Russian S&T Foresight 2030: identifying new drivers of growth

Leonid Gokhberg, Alexander Sokolov and Alexander Chulok

Abstract

Purpose – *The purpose of this paper is to present the results of the recent Russian Science and Technology Foresight – a full-fledged study targeted at the identification of the most promising areas of science and technology (S&T) development in Russia towards 2030 to ensure the realisation of the nation's competitive advantages. It was organised as a complex project involving dozens of organizations performing particular tasks under the overall coordination by the National Research University Higher School of Economics (HSE) and more than 2,000 experts in various S&T fields.*

Design/methodology/approach – *Its methodology embraced a set of qualitative and quantitative methods and combined technology push and market pool approaches. For seven S&T areas (information and communication technologies, biotechnologies, medicine and health, new materials and nanotechnologies, rational use of nature, transportation and space systems, energy efficiency and energy saving), the following types of results have been obtained: global trends, national challenges and windows of opportunities; new markets and niches; innovation products and services; prospective technologies and R&D fields (50 thematic groups, over 1,000 items for all areas); assessment of the country's positions* vis-à-vis *global leaders; recommendations for S&T and innovation policies.*

Findings – *The paper covers prospective drivers of economic growth and relevant implications for anticipatory evidence-based policy; discussions of national challenges and building a common vision of the future among key stakeholders; the role of Foresight in particular as a communication platform that helps integrating stakeholder interests; strengthening existing and developing new capacities to increase national competitiveness; and to move up along existing and emerging global value chains.*

Originality/value – *The Russian S&T Foresight, being deeply integrated in the national policy, can be considered as an exemplar tool for "wiring up" the national innovation system (NIS) of an emerging economy with its specific features and problems facing large-scale challenges.*

Keywords *Foresight, Russia, Grand challenges, Science and technology*

Paper type *Research paper*

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1. Introduction

Over the past decade, both developed and emerging economies have faced a number of challenges that can hardly be responded with traditional policy instruments. Science and technology (S&T) and innovation, being a key driver of socio-economic development, in particular requires smart, well-informed and transparent policies aimed at fostering competitive advantages under conditions of emerging new markets, breakthrough technologies and alternative business models, consequent dramatic changes in the composition of global value chains and gradually fading traditional businesses. Using S&T Foresight as a tool for anticipatory evidence-based polices has been a major trend in both development and emerging economies across the world during the recent decades (Meissner *et al.*, 2013; Gokhberg *et al.*, 2016; Miles *et al.*, 2017). It is used to shape S&T and innovation policies, particularly by setting priorities for allocating R&D funding, designing appropriate institutional frameworks and economic mechanisms and making better informed strategic decisions in the light of those priorities. Obviously, in identifying the priorities and establishing criteria for their selection, one must keep in mind the "big

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picture" of the future, grand challenges and allied major windows of opportunity, technological wild cards and the available S&T capacities. Such a level of complexity requires use of Foresight at the national level with the involvement of key stakeholders and experts representing all S&T areas, as well as the sectors of the economy (Zweck *et al.*, 2014).

Most of national and large-scale sectoral Foresight studies are based on the analysis of global challenges across key S&T areas (Cagnin *et al.*, 2012). Those challenges are usually classified and analysed with respect to their effects on particular S&T areas. For example, in the 10th Japanese S&T Foresight, the challenges are addressed for such areas as ICT and analytics; health, medical care and life sciences; agriculture, forestry and fisheries, food and biotechnology; space, ocean, earth and science infrastructure; environment, resources and energy; material, device and process; social infrastructure; and service-oriented society (Ogasawara, 2015).

A series of Foresight studies in the UK also started from the identification of global trends and challenges. Thus, the Future of Food and Farming study addresses the following issues: balancing future demand and supply sustainably; the threat of future volatility in the food system; ending hunger; meeting the challenges of a low emissions world; maintaining biodiversity and ecosystem services while feeding the world (UK Government Office for Science, 2011).

The EU Horizon 2020 Programme has been focused on a number of grand challenges, such as health, demographic change and wellbeing; food security, sustainable agriculture and forestry; secure, clean and efficient energy; smart, green and integrated transport; climate action, environment, resource efficiency and raw materials; inclusive, innovative and reflective societies; and secure societies (European Commission, 2013).

The Korean National S&T Foresight (Hwang *et al.*, 2011) considered a bit different list of global challenges: international economic order, problems of energy/resources/environment, S&T development and acceleration of fusion, change of population structure and new security issues.

The Chinese National Road Map-2050 identified eight key systems driving social and economic development of the nation: system of sustainable energy and resources; green system of advanced materials and intelligent manufacturing; system of ubiquitous information networking; system of ecological and high-value agriculture and biological industry; generally applicable health assurance system; development system of ecological and environmental conservation; expanded system of space and ocean exploration capability; and national and public security system (Lu, 2010).

