asia more broadly will help Russia to withstand and circumvent Western sanctions, particularly in the field of technology (Shagina 2020).

In addition to the reorientation of Russian trade towards Asia that started already in 2014, Moscow's recent attempts to blunt the new round of Western sanctions will likely tie Moscow even closer to Beijing. However, the integration with China and the dependencies that come along with can also prove to be an increasing source of resentment, friction and mutual distrust because of the growing asymmetry in the partnership. Nonetheless, it seems increasingly likely that Russia's dependence on China will increase substantially, even to the point of Russia becoming a vassal of China especially in terms of technology and trade, even though this would not be reflected on an official and rhetorical level.

6.1.4 Brain drain

Even before the current war in Ukraine, it was estimated that Russia will continue to lose a substantial amount of its STI talent to brain drain. Nonetheless, it was argued in the Delphi-survey that "the specific volume and intensity of the brain drain remains an open question". However, as a result of the war, it would seem that the brain drain has been accelerating significantly, particularly in fields such as IT specialists, software developers and engineers. The brain drain will most likely continue unless and probably even if the state interferes in the outflow of people more strongly.

In particular many highly educated specialists such as tech workers are looking for new opportunities around the world, since they are a part of a global market. According to the estimates of Russian Association for Electronic Communications[56], over 70,000 IT specialists and programmers have emigrated from Russia since the war began. More importantly, over 100,000 tech workers are expected to leave during April alone. The accelerating brain drain will negatively affect the long-term competitiveness of Russia's high tech sectors as well as the efforts to develop, diversify and modernize the Russian economy. (Dapkus 2022)

Since the disintegration of the Soviet Union in the 1990s, Russia has suffered from demographic decline and a brain drain of talent, which has contributed to the country's stagnation. A shortage of young scientists, tech experts and engineers are a particular worry for Putin's regime. Depriving Russia of its engineers, programmers and IT specialists will hamper the development of Russia's military-industrial complex. (Kokorich 2022; Plaks 2022)

The selection and effectiveness of possible governmental countermeasures against brain drain, such as the extent of coercive policies, the ability to offer financial rewards or the

56 https://www.interfax.ru/digital/830581 Accessed 19th April 2022.

attractiveness of patriotic sentiments, remains an open question. Thus far the government has relied more on financial incentives[57] and patriotic sentiments[58] than on coercion[59].

6.2 Russian STI and R&D

6.2.1 Russian technology ecosystem

Russia recognizes the global technological race as a crucial part of the ongoing great power competition, which is why Moscow has aimed for an autonomous approach to the development of technology vis-à-vis the other great powers. Indeed, there was a relatively shared understanding among the Delphi-respondents that Russia will try to create its own technology-ecosystem and techno-economic bloc in order to preserve its technological sovereignty and great power status. Because of the war and the resulting Western sanctions, Russia will continue to pursue the objective of technological sovereignty even more aggressively.

However, precisely as a result of the war, it seems that the attainment of these aspirations will be increasingly out of Russia's reach. Even though Russia has many of the elements needed to create its own tech-ecosystem, such as scientific and technological expertise, the creation of a diverse technological ecosystem with a global significance is a pipe-dream for an internationally isolated Russia. The Delphi-survey noted that Russian companies were having difficulties in trying to keep up with the developments of US and Chinese private companies already before the war. The attempts to emulate and combine European, American as well as Chinese models of technology development into the Russian National Innovation System (NIS) have led to mixed results because Russia has not been able to find a way to assemble these models to a coherent whole (Dezhina 2017, 20-21).

57 Russian leadership is trying to stem the current wave of brain drain by introducing emergency benefits to domestic IT companies that include a three-year zero tax rate, subsidized loans and a pledge that tech workers will not be conscripted before they are 27 years old. Borenius. Emergency benefits for the IT sector. Legal Alerts 3rd March 2022. https://www.borenius.ru/en/2022/03/emergency-benefits-for-the-it-sector/ Accessed 19th April 2022.

58 The regime is trying to stir up patriotic sentiments by reminding Russian tech workers of their motherland and by calling them to create "our own ecosystem". Metz, C. and Satariano, A. Russian Tech Industry Faces 'Brain Drain' as Workers Flee. New York Times, April 13, 2022. https://www.nytimes.com/2022/04/13/technology/russia-tech-workers.html Accessed 19th April 2022.

