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The future of Russia's renewable energy sector: Trends, scenarios and policies

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A B S T R A C T

Today the global energy industry is undergoing major changes shifting towards the green growth and circular economy solutions. The paper offers the outcomes of the foresight study of the Russian renewable energy sector and focuses on three areas: converting solar energy into electricity; converting wind energy into electricity; and converting biomass into thermal energy and electricity. The goal of the study was to foresee and agree on the visionary future for the nascent renewable energy sector in the country, as well as to provide the scientifically justified grounds for government and corporate decision-makers. The research is based on a mixture of methods: bibliometric analysis and text mining, literature review, expert surveys and interviews, workshops, STEEPV analysis of trends, scenario analysis, and applied policy analysis. As a result of the study, major trends and uncertainties that may affect the Russian and global renewable energy sector in the next 15–20 years were identified. Other results include the scenarios for Russia's renewable energy sector that are proposed together with recommendations for the Russian companies and public authorities. The study's policy and market implications go beyond Russia: the outcomes may be useful for similar studies, early stage renewable energy policy planning and investment decision.

1. Introduction

Several technological revolutions have been simultaneously occurring in the energy industry since the early 2000s. Advances in robotics and personalized production equipment, combined with the application of new materials, led to rapidly changing characteristics of industrial and energy equipment: increased productivity, reduced negative impact on the environment, and lower costs. In 2017, global energy consumption predominantly relied upon fossil fuel. At the same time, most countries were steadily diversifying their energy resources mix to increase energy security and including this objective on their national strategic agendas [1].

The success of specific energy technologies largely depends on government support, which is provided either through technology-push (e.g., direct government subsidies or regulations) or market-pull tools (e.g., emission trading schemes) [2]. By switching to renewables governments also intend to significantly reduce the anthropogenic impact on the climate [3–7] and fulfil their international climate obligations [8].

These changes led to a substantial revision of energy security in the 2000s, when the focus shifted from assuring uninterrupted supply of energy resources (primarily fossil fuels) at an affordable price to providing equal access to a safe energy supply to all population groups, and reducing the energy industry's negative impact on the environment and climate [9,10].

The need to ensure energy security is a major driver for new energy technologies that allow the exploitation of new energy sources or the reduction of the costs of existing ones. Any country could obtain a competitive advantage on the global markets by increasing research and engineering capabilities, while the lack of these force countries to follow the leaders [2,11]. For developing countries, international technology transfer is the main source of technologies for low-carbon growth and cleaner production [12].

Today the global economic development milestones are changing: the resource-intensive growth model is being replaced by the green growth one: a hydrogen economy, distributed and small-scale energy generation, and smart grids. International organizations and countries realize that a new development

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paradigm is inevitable, and so do business communities. Those who set off along this path first would enjoy a competitive advantage. In 2015, more than a thousand companies and 70 national governments stopped using coal for energy generation purposes, and an equal number of companies announced their intention to reach a zero emission level by 2050 [13]. There is every reason to believe that renewable power generation will re-shape the global energy industry in the coming decades [14].

Historically the Russian energy industry has been following a conventional development path. The availability of large hydrocarbon reserves (natural gas, oil, and coal) and water resources has turned into a significant barrier hindering the advancement of safe and efficient alternative energy sources. Also, until recently, the country lacked programs supporting the renewable energy sector. In addition, only a decade ago, the renewable energy technologies were not profitable and efficient enough for most Russia's regions. *Therefore, the goal of the study was to foresee and agree on the visionary future of the nascent renewable energy sector in the country, as well as to plan for achieving that future by providing the scientifically justified grounds for government and corporate decision-makers.*

Russia remains a key player on the global energy markets. In 2015, after oil prices fell, the country increased oil production to a record 534.081 bn tons (with gas condensate) - 1.4% more than in 2014 (Interfax, 2016). However, relying exclusively on the fuel and energy sector will not lead to the achievement of sustainable and dynamic economic growth [15,16]. The analysis conducted by the Energy Research Institute of the Russian Academy of Sciences (ERI RAS) and the Russian Government Analytical Center experts shows that the energy sector's contribution to GDP is going to drop twofold: from 31% in 2015 to 13%–15% in 2040. Likewise, its contribution to the country's consolidated budget is going to fall from 30% to 14%–18% during the same period [17].