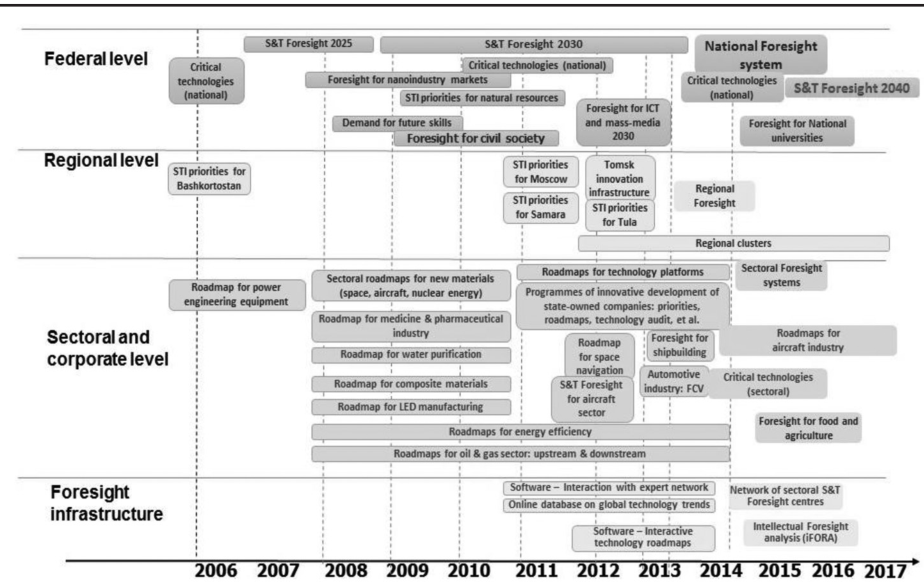
A number of Foresight studies in the field of S&T and innovation have been performed in BRICS countries (Cagnin, 2014; CAS, 2010; Kahn, 2008). Agendas of those studies have very much in common: they aim at formulating S&T and innovation policies and foster efficiency of the national innovation systems on the basis of new technologies. They usually propose long-term S&T priorities focused on both societal development and future economic growth; describe the opportunities for entering prospective markets while creating new ones; and present guidelines for technological modernisation of the economy sectors and generation of much-needed skilled and competent labour force for these transforming systems.

The aforementioned national and international practices have significant importance for the development of the Russian innovation system, which needs to bridge the gap between R&D and business historically inherited from the former Soviet Union (Gokhberg and Kuznetsova, 2011). In the past decade, S&T and innovation policies in Russia have undergone significant changes primarily related to reshaping the network of R&D-performing organizations, institutional framework and policy toolkit. An ambitious goal of achieving sustainable economic growth rates and higher living standards for the population cannot be implemented within the framework of the current resource-based growth model which is prone to exhaust itself. A twofold objective will have to be accomplished, which requires both interventions on global high-technology markets and modernisation of traditional economy sectors. Obviously, the country's future positions in the global value chains largely depend on the ability of its economy to successfully fit into the new wave of technological change. This, in turn, requires concentrated efforts by all key actors in business, R&D, education, government and the whole society.

Russia has witnessed a significant growth in the number of Foresight studies during the past decade (see Figure 1). The first large-scale study at the national level was the S&T Foresight 2025, which was initiated in 2007 by the Russian Ministry of Education and Science. It included a macroeconomic forecast for the Russian economy; a Foresight study for priority S&T areas and several sectors of the national economy (Chulok, 2009; Gokhberg and Sokolov, 2017). The second cycle of the national S&T Foresight (2008-2009) was devoted to the future of the global economy and major markets. While at first, the initiatives came mostly from the top level – i.e. government, sectoral public agencies and development institutions, later on, enhanced activities have been witnessed at the regional level – mainly in industrially developed regions with major S&T capacities, such as the city of Moscow, Yekaterinburg, Samara, Tomsk and several other regions. Industrial agencies and large companies increasingly initiate Foresight studies while developing their long-term strategies (Dekhtyaruk *et al.*, 2014). This process has its outcome in gradual dissemination of Foresight culture and its penetration at various levels of decision-making – national, regional, industrial and corporate. The accumulation of a "critical mass" of Foresight activities in Russia has led to a demand for establishing a more comprehensive and coordinated system of technology Foresight.

The fully fledged S&T Foresight-2030 was initiated by the Ministry of Education and Science at the request of the Government of the Russian Federation in 2011. Its goal was to identify the most promising areas of S&T development in Russia towards 2030 to ensure the

Figure 1 Rapid growth of Foresight studies at all levels creates a platform for a nation-wide S&T Foresight system



Source: Authors analysis

implementation of the nation's competitive advantages (Sokolov and Chulok, 2016). It was organised as a large-scale project involving dozens of organizations specialized in various fields of S&T and industries under the overall coordination by the National Research University Higher School of Economics (HSE).