59 Currently, no permission is required to exit Russia, although some have advocated that Russia should limit the movement of experts in the name of "strategic interests", which could include a clearance by the FSB. Prince, T. 'A Nail In The Coffin'. Radio Free Europe, April 03, 2022. https://www.rferl.org/a/russia-it-workers-brain-drain/31783558.html Accessed 19th April 2022.

Moreover, it is highly unlikely that Russia's national security sector and military-industrial complex can provide the impetus for broader STI development. Despite the state-directed push for the development of dual-use technology through the development of the military-industrial-complex, Russia does not possess the know-how required to create conversions, spin-offs and synergies between various sectors as seen in the US and China. The Western sanctions regime will further complicate these efforts.

Notably, Chinese support for Russia is limited in nature. One reason for China's lackluster support is the importance of commercial relations between Washington and Beijing. As an article in the Diplomat puts it: "Beijing continues doing the minimum it should to maintain momentum with Russia, while not overextending any of its efforts so as not to harm its ties with the West."[60]

Moreover, a weakened Russia might actually be beneficial for China. The fact that Western companies are leaving Russia decreases competition in the Russian market and increases Beijing's leverage (Bochkov 2022). In particular, Beijing is seeking to leverage access to Russia's advanced nuclear weapons technology in order to modernize its own nuclear arsenal (Economist 2022).

Notably, advanced weaponry is the only category where Russia still has advantages over China. If Russia is forced to sell its remaining high-end military products to China, Moscow will lose an important leverage in the Sino-Russian partnership and Russia's military-industrial complex will become more dependent on Chinese technology. In short, the likely result of these recent and more long-term developments is that Russia will be, at least partially, integrated into the Chinese technology ecosystem, which will have an adverse impact on Russia's technology sovereignty.

6.2.2 Investment in R&D

In terms of R&D, Russia will continue to suffer from a weak rule of law and property rights; constraints of state-intervention and corruption; as well as from an overall weak societal trust. Despite these structural weaknesses, the Delphi-survey pointed out that the relatively "stable macroeconomic conditions" and "resources provided by the National Wealth Fund" would "provide viable opportunities for an increase in the share of R&D funding". The advent of the stringent Western sanctions and the resulting financial and economic pressures would indicate that this is no longer a viable possibility.

60 Meanwhile, India has actually been more supportive of Russia in practical terms, increasing trade and purchases of Russian oil (Bochkov 2022).

Moreover, the problems plaguing the civilian R&D will intensify because of the sanctions. Already before the war Russian R&D had only a limited commercial potential and the business environment and investment climate were affected by the low rate of investments by the private sector. In particular for the Western companies operating in Russia, the war has meant a "realization of the country risk" related to Russian operating environment. Gruesome news about the war in Ukraine combined with the threats of nationalization, such as the seizing of airplanes leased to Russia (Rains 2022), have led hundreds of Western companies to leave Russia. Notably, in addition to the state-enforced sanctions, many private companies are "imposing their own boycott of Russia", not merely for commercial reasons, but because of ethical reasons and values (Gould-Davies 2022).

These developments mean that the Russian state will have to take on an even more substantial role in the field of R&D in addition to the significant responsibilities that it already had. As a result, the state and the regime will increasingly set the strategic technology priorities. Russia will seek to maintain its leading position in traditional fields of strength such as nuclear and military technologies.

6.2.3 National security and R&D

Already before the Russian invasion of Ukraine, our report argued that the emphasis on security present in Russia's strategic culture will hold increasing sway in STI policymaking. The Delphi-survey respondents recognized national security as the key driver of Russian R&D and STI. Moreover, Russia's need for both international and internal power projection was identified as a priority for the foreseeable future, most likely stretching even beyond the current regime.

The main point of consensus of the Putin system and his regime is that Russia must sustain its great power status (Sakwa 2019, 169). However, a clear gap exists between Russia's resources and its great power aspirations. Russia has a strong base in fundamental science but only limited success in products and services. Moreover, even the sustained continuation of Russia's traditional edge in fundamental scientific research is questionable (Breedlove 2019). For one, despite many efforts to improve the quality and productivity of Russian science, in global terms much of it remains "poorly funded and little-cited" (Schiermeier 2020). In the field of technology development Russia will increasingly operate in a catch-up mode.