The innovative activity of Russian companies – in the overall economy and in the energy industry, in particular – is not high, at 9.9% and 10.9%, respectively [18,19]. Setting off along a sustainable development path requires, in addition to stepping up innovation activity, the diversification of the economy and energy sources. The exhaustion of existing economic growth sources drives the advancement of new energy industry segments and the reduction of energy costs, making energy available in all regions and to all population groups, thus prompting the creation of new skilled jobs, and mitigating the industry's negative impact on the environment and climate [20].

The next section of the paper describes methods used in the study. Third section presents the key trends and uncertainties that impact on the global energy industry and their manifestation in Russia. Fourth section features four scenarios for the Russian renewable energy sector, developed in the course of the study, and their comparative analysis. Fifth section offers policy implications and recommendations for government and corporate decision-makers.

2. Methods

This study was based on Foresight methodology and comprised three stages. This type of methodology has been commonly used in future studies of the energy sector in many countries [21–24], and has previously been applied to identify energy-related science and technology priorities in Russia [25,26]. The combination of methods were selected to fit the study purposes from a wide range of foresight methods described by Miles et al. [27] and Gokhberg et al. [28] and tested in 2015 with the study of the water sector in Russia [29]. Research novelty is also proved by the need for a qualitative review of the possible consequences of Russia's transition to renewable energy, underlined in the previous studies ([16]: 35). There are two research questions of the study:

- What is the visionary future of the Russian renewable energy sector shared by major stakeholders?
- What could the government agencies and the corporate sector do to best prepare for the challenges and opportunities posed by the global and national renewable sector future developments?

At the first stage key global energy trends (that represent both threats and opportunities), weak signals (unnoticeable possible future developments) and wild cards (unexpected events with small probability and potentially high impact) were identified and their impact on Russia was assessed [30]. Identifying relevant uncertainty factors is a widely used approach in energy, especially renewable energy, research [31–33].

The following information sources were used to identify trends and uncertainties:

- Publications indexed in the Scopus (search by keywords 'energy trends' and 'energy uncertainties' in title, abstract and keywords) and Web of Science (used for big data analysis through specialized software iFORA©) databases, 2011–2018;
- Publications in business and industrial journals (used for big data analysis through specialized software iFORA©);
- Strategic and analytical documents by international organizations, companies, public authorities, research and analytical centers, financial institutions, such as REN21, OECD, UNFCCC, the Russian Association of Solar Energy Companies, RusHydro, etc.;
- Statistical data and forecasts by International Energy Agency (IEA), International Renewable Energy Agency (IRENA), IHS, Greenpeace, BP, Shell, Fraunhofer ISE, Energy Research Institute of the Russian Academy of Sciences, Global Wind Energy Council and other organizations.

Based on the analysis of the above sources, a draft list of 42 trends was composed. The identified trends were structured into STEEPV categories (social, technological, economic, environmental, political, and value-related factors) [34], and the linkages among them were revealed. The selected systemic approach allowed covering a wide range of trends engendered by various external (to the energy industry) and internal (industry-specific) factors. Expert panels and a Delphi survey were conducted to discuss and validate the draft list of trends, comprising more than 300 experts: representatives of research organizations, universities, companies, public authorities, development institutes, industry associations, energy consumer groups, and technology platforms. The survey was undertaken in two rounds and the response rate exceeded 20%, which is considered high for this type of methods. The Delphi method is a type of survey where respondents are repeatedly asked the same questions, after the first round are informed about the results of the previous one, and, thus, are given a possibility to reconsider their responses. The method is typically used for consolidating experts' views [21,35]. Moreover, a bibliometric analysis of the Web of Science-indexed publications was conducted using keywords that cover major energy industry segments, followed by a text mining exercise. The results were validated at an expert workshop held in Moscow on December 11, 2015, with the participation of 30 researchers and practitioners from Russia, Austria, Germany, and Finland, and from the REN21 global multi-stakeholder network. Preliminary results of the study were presented at various international academic conferences.

As a result of this exercise, three renewable energy sources were identified for further analysis based on their high potential in Russia and worldwide during the selected time horizon: solar energy, wind energy, and biomass energy [36]. Accordingly, the research was focused on three research topics: the conversion of solar energy into electricity; the conversion of wind energy into electricity; and the conversion of biomass energy into heat and electricity.

At the second stage of the study four possible scenarios for the renewable energy sector's development were elaborated. A set of variables, together with qualitative and quantitative indicators that reflect macroeconomic factors and the subject areas, were identified for each of the scenarios. Over the course of the scenario analysis expert methods were also applied, such as expert panels, interviews, and consultations. The scenarios were discussed and validated at the expert panel held in Moscow on April 22, 2016, with the participation of 37 experts from Russia, Brazil, Germany, the US, Finland, Switzerland, Japan, and international organizations (REN21, UNESCO, etc.).