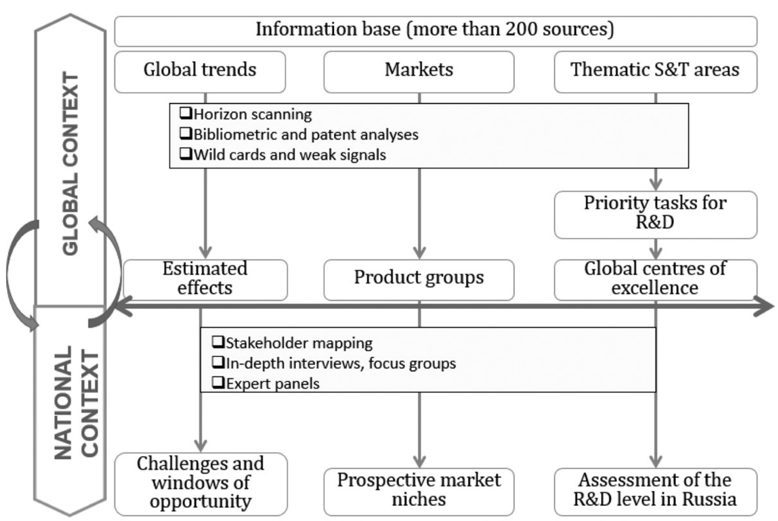
The starting point for this study was to consider global challenges affecting competitive positions of the national economy and its S&T establishment in particular. Bibliometric and semantic analysis, as well as expert discussions, allowed to highlight five groups of such challenges, namely, climate change and use of natural resources, emergence of a new S&T paradigm, new models of economic development, socio-cultural transformations and urbanization and rise of megacities. Many commonly discussed policy issues, such as cybersecurity, energy and water supply, health, industrial competitiveness, etc., strongly depend on the national R&D capacities as a basis for integrated and interdisciplinary solutions in response to grand challenges (European Commission, 2010; Miles, 2012). In this respect, R&D is expected to provide an immense contribution in a number of areas, for instance, for the purpose of the depletion of strategic mineral resources, discovery of alternative energy sources and ensuring energy security, tackling with the ageing society and changing lifestyles, fighting against diseases and creation of a "green economy" towards a "post-carbon" society.

2. Methodology

The methodology applied in the S&T Foresight-2030 combined both "traditional" instruments widely applied in international practices and novel tools that were developed to address particular issues specific for the study. One of the major methodological problems was to find a proper balance between long-term challenges to be addressed and available resources required to respond to these challenges. A combination of "market pull" and "technology push" approaches was used to choose R&D areas that would be required for developing relevant "technology packages" and innovative products/services with a promise of major economic and social effects (Figure 2).

The project engaged prominent Russian and international scholars, businessmen, government officials. Over 3,000 participants were involved in field-specific interviews and surveys, while some 150 prominent experts composed seven thematic panels devoted to

Figure 2 Methodology of Russian S&T Foresight-2030



Source: Gokhberg (2016)

broad priority S&T areas. These thematic panels intensively operated during the whole period of project implementation.

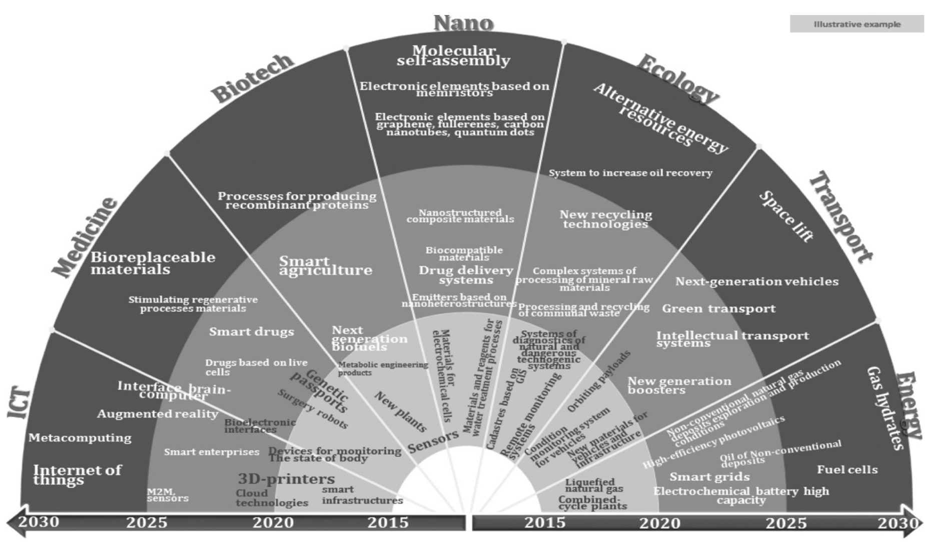
The Foresight process was organized in several stages (for details, see Sokolov and Chulok, 2012; Sokolov and Chulok, 2016).