Because of the war in Ukraine, accelerating confrontation with the West and Russia's inability to sustain great power status in multiple technological fields, the existing trend of gearing limited R&D funding towards the needs of the national security and military sectors will continue. However, despite the growing need for national security and military related R&D, the ability of the Russian state to provide resources and ensure outcomes in the form of capacities will be increasingly under question because of the restraints posed by sanctions and the economic downturn. For one, the ability of the Russian state to harness the private sector innovations towards its objectives will be increasingly difficult because of the Western sanctions regime.

The ongoing war in Ukraine combined with an increasingly contested security environment and intensifying great power competition only serves to increase the existential stakes in the race to develop and sustain power projection capabilities. Therefore, Russia's technology ecosystem will increasingly serve the objective of regime security and survival rather than that of commercial influence on a global scale. Russia has focused on niche capabilities in areas deemed important for national security and power projection. In strategic terms, Russia's new weapon's systems such as the Sarmat and Avangard, are relatively low-cost responses to American conventional superiority. (Bendett et al. 2021)

The war in Ukraine is a part of an existential struggle for Putin's regime and it has provided the regime with increasing leeway for repression against the society. One of the main questions at the moment is whether or not the increasing isolation of Russia from the West will increase or decrease the elite coherence? In terms of the internal political situation in Russia, even before the war, there has been some talk about possible cracks in the elite consensus. For example, the halting of 5G rollout in Russia 2021 over disagreement about the business model of the operator, correct radio spectrum and the degree of import substitution provides an example of the lack of agreement about the common vision for the technological and economic development among elites (Kluge 2021, 489-490,500).

6.3 Future prospects

On the basis of the Delphi-survey it was argued that the Russian leadership has a relatively realistic assessment of its abilities and weaknesses. The war in Ukraine and its impact casts a shadow on this assessment, especially in terms of scientific and technological development of Russia. Indeed, the scientific and technological decoupling of the Western world from Russia will have substantial medium and long-term consequences.

First, in addition to the economic effects of sanctions, Russia faces both scientific and technological isolation from the West for the foreseeable future. Russia is cut off from the global supply chains of high-tech goods and scientific enterprise. It seems that a combination of isolation from the West and a growing dependence on China will characterize Russia's international relations for the foreseeable future.

Secondly, in the international realm, the global norms of technological interdependence and scientific openness might also suffer from the impact of scientific decoupling, sanctions and the geopolitical tensions between the West and Russia. China in particular will draw its own conclusions from the Western sanctions, which could lead it to seek more scientific autonomy and technological sovereignty from the West.

Thirdly, sanctions will fuel brain drain from Russia to the West and elsewhere, thus clouding Russia's future horizons in terms of scientific and technological development. Brain drain will negatively affect Russia's ability to develop its high-tech sectors. Conversely, the influx of Russia's emigre ICT talent will benefit the Western economies. However, brain drain might also hamper the possibility of domestic change in Russia, if the people that most oppose the current regime are leaving the country.

Indeed, many scientists feel that they have no option but to leave the country as it is becoming increasingly difficult to pursue science on a global scale in Russia. The Russian government recently took action to prohibit "its scientists from taking part in international conferences or allowing their published work to be listed on international science databases"[61], while the Russian rector's union has been toeing the official line by publishing a statement supporting the leadership's decision to go to war[62].

Despite the growing climate of fear and the risks involved, some Russian scientists and scholars have nonetheless publicly opposed the war. On 24. February around 7,750 Russian scientists and journalists posted an open letter that condemned Russia's invasion of Ukraine.[63] The letter warned of the catastrophic consequences of Russia's war in Ukraine for scientific enterprise and to the future of the country:

"Having unleashed the war, Russia has doomed itself to international isolation. It has devolved into a pariah country. This means that we, Russian scientists and journalists, will no longer be able to do our job in a normal way because conducting scientific research is unthinkable without cooperation and trust with colleagues from other countries. The isolation of Russia from the world means cultural and technological degradation of our country with a complete lack of positive prospects. The war with Ukraine is a step to nowhere."[64]

61 https://www.theguardian.com/world/2022/apr/02/no-hope-science-russia-academics-trying-flee-to-west?CMP=share_btn_link Accessed 19th April 2022.