The third stage was focused on drafting proposals for Russian companies and public authorities in the scope of each of the scenarios. Recommendations were prepared using expert methods (surveys, interviews, and workshops); analysis research publications; and applied political analysis of laws and regulations. Semi-structured expert interviews were held with 10 practitioners from Russian companies, business associations, non- -profit organizations, and development institutes. The preliminary results were validated at the expert workshop held in Moscow on May 17, 2016 with participation of 40 Russian experts, and at the international conference "Foresight and STI Policy" held in Moscow on October 19–20, 2016.

3. *Global trends and uncertainty factors in the energy industry*

Global energy consumption has significantly changed over the past 40 years: the OECD countries have managed to slow down energy demand and partially substituted coal with natural gas and renewables, while the economic boom in Asia and Latin America resulted in rapidly accelerating demand for energy resources and an increased share of coal in final energy consumption [37,38]. Forecasted energy demand over the next 20 years varies significantly. However, many experts agree that the demand for nuclear energy will remain unchanged or even slightly drop, demand for oil and coal will drop more significantly, while demand for natural gas and renewables will grow (Fig. 1).

By 2035, the production and consumption of primary energy resources in Russia is expected to increase by 27%–28% compared with 2010. Provided that the population stabilizes at about 140–145 mln [42], while life expectancy and population density in Siberia and the Far East increase, energy consumption will grow by 1.5% per year on average until 2040 [43]. However, the energy balance will change: between 2015 and 2040 the share of oil will drop from 31% to 27%, of coal – from 28% to 25%, while the share of natural gas will increase from 22% to 24%. As to renewable energy sources, the share of hydropower is forecasted to grow from 2% to 3%, bioenergy – from 10% to 11%, and other renewables – from 1% to 4% (Plausible scenario; [17]). The production of electricity from renewable sources is expected to increase ten to fourteen times [44].

Given the current rate of global hydrocarbon extraction, they may be exhausted in several decades: coal in 109 years, natural gas and crude oil in slightly over 50 years [1]. These periods may either be extended or shortened due to external factors such as the discovery and exploration of new deposits, the development of new production technologies, the introduction of a "carbon tax," and stricter environmental legislation, etc. Accordingly, the future development of this trend is an important uncertainty factor. If the calculations are correct, there is approximately 50 years left to find new energy sources and apply innovative energy technologies on a large scale.

Urbanization and better quality of life, the growing number of personal vehicles, and geographical factors all lead to increased consumption of heat and power in cities [45]. This trend is particularly obvious in rapidly urbanizing regions such as Asia, Africa, and the Middle East. If the above trends continue, energy consumption in cities will more than triple – from 240 EJ (EJ) in 2005 to 730 EJ in 2050. Efficient policy and transport infrastructure planning tools may limit the energy consumption increase in cities to 540 EJ by 2050, and contribute to the mitigation of climate change [46]. This is particularly relevant in China where urbanization has not yet reached 50% and the government expects a further 350 mln people to move into cities over the next 15 years that would result in a multiplex increase of energy consumption. Several of the largest Russian cities have also turned into large urban agglomeration centers, where unsound industrial, economic, urban, and transport infrastructure and energy policies, obsolete infrastructure facilities and environmental problems create substantial threats.

In recent years, energy demand has shifted towards Asian and Latin American countries. By 2040, China and India may account for 30% and 20% of global energy consumption, respectively [47]. Their combined oil consumption already amounts to 50.8% of global consumption. This trend opens new opportunities for the Russian energy industry in the Asia-Pacific region. The expected accelerated growth of global gas consumption will lead to increased demand for gas transportation and distribution infrastructure, so Russia will