- The first stage was aimed at analysing over 200 analytical reports, strategic documents and results of earlier Foresight studies. Along with bibliometric and patent analyses, it allowed to draft a list of 150 global S&T, socio-economic and political trends and to assess their potential effects and timing of maximal impacts.
- Subsequently, trends were selected that could create windows of opportunity and threats for Russia for further more in-depth analysis.
- More than 80 promising innovative markets and over 250 relevant prospective product groups were identified and described (including their technological and consumer properties). These formed a pool for identification of prospective market niches for domestic technologies.
- The expert panels identified over 50 priority thematic S&T areas and more than 1,000 key R&D tasks to be addressed by the public S&T programme.
- In the next step, global centres of competence for each S&T area were identified, and leading Russian research units were benchmarked against the global leaders.
- The final recommendations for policy-makers were based on a wide consultation with different national innovation system (NIS) actors and covered three major aspects: markets, technologies and governance. A dialogue with various beneficiary groups allowed not just to define promising S&T areas, but also to understand potential policy tools for their future priority promotion.

3. Results

The Foresight study identifies future-oriented S&T areas and results to be achieved, which may serve as drivers of economic competitiveness and potential Russia's "entry points" to global value chains to increase its niches in global markets (see Figure 3).

Figure 3 Prospective innovative products and breakthrough technologies



Source: Gokhberg (2016)

The study has also revealed a number of "white spots" where domestic S&T is significantly lagging behind the world leaders. The results of the S&T Foresight-2030 were mentioned in the annual Presidential Address to the Federal Assembly[1]. A high-level Interdepartmental Commission on Technology Foresight established in April 2013 was headed by the Minister of Education and Science and included top-level officials from government agencies, heads of large high-tech companies and leading research centres and universities. It has been playing an important role in establishing and promoting the overall national S&T Foresight system. The S&T Foresight-2030 recommendations were discussed at the commission meetings with a focus on their wide dissemination and implementation. Furthermore, this study was listed by the OECD amongst six recent national and international Foresight exercises for the purpose of mapping emerging technologies for the future (OECD, 2016).

The S&T Foresight-2030 covered seven S&T priority areas, namely:

1. information and communication technologies;
2. biotechnology;
3. medicine and health;
4. new materials and nanotechnologies;
5. rational use of nature;
6. transportation and space systems; and
7. energy efficiency and energy saving.

The main issues for each of these seven S&T areas are described below.

3.1 Information and communication technologies

Information and communication technologies (ICTs), being a principal vehicle of economic development worldwide, have been penetrating all areas of human activities. Introduction of new ICT platforms leads to radical transformation of different industries and sectors. Advanced manufacturing technologies (robotics, additive technologies, etc.) shift added value creation from material production to engineering and design. New ICT-based business models (such as Uber, Airbnb or Alibaba) disrupt whole sectors of services. E-government, online university courses (Coursera), emerging applications of blockchain technologies are re-establishing backgrounds of public sector. ICTs create new forms of employment, help disabled people become more engaged in working and social life.

The fast dynamics of the ICT sector require adequate pace of development from relevant research fields which become increasingly important. The expert panel established for this R&D area identified the following areas of applied research, which have the greatest capacities to contribute to the country's socio-economic development:

- telecommunication technologies;
- data processing and analysis technologies;
- hardware components, electronic devices and robotics;
- predictive modelling and simulation;
- algorithms and software;
- information security; and
- computer architecture and systems.

The results which can be obtained before 2030 include prototype systems based on new computational principles; prototype multilanguage programming systems for knowledge extraction and formalisation; data processing technologies to tackle Big Data; and next-generation business intelligence with new analytical tools, including personal analytical systems, tools for real-time data processing, mobile analysis, etc.

The highest market growth rates for the aforementioned S&T products are expected to be in health, power engineering, mechanical engineering, transport and in personal consumption of ICT products and services. In the medium term (before 2020), the experts expect introduction of electronic health passports, emergence of distributed networks of telemedicine centres, development of quality control and safety system for drugs and medical services. By 2025, medical micro-devices are expected to emerge, implanted into the body to support its vital functions; technologies for exchanging standardised data between transport vehicles; universal global positioning and identification techniques within the framework of the "Internet of Things" concept; promising platforms for collecting, summarising and presenting the content and knowledge. Inbuilt digital devices and relevant software will be integrated into mechanical engineering products.

Evolution of cloud computing and the development of new architectures and computational principles lead to transformation of software and may bring radical changes in business strategies of companies operating in all sectors of the economy. A colossal growth of data volumes available for analysis provides a foundation for a radical increase of efficiency of managerial decisions, including in the analytical business applications segment (business intelligence).

Russia occupies advanced position in few ICT areas like "New data transfer, networking, and content distribution technologies"; however, in general, it lags behind global leaders in most fields, in particular in "Computer-aided element base design technologies", "New data transfer technologies" and "Digital reality technologies and systems, prospective human-ICT interfaces".

3.2 Biotechnology

Biotechnology, along with ICT, serves a technological platform for creating breakthrough products to heal, fuel and feed the world. Biotech-based diagnostics tools, health products and vaccines help to combat diseases earlier untreatable ones. Agricultural biotechnology already helps to feed the hungry via increasing yields, prevent damage from insects and pests, thus reducing environmental footprint. Modern biorefineries produce biofuels and chemicals from renewable biomass, thus reducing greenhouse gas emission. Industrial biotechnology contributes to making manufacturing processes cleaner, safer and more efficient, decreasing use of water and waste generation.