62 https://www.rsr-online.ru/news/2022-god/obrashchenie-rossiyskogo-soyuza-rektorov1/ Accessed 19th April 2022.

63 https://www.nytimes.com/2022/03/12/science/physics-cern-russia.html Accessed 19th April 2022.

64 "Open letter of Russian scientists and science journalists against the war with Ukraine". "Troitsky Variant", 26.02.2022. https://web.archive.org/web/20220226224817/https://trv-science.ru/en/2022/02/we-are-against-war-en/ Accessed 19th April 2022.

7 Conclusions

Russia perceives technology as a basis for a country's sovereignty in the ongoing great power competition

The key Russian strategic documents suggest that Russia sees itself in the middle of an ongoing international struggle for technological supremacy. This perception is not generated in a vacuum but can be seen to reflect an increasing global emphasis on geoeconomic influence, technological sovereignty, and great power competition.

Russia seeks to increase its technological sovereignty by controlling "strategic sectors", developing domestic technology alternatives, and limiting the degree of foreign dependence in security-critical sectors. In Russia, commercial and strategic goals are intertwined through the principles of state control, sovereignty, and self-sufficiency. Despite the utilization of both market-oriented and state-led instruments in the execution of its STI strategy, this study suggests that Russian STI policy continues to be heavily characterized by the continued presence of state intervention, paternalistic steering, and a dirigiste mindset, which places fundamental limits on the growth potential of Russia's science, technology, and business innovations.

As a result, Russia's global competitiveness has slowed down, and is restricted by Russia's drive for self-sufficiency and domestic control. However, while these features are likely to be a hurdle in developing completely new emerging disruptive technologies, they can be helpful in "catching up" and in prioritizing certain fields of technological development. Indeed, this study notes that, from a Russian point of view, its centralized approach to STI policymaking provides a relative advantage in contrast to Western liberal democracies.

Russian STI policies rely on niche strategy—carefully selecting a few priority fields in which Russia can compete with the leading countries and pooling national resources together through a carefully managed, state-led planning process. This technocratic planning has had some successes, but in terms of the global impact on the state of the art in S&T, Russia has not been able to catch up with its great power rivals. On the contrary, Russia has been left behind. Whether one looks at the quality of science, international collaborations, or economic impact, Russia remains stagnated.

The difference compared to Russia's former "junior partner" China is particularly striking. While China has emerged as an engaged and influential global power in S&T, Russia seems content with a focus on its own traditional strengths. Moreover, while China has achieved global impact not just in terms of S&T but also in trade, market share, and standard setting, Russia focuses mostly on the development of nationally and regionally oriented solutions in the field of S&T.

In comparison to China, Russia is a "non-adopter", with only a limited engagement with the global S&T system. This is somewhat surprising considering Russia's size, potential, and capabilities in the field of STI. Russia's ability to succeed in the global great power competition with its strategy of "detachment" from the global S&T system is questionable.

Most likely, the backbone of Russia's great power status continues to be its military prowess, particularly its nuclear arsenal. Russia's great power aspirations are constrained by its political system, economic resources, and dependency on foreign technology. Especially in terms of economic power, Russia is not in the same league as the US, the EU, and China. A true (super)great power status would require a stronger economy built on diverse foundations.

Russian leadership interprets global technology trends from the point of view of security

Russia's national interests are shaped by its threat perceptions, both real and instrumental. Although the international shift toward multi-polarity provides Russia with various opportunities, Russian leadership has a somewhat pessimistic view of the global situation, mostly due to the accelerating great power competition and broader international instability.

Russian leadership tends to emphasize the immense potential and power of S&T to determine the fate of nations. Russia's strategic documents are characterized by the fear that this potential will be increasingly centralized to a few dominant actors in the field of STI, who are able to set international standards and shape global markets and trade, thus marginalizing Russia's international position.

For the Russian leadership, a scenario of stagnating domestic S&T would also mean that Russia would lose its technological sovereignty and be left to the global periphery of technological development. This increased dependence on the geopolitical interests of other states and a demotion to the position of a mere "donor" to the international pool of talent for advanced economies would critically threaten Russia's great power status. Somewhat paradoxically, there is a possibility that the repercussions from Russia's invasion of Ukraine might lead to this very scenario.

Given the combination of limited resources and the increasingly contested international environment, R&D funding continues to be geared towards sectors that matter the most in terms of national security and regime survival. This approach provides comparative advantages for the state but sets limits to the overall global diffusion, quality and impact of the Russia technology-ecosystem, especially in terms of commercial products. Moreover, Russia's aggressive foreign policy and the use of cyber coercion have hindered the global scaling of Russian tech products; a case in point is the US federal government ban on the products of the Kaspersky Lab.

The Russian state has securitized STI development through various means, such as legislation and restrictions. As a result, the potential for societal benefits of technology development is often eclipsed by an excessive concern for state interests, such as security and sovereignty. This can be seen for example in Russia's failed attempt to utilize its significant military-industrial sector as a driver for Russia's broader economic development. For the military–industrial complex to yield broader societal impacts, there would need to be an improved capacity to convert defense innovation to civilian uses. The securitization of technology works against this objective.

Russia is seeking to create an independent technology-ecosystem and techno-economic bloc

In terms of capabilities and resources, Russia has the scientific and technological expertise to achieve breakthroughs and competitive advantages in S&T, but only in limited areas. As a result, Russia seeks to sustain and develop internationally recognized leading positions in selected technological fields to have a more substantial impact while maintaining a "good enough" approach to technology R&D as a whole.

This study supports the conclusion that Russia is leveraging a "mission approach" to innovation, described by Ergas (1987) as "big science deployed to meet big problems." At the core of mission orientation is the concentration of R&D to selected areas of focus. Mission approach is reflected in Russia's emphasis on technology development in areas of relative advantage and cost-effectiveness. Russia aims to create asymmetric enablers and force multipliers to contest and disrupt Western and Chinese supremacy in global technology competition, both in civilian and military fields.

Russia is investing in globally recognized emerging technologies, such as quantum computing and AI, where Russia builds on a strong foundation of excellence in mathematics and physics. Interestingly, the Russian technology profile often focuses on fundamental and theoretical research in areas of relative strength, such as cryptography, AI, and nuclear science. However, it is important to note that the relative overrepresentation of theoretical research in areas closely related to national security, such as cryptography, can result from the high number of classified projects.

Despite the national security relevance of many of the aforementioned technologies, Russia has been collaborating with various countries in these areas. Germany and the broader European research sphere have been particularly important partners in both nuclear science and quantum computing, while cooperation with China is increasing in the field of emerging technologies, such as AI, ICT, and robotics. However, the Western sanctions regime will likely result in a broad S&T decoupling between Russia and the West for the foreseeable future.

Russian ambitions in technology development are constrained by various structural challenges

Russia has not been able to solve the structural problems within its National Innovation System. Indeed, while Russia's capacity in the field of STI should not be underestimated, it must be noted that in the absence of systemic reforms in terms of economic models and broader governance structures, Russia will not be able solve its long-term challenges.

Russia continues to suffer from the historical legacies of the USSR and the immediate post-Soviet period: corruption, insufficient property rights, and a weak rule of law. Moreover, the weak link between fundamental research and commercial actors, as well as the lack of demand from the private sector, have resulted in the inability to utilize Russia's relatively strong fundamental research capabilities and educational base.

Increasing authoritarianism and repression are driving out talented and educated young people who seek new and improved opportunities abroad. The acceleration of talent brain drain away from Russia can be seen as the result of globalization and Kremlin's failed authoritarian modernization efforts (Lassila 2019). Moreover, as a result of the war in Ukraine, both the brain drain and the perception of risk related to Russian business climate have further intensified and are likely to have substantial negative consequences for Russia's STI development.

Russia has sought to ensure its technological sovereignty through import substitution policies and investments in the domestic development of critical technologies, such as microprocessors. However, the overall drive to replace foreign technology with domestic alternatives will likely not succeed, because Russia does not have the required technological-industrial base, economic competitiveness, or market volume to "do it alone."