In the study, the following most promising research areas with a multifold effect for the national economy were identified:

- development of the scientific and methodological basis of biotech R&D;
- industrial biotechnology;
- agrobiotechnology;
- environmental biotechnology;
- food biotechnology;
- forest biotechnology; and
- aqua biotechnology.

Amongst others, application areas of biotech are highlighted as the diversification of the energy sources, use of biomaterials for intensification of production processes, e.g. in chemical industry, waste treatment and disposal, preservation of nature and reducing environmental pollution, producing new varieties of agricultural plants and new breeds of animals with improved properties.

At the same time, achieving the above-mentioned effects and securing a meaningful niche on promising emerging markets require a radical improvement of domestic technological capacities and skills, which are quite uneven yet. The most advanced areas of applied research identified in the study include "High-performance techniques for genome, transcriptome, proteome, and metabolome analysis"; "Systematic and structural biology"; and "Microorganism strains and microbe consortia for creating symbiotic plant-microbial communities". On the other hand, in a number of other areas, such as "Biotechnological processes for making biomaterials, fine and mainline organic synthesis products from renewable raw materials", "Techniques for building genetic databases of plant varieties and seed certification" and "Environmentally safe biocides", Russia still has to catch up global leaders.

3.3 Medicine and health

Russia is still rather far from the leading countries in the quality of its health system (Tandon *et al.*, 2000). Therefore, its improvement is one of major priorities of the government. Increasing life expectance and prolonging time-span of healthy life can be considered as a challenge for any country. The most promising fields of R&D identified within the study included the following:

- molecular diagnostics;
- molecular profiling and identification of molecular and cellular pathogenesis mechanisms.
- biomedical cell technologies;
- biocomposite materials for medical application;
- bio-electrodynamics and radiation medicine;
- genomic passportisation of humans; and
- discovery of candidate drugs.

Main problems to be addressed in this area include spread of oncological, cardiovascular, infectious, deficiency diseases and brain pathologies leading to increased level of morbidity and mortality caused by them. It creates a demand for innovative products based on new technologies. It refers to numerous applications, such as: personalised and "home" medicine; "smart" medicine; bio-electric interfaces; non-invasive diagnostics epigenetic methods and many others.

Around half of new drugs available on the global markets have pharmacogenetic properties. Regenerative medicine technology is a major area of modern R&D, which is expected to be used for treating brain, locomotorium, oncological and many other diseases. The leading countries of the world have already achieved promising results in human organs regeneration, while Russia has yet made very modest progress in this area.

Best chances for Russia to achieve sound research and practical results refer to such fields as: "Biocompatible biopolymeric materials"; "Self-sterilising coatings for medical applications"; "Testing systems based on genomic and postgenomic technologies, for diagnosing cancer, system, infectious and hereditary diseases"; "Biosensors and biochips for clinical diagnostics, based on new types of biological devices"; and "Techniques for fast identification of toxic substances and pathogens".

Successes achieved in innovative pharmaceutics – biotechnologies, synthetic biology, targeted therapeutic effects, production of advanced effective vaccines – would allow national companies to enter promising global markets and to raise citizens' quality of life.

In a number of areas, such as "Gradient ceramics-based biodegradable materials" and "Medical textile with unique therapeutic properties", Russia has already a great potential.

Further advancement of future-oriented research and securing advantages would require development of existing and establishing new translation medicine centres, first of all to develop advanced pre-clinical technologies.

3.4 New materials and nanotechnologies

Changes in the present image of the economy and society are strongly linked to a widespread application of new materials and nanotechnologies in manufacturing and the service sectors. It is related to the increasing deficit of cheap raw materials used for mass production, stricter environmental standards for products and the role new materials play in rapidly developing advanced manufacturing systems.

The promising fields of applied research include the following ones:

- structural and functional materials;
- hybrid materials, converging technologies, biomimetic materials and medical supplies;
- diagnostics of materials; and
- computer simulation of materials and processes.

Such areas as nanoelectronics, photonics, nanobiotechnology and nanoelectromechanical systems have already proved their potential and are expected in the near future to bring significant effects in a number of sectors of economy. Other promising application areas are medicine and health where new materials are used in medical products, equipment, neuroelectronic interfaces, etc. Convergence of nano-, info-, bio- and cognitive technologies has also a great potential for many applications both in industrial sectors and in enhancing human health, physical and mental capacities of people; "desktop nanofactories" will be able to assemble objects at nano- and even atom-scale.

New materials will play a key role in the development of a wide range of other technologies, such as development of hybrid (organic and non-organic) structures, synthetic components for live tissues; nanocomposites ensuring unique strength, elasticity and conductivity of new materials (in particular for alternative power engineering); mathematical modelling of nanomaterials' properties; etc. Nanomaterials will contribute to reducing environmental footprint and responding increasing safety requirements to many consumer goods (from food and drugs to buildings and infrastructure, water treatment, medical diagnostics and many others).