Indeed, in many areas of technology development, Russia is dependent on the capabilities, resources, and knowhow of its international partners. Because of Western sanctions, Russia has been increasingly advancing its S&T partnerships with major non-Western powers, primarily with China. Russia has been particularly interested in Chinese[65] investments, markets and technological expertise. However, technological integration with China will not happen on Russia's terms. Technological decoupling from the West will increase Russia's dependency on Chinese technology, which will endanger Russia's drive for self-sufficiency and sovereignty.

7.1 Implications to the EU and Finland

From the vantage point of Finland, the strengthening emphasis of technological sovereignty and great power competition globally—and in Russia particularly—is bad news. Rule-based, free market principles of the global economy are the basis of Finland's economic and technological success. Finland is a small trade-and technology-dependent country that embraces collaboration and requires a level playing field in both to succeed (Wigell et al. 2022).

In terms of security, Finland's relationship to Russia is characterized by the war in Ukraine, the increasing geopolitical tensions in Europe and in the Nordic region (Saari & Lavikainen 2022) as well as by the global context of geoeconomic competition (Wigell et al. 2022). With regards to Russia's invasion of Ukraine, "Finland firmly supports Ukraine's independence, sovereignty, self-determination and territorial integrity"[66] and stands behind the EU's restrictive measures against Russia.

Apart from the war, a particular worry related to the accelerating great power competition from the Finnish perspective is the potential "balkanization" or regionalization of global S&T development and trade (Wigell et al. 2022). In this sense, EU membership is a key factor in Finland's relationship to Russia. Finland is a small country with an open economy; which is sensitive to changes in the global economy. Therefore, it is in Finland's interests to act as a part of a larger multilateral effort (Helwig et al. 2020).

The Finnish scientific community has traditionally benefitted from collaboration with Russian universities and the science community; Russians are the biggest foreign national

65 In 2021 China and Russia cooperated in "China-Russia Year of Scientific and Technological Innovation" resulting in partnership around e.g. Nuclotron-based Ion Collider Facility (NICA) and to the creation of the Russian-China Mathematical Center. Refer to e.g. Press release by Ministry of Foreign Affairs, the People's Republic of China https://www.fmprc.gov.cn/mfa_eng/zxxx_662805/202111/t20211128_10454394.html Accessed 9.2.2022

66 https://valtioneuvosto.fi/en/ukraine Accessed 19th April 2022.

group in Finnish universities (Juusola et al. 2021). However, the implications for the future are not clear-cut. On the one hand, decreasing scientific collaboration with Russian institutions may reflect negatively on Finnish innovation potential, but on the other hand, tightening domestic control in Russia has already encouraged some professionals to seek opportunities abroad, including Finland.

Technological and scientific collaboration as well as business relations between the EU and Russia have suffered since 2014 due to restrictive measures imposed on Russia by the European Union in response to the Russian involvement in the war in Ukraine (European Council 2014), and the subsequent counter-sanctions by Russia. After Russia’s invasion of Ukraine in 2022, the new rounds of sanctions have targeted Russia’s dependencies in high-tech components, in particular semiconductros and microelectronics (Sanger & Schmitt 2022). This will hurt Russia’s S&T capabilities in addition to the significant increase in Russia’s dependency on China.

Russia’s growing efforts to integrate S&T capabilities with its geopolitical and military power also means that Russia is increasingly ready to utilize its innovations and technological edge in its subversive and hostile operations abroad. Russian interest in developing AI is not simply to gain international prestige but, essentially, to develop destructive weapons of the future. Further, it has milder but hostile applications in cyber and information technologies below the threshold of war. This has significant implications for the EU and Finland alike, which need to prepare for Russia’s high-tech coercion in policy planning and preparedness.

Appendix – Delphi process

The Delphi process was implemented as a two round survey focusing on the 15 statements identified during the previous stages of the research. The Stakeholder Saliance approach was utilized to understand what type of respondents would be essential for the Delphi process. In consultation with the project steering group, the project focused the survey to national experts on Russia, but also including selected experts globally to limit potential contextual biases.

In total 46 experts were invited to participate in the Delphi process. Each expert was carefully selected so that they would possess clear expertise on Russia. Moreover, a selected number of experts was required to have agency in decisions implemented in Finland. The invitations were sent on the 11.11.2021. In the personal invitation to take part in a expert opinion Delphi-process on Russia's current technological knowhow the experts were told that they would be evaluating the effectiveness of Russia's science, technology and innovation policies & strategies. The respondents also received information that the project is funded by the Finnish government's analysis, assessment and research activities, implemented by VTT Technical Research Centre of Finland, Finnish Institute of International Affairs, and the Aleksanteri Institute at the University of Helsinki

The invitation emphasized the fact that geopolitics of technology has become the center stage in policy and business. Understanding the science and technology capabilities of nations is central to the analysis of the evolving great power competition. The Russian Federation has been active in the field of science and technology policy. Russia has adopted a wealth of governmental strategies, programmes and plans for technological development. As a result, a renewed national science, technology and innovation (STI) infrastructure has been set up together with national funds for investment in STI as well as technology parks and business incubators for R&D.

The letter also highlighted the fact that simultaneously with Russia's progress, the global technological competition has become increasingly fierce and geopolitical in nature. These changes have increased the importance of evaluating the aims of Russia's technology policy, the competitiveness of Russian technology knowhow as well as the geopolitical implications therein for both Europe and Finland.

As a procedural observation, the experts were told that the Delphi approach is reliant on candid expert comments and debate on Delphi statements derived from the projects findings. Delphi was described as a wellknown participatory innovation research method that aims to have an anonymous and facilitated discussion between experts on a specific topic. In Delphi, experts are presented with arguments during two or more rounds. Between the rounds the moderator synthesizes results from the previous round and offers the results for comments and debate in the subsequent round.

Experts were told that the study will consists of two rounds. The first round consists of 15 arguments where the experts are asked to give a five point Likert scale response of agreement, from strongly disagree to strongly agree, with the argument. The experts were also asked to justify each Likert response with an open-ended response. For the second round, the experts were told that they would receive a summary of the Likert scale responses and a narrative based on comments received for each question. During the second round, experts were invited to re-evaluate their Likert scale responses and comment on the statement-specific narratives prepared ans synthetized by the moderatior. The open-ended comments are central to the debate during the second round, so the project team emphasized the importance of spending some time in explaining the opinions.

The guidance provided to the experts emphasized that all gathered information is treated confidentially. Only aggregated results, which do not disclose any individual experts, are reported between the rounds as well as in the final reporting

For the first round, after three reminders in two weeks time, a total of 22 experts (47,8 percent) responded. After creating the synopsis and aggregated results, the second round of comments were sent to the 22 experts on the 9.12.2021. After three reminders this round closed on the 22.12.2021. In total, 18 experts participated in the second round.

Appendix – Round 2 results

	Stronly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree	N	Consensus
The science and technology (S&T) collaboration between Russia and the EU continues to develop in a positive way through avenues such as science diplomacy and scientific cooperation.	0 %	83 %	11 %	6 %	0 %	18	No
As a result of Russia's growing technological dependence on world leaders, the Kremlin will most likely intensify the strategic partnership with China in order to develop its S&T capabilities.	0 %	11 %	17 %	67 %	6 %	18	No
Because of federal budget constraints and the unwillingness of the private sector to invest in research, the overall funding and impact of R&D in Russia will not improve.	0 %	11 %	33 %	56 %	0 %	18	No
Russia is unable to utilize the potential of ICT technologies for the improvement of labour productivity.	0 %	50 %	22 %	28 %	0 %	18	No
Russia's historical inability to sustain and utilize its technological innovations for broad societal benefits stems from a technocratic approach to innovation policy and the resulting lack of entrepreneurial culture.	0 %	33 %	17 %	39 %	11 %	18	No
Russia uses its innovation capability first and foremost as a geoeconomic tool in order to shape the international environment. Any other considerations, such as scientific impact or economic competitiveness are subordinated to this mode of governance.	11 %	17 %	33 %	39 %	0 %	18	No
Russian efforts in R&D will continue to be significantly driven by national security considerations.	0 %	0 %	0 %	67 %	33 %	18	Yes, positive
Russia will invest considerable resources and effort to the creation of its own technology-ecosystem and techno-economic bloc in order to preserve its technological sovereignty and great power status.	0 %	6 %	0 %	56 %	39 %	18	Yes, positive
Russia has the necessary science and technological know-how to create its own tech-ecosystems as well as converging physical, digital and biological capabilities to ensure its great power status.	0 %	44 %	33 %	22 %	0 %	18	No

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