There are a number of application areas and promising markets for nanotechnologies and new materials, such as lighting equipment, sports, textile industry (in the short term) and automobile and aerospace industries, shipbuilding, mining and processing equipment, pharmaceutical and medical equipment, power engineering, food industry and construction (in a longer term).

Unlike most of the other priority areas for research covered in the study, the level of R&D in nanotechnology and new materials in Russia is assessed as quite high, particularly in such fields as "Nano-size catalysts for deep processing of raw materials" and "Nano-structured membrane materials". However, there are also a number of "white spots", such as "Construction materials for power engineering", where it is lagging behind the leading countries.

3.5 Rational use of nature

Environmentally friendly technologies that have been rapidly improving during the past decades create a disruptive effect on energy production and traditional sectors of economy, where new, more efficient products, such as photovoltaic batteries, with lesser environmental footprint increasingly replace obsolete existing ones. Therefore, lagging behind in relevant technology areas means risks of the loss of competitiveness.

Depletion of some easy-to-extract critical natural resources, which constitute a significant part of national export and the main source of the budget income, is amongst the crucial issues for the Russian economy. On top of that, increasingly important become environment-related issues: climate change; growing anthropogenic pressure and pollution of natural environments; loss of biodiversity; etc. Future-oriented research certainly plays a major role in providing systemic and integrated responses to these challenges.

The following five promising thematic fields for applied research under the “Rational use of nature” priority area were considered in the study:

- environmental protection and safety technologies;
- monitoring of environment, assessment and forecasting of natural and technogenic emergencies;
- rational use of natural resources;
- exploration of subsoil assets, mineral prospecting and integrated development of mineral and hydrocarbon resources; and
- exploration and utilisation of oceanic resources, the Arctic and Antarctic.

Results to be achieved in the long term include systems for environmental monitoring, assessing and forecasting natural and anthropogenic emergencies; exploration and integrated development of mineral resources; highly efficient and safe techniques for marine prospecting and mining of hydrocarbons under extreme natural and climatic conditions. Relevant technologies would provide a more efficient utilisation of mineral resources and their reproduction; decreasing the level of environmental pollution; and minimising damage caused by natural and anthropogenic emergencies.

Gradual transformation of environmental technologies from a cost item into a revenue-generating factor contributing to increasing the investments flow and entering new markets have become a significant trend in recent years. In the medium term, the following application areas for these technologies will have the highest growth rates: environmentally clean materials and products; software and geoinformation systems; equipment and materials for increasing efficiency of mining and processing of minerals; systems for early detection and forecasting natural and anthropogenic emergencies. In the longer term, a significant growth is envisaged in water treatment and recycling markets; environmentally safe waste disposal; secondary raw materials and finished products made by recycling waste and drainage; and related equipment.

The need for future-oriented research in the rational use of nature area is due not just to the opportunities to secure significant shares of the above promising markets, but also because of the threat to lose current country’s positions in the traditional segments – as a consequence of continuous toughening of international environmental-related standards for product quality and for technologies used for their production.

3.6 Transportation and space systems

Development of accessible, affordable, safe, speedy and predictable transport links, both on regional and international levels is of particular importance for Russia with its huge territories. Improvement of transport communications will bring about the “space compression” effect – i.e. distances between locations would seem much shorter to consumers of transport services. Achieving that kind of socio-economic effect involves various applied studies across the whole transportation complex, including aviation and space. The key research areas considered in S&T Foresight-2030 were as follows:

- models of transport-economic balance and smart transportation systems with the use of supercomputing resources at the exaflop level;

- new materials and technologies for construction and operation of transport infrastructure in the Arctic and sub-Arctic areas;
- technologies to reduce the harmful impact of transport on the environment;
- technologies to ensure safe travel in difficult conditions;
- small spacecraft clusters;
- aircrafts and spacecrafts for launching suborbital small satellites;
- systems for wireless energy transmission to transport and space equipment;
- systems of autonomous landing of aircrafts and landing space vehicles and autonomous navigation of land and water vehicles;
- extra-long flexible elements for static and dynamic space tether systems; and
- materials for the extreme conditions of space flights, high-speed travel in terrestrial and aquatic environments.

A means for improving transport planning – by creating transport-economic balance and applying advanced modelling techniques; increasing accessibility and quality of services; speed, reliability and safety of transport; and organisation of high-speed transportation to increase people's mobility are principal challenges to be responded by new-generation transport technologies.

An efficient modern transportation complex can become a "locomotive" of the national economy and promote the country's innovation-based development; however, it requires significant financial resources, which cannot be fully budget funded. Therefore, the key economic problem for the transport sector is increasing its investment attractiveness – which can be achieved by reducing costs, increasing efficiency of construction and maintenance of infrastructure and increasing productivity.

At the same time, innovative domestic products could compete in international high-tech markets. The highest growth rates in the medium term are envisaged for smart transportation systems and new management systems, as well as for environmentally safe and energy-efficient transport vehicles. Particular attention should be paid to markets with long-term expected growth rates, such as multimodal passenger and freight transportation and logistics systems; new materials and technologies for transport construction; prospective transport vehicles and systems; and space services.

Among the R&D fields with highest domestic competitive advantages are: "Development of research models to study transport situation in the Arctic and subarctic areas", "Development of air- and spacecraft to launch suborbital small-size space satellites", as well as several other topics related to new-generation carrier rockets and spacecrafts, innovative transportation vehicles and systems for marine and air transport. Still, this is by no means an exhaustive list of priority S&T development areas matching the anticipated dynamics of global markets.

3.7 Energy efficiency and energy saving

The energy sector plays an important role in the leading export positions and its contribution to sustaining the national economy. Recent changes in the basic energy technologies (smart grids, fracture for extracting shale oil and gas, smart houses, etc.) directly influence the cost of exported fossil energy resources, thus decreasing government budget revenues. Another important trend relates to the role of energy in providing the quality of the environment and sustainable development. A long investment cycle of new energy technologies, their high costs require careful long-term anticipation of future developments in this area and supporting relevant research areas. In addition, practically in every case, there are several possible S&T development areas to pursue, and a wrong or non-optimal choice can result in major losses and increased lagging behind the leading economies. Accordingly, identifying long-term global energy trends and conducting relevant future-oriented research become particularly important. The following essential areas of research were considered in the framework of the Foresight study:

- safe nuclear power engineering;
- efficient exploration and mining of fossil fuels;
- efficient utilisation of renewable energy sources;
- efficient and environmentally clean heat and power engineering;
- prospective bioenergy;
- efficient storage of electric and thermal energy;
- efficient transportation of fuel and energy;
- modelling prospective power-generation technologies and systems;
- new materials and catalysts for power engineering of the future;
- efficient energy consumption;
- development of advanced electronic component base for power engineering;
- smart power-generation systems of the future;
- hydrogen power; and
- deep processing of organic fuels.

Regarding fossil fuel production, the most significant R&D areas are: remotely controlled robotic installations for submarine and subterranean hydrocarbon production with prolonged automated operation periods; technologies for efficient hydrocarbon production at nonconventional sites (including gas hydrates, oil sands, extra-heavy crude oil, shale gas, coal strata gas); and under anomalous conditions (dense formations, abnormally high pressure, ultra-deep horizons, large depths, low volume density of resources, etc.). The most promising upstream technologies include: deep processing of off-grade resources of natural gas and low-quality coal; production of competitive motor fuels and chemical products.

A clear trend in heat and power engineering is the development of materials and technologies for manufacturing highly flexible high-power gas-turbine installations with maximum efficiency factor and minimum pollutant emissions, which in the future are going to become the foundation of major energy industry. Also, under way is active research of fast reactors' safety and safe closed nuclear cycle – an important element of centralised electric energy supply. Future development of low-power energy installations is connected with the production of low-temperature fuel cells with extremely high efficiency factor and long service life, without specific requirements to fuel quality, and low production and maintenance costs.

4. Conclusions

The results of the S&T Foresight-2030 have been widely discussed at regular high-level expert panels, series of national and international conferences and workshops. The dissemination of results included numerous presentations at the sites of federal and regional authorities, development institutions, business associations, companies, technology platforms, innovative regional clusters, domestic and foreign universities and research centres and international organisations.

Amongst the beneficiaries of the Foresight results are the government agencies in charge of formulation and implementation of S&T and innovation policies; large state-owned and private corporations dealing with high tech; development institutes supporting innovations; regional authorities working out regional innovation strategies; and developing innovation territorial clusters. The project communication platform included the internet portal, dozens of conferences and expert workshops. The wide dissemination of the S&T Foresight outputs allowed the research community for better navigation in the broad spectrum of promising R&D areas and their potential applications, as well as promoting results of their research amongst companies, which, in their turn, used the project results to formulate innovation strategies and validate investments in technological modernisation.

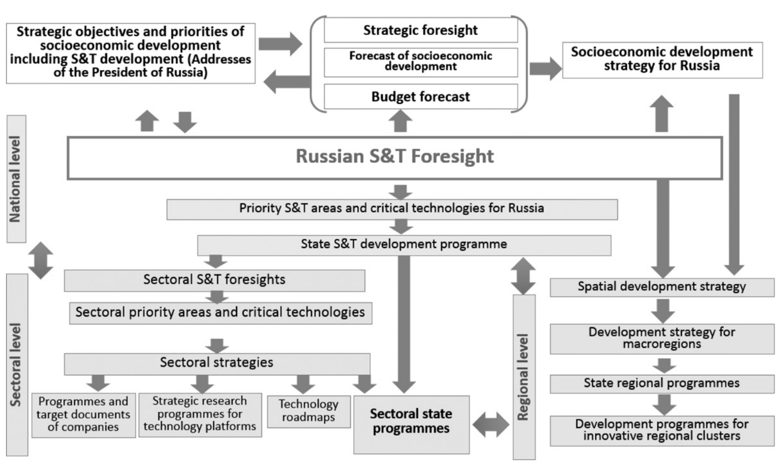
Practical implementation of Foresight results and their influence on the decision-making processes reflect the impact of the study. The tools for practical use of the results achieved include development of detailed technology roadmaps, lists of S&T fields to be funded through government programmes and a set of policy recommendations at different levels. To some extent, the Foresight study has played the role of a pacemaker for building up reflexivity in the policy-making system (in a sense elaborated by Havas *et al*., 2010)

As shown above, the S&T Foresight-2030 has been implemented as a kind of a "rolling exercise" to a great extent based on the previously performed projects. In its turn, it initiated wide discussions of Foresight-related issues amongst various stakeholders, which promoted the idea of establishing a permanent national system of S&T Foresight.

Actions made at the federal level create a solid background for initiating new rounds of S&T Foresight and building linkages between this activity and Foresight studies implemented by different players at the federal, sectoral, regional and corporate levels. A federal law "On Strategic Planning in the Russian Federation", adopted after the completion of S&T Foresight-2030, determined hierarchy and structure of principal documents of national long-term strategic planning. It identified the place of S&T Foresight in this system at the federal and sectoral levels and constituted its role as one of the major components of the overall national strategic planning system along with similar exercises on socio-economic development (Figure 4). The law sets basic requirements to the system, responsibilities of the parties involved, information and regulation provisions, procedures to control and monitor the implementation of the strategic documents.

Foresight exposes the potential of S&T to respond to the grand challenges, which the society and economy are expected to face in the medium to long term. The results of the

Figure 4 Russian S&T Foresight in the strategic planning system



Source: Authors analysis

study are used in setting priorities for allocating R&D funds, with a focus on bridging the gap between R&D and market applications.

Setting long-term priorities for S&T and innovation creates a foundation for future economic growth. It determines the opportunities for entering prospective markets while creating new ones and provides a basis for technological modernisation of various sectors of the economy and for generating much-needed skilled and competent labour force.

The modern trends in S&T Foresight studies, which are witnessed in many countries, reflect gradual "incorporation" of Foresight into the S&T policy. Russia, which has been increasing the scale of its forward-looking activities, to fully exploit the capacity of S&T Foresight has to take into account two major dimensions. First, establishing of closer cooperation between key stakeholders is of crucial importance for wiring-up the national system of forward-looking activities. It should be targeted at involvement of different government agencies and large companies in the process of building long-term visions and developing shared and coordinated policies and sets of actions. The second dimension is related to engagement of key experts (both Russian and international) from particular research areas and sectors of economy. All this will allow the transformation of Foresight into a more efficient S&T and innovation policy instrument, oriented towards a longer-term prospective.

The identified and analysed global trends in the seven priority areas of S&T development are becoming increasingly important for drawing up S&T and innovation policy and for identifying the promising markets and product groups in the interest of companies of the real sector of the economy. Trends in various S&T areas are often closely interconnected, which means that, in the future, the most successful technologies can be widely diffused and have large indirect impacts. Among the priority sectors to be addressed by S&T in the medium and long term are the following: energy, oil and gas processing, petrochemical industry, mechanical engineering, information and communication systems and transportation.

The major long-term socio-economic trends like post-industrial development, the shorter life cycles of industrial production, birth of "glocalisation", "new industrialisation" in developed countries and others create demand for ensuring a new quality of industrial growth. It requires more efficient S&T and innovation policy and intensifying the ability of economic agents to innovate. Introducing culture of technology Foresight has become a major tool for conducting studies about possible trajectories of S&T development that allow to combine and coordinate activities of the government, business and academic community in the search for the new sources of long-term growth. In Russia, this is reflected in the formation of a national technology Foresight system and the development of the infrastructure and mechanisms that make possible systematic interactions between stakeholders in the national innovation system and their participation in the development of national S&T and innovation policy by the construction of legitimised and shared technological visions of the future economy.

A gradual "incorporation" of Foresight into the S&T policy-making should be complemented with converging existing (e.g. quantitative and qualitative) methods, as well as developing and implementing more sophisticated methods and using new sources of data provided by the growing power of ICT. Amongst the first steps in this direction is a system of continuous monitoring of global trends based on intellectual analysis of unstructured Big Data, which analyses thousands of events and factors related to global challenges (emerging markets, new technologies, etc.) across a wide spectrum of social, technological, economic, environmental, political and values-related issues (HSE, 2017).

The Russian S&T Foresight-2030 has shown that there still is a big room for further development of Foresight: methodology and organization; engagement and networking of wider expert communities (e.g. international) and citizens; invading new sectors; highlighting needs to develop and coordinate policies and strategies; assessing priorities for resource allocation; integrating Foresight studies at different levels (national, sectoral, regional and corporate); and deeper integration into policy formulation and implementation. The steps in this direction will allow increasing Foresight capacities and making it a powerful built-in tool for S&T and innovation policy.

Note

1. http://eng.kremlin.ru/transcripts/297

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