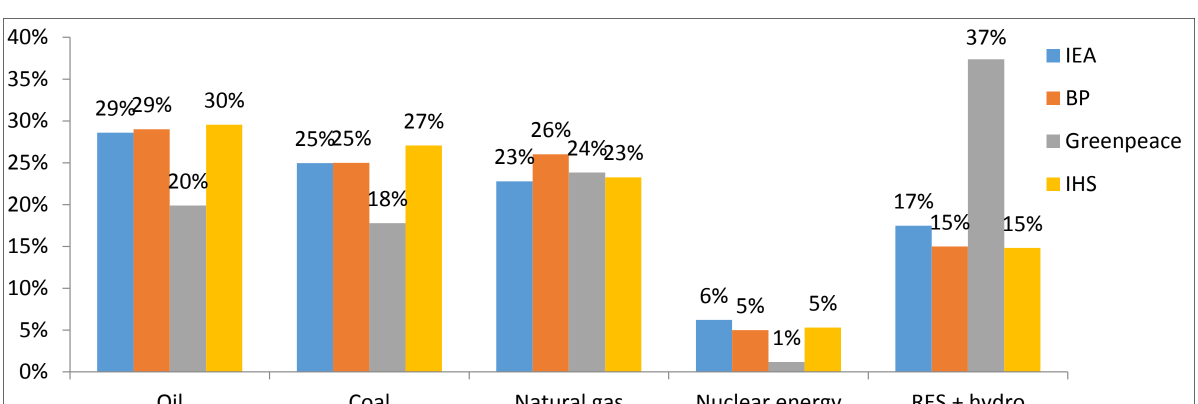

Fig. 1. Forecasted total primary energy demand: 2030 (%). Note: BP: data for 2035; Greenpeace: prospective energy revolution scenario (Advanced energy [r]evolution scenario); IHS: Vertigo scenario. Sources: BP, [1]; OECD/IEA, [39]; Greenpeace Russia, [40]; IHS, [41].

have a chance to participate in construction of gas-fired plants in this region. Moreover, there is an unmet demand for liquefied natural gas (LNG) supply infrastructure, and equipment for gas-powered generating facilities in China and India. Additionally, there is an opportunity for exporting electricity to Japan and China due to their geographical proximity and existing demand.

As conventional and unconventional hydrocarbons will likely still dominate the energy balance in the next few decades, prospective technology trends include the new solutions for the extraction of unconventional hydrocarbons, suitable for application in extreme environments and climates [48]. Russia is expected to produce up to 70 mln tons of liquid hydrocarbons by 2030 (oil, gas condensate, etc.) from low permeable collectors [115]. The US, Canada, China, Argentina, and Brazil are also exploring this type of resources. However, the exact amount of confirmed extractable hydrocarbon reserves is difficult to measure [49]. This uncertainty is further exacerbated by another one related to estimating production costs and commercial viability. Even at conventional oilfields the oil recovery factor does not exceed 20%–30% [50], while in developed countries it could reach 60%–70% (OECD/IEA, 2016b). To sustain the output above 420 mln tons a year by 2030, at least 12.5 bn tons of new reserves will have to be discovered, four bn tons of that at active deposits, by increasing the recovery.

Renewables are rapidly growing: their share in total consumption of primary energy resources that was expected by 2020 [51] was actually reached in 2010 [52]. The renewable energy industry keeps growing at a high rate due to the increased technological and economic efficiency. In 2015 the share of global renewable electricity reached 23%, renewable heat – 9% and biofuels for transport – 4%. The share of renewable electricity is expected to grow more than one-third by 2022 [38]. Global investments in the renewable energy sector in 2012–2016 have reached over 1.5 trln primarily due to the growing interest in solar and offshore wind energy generation [53]. If no new competitive energy sources emerge, by 2050 wind (34%), hydro (30%), and solar energy (18%) will be the leaders among renewables [54]. According to Yu. Manzhilevskiy, Managing Director at SOWITEC Russia, renewable energy projects are particularly in demand on emerging markets such as Latin America (including Mexico), Russia, Kazakhstan, Saudi Arabia, Thailand, and African nations (in particular Kenya).

One of the major energy-related challenges is global climate change. It has substantial consequences including the mass migration of the population, significant changes in the productivity of agriculture at most locations, and the increased occurrence of extreme natural phenomena, ocean acidification, etc. About three quarters of anthropogenic CO_2 emissions in the last 20 years are associated with production, transportation, and processing of hydrocarbons, and its subsequent combustion to generate electricity, heat, and mechanical energy. Russia is the largest CO_2 emitter among all IEA member states: in 2015, its carbon intensity was still higher than in most OECD countries: 0.47 tons of CO_2 per $1,000 of GDP (PPP) [37]. This is largely due to the energy industry's performance (Fig. 2).

Russia is also a signatory of the UN Framework Convention on Climate Change (including Annex I) and the Kyoto Protocol (including Annex B), and has to fulfil its obligations to limit CO_2 emissions and submit annual emission inventories and national reports [55,56]. Subsequently, the Paris Agreement on the climate, which was approved in December 2015 and became effective in November 2016, provides for the regulation of greenhouse gas emissions as of 2020 [57]. This means that the country has to explore various options for greenhouse gas emission reduction [58].

The trend towards creating autonomous distributed energy supply systems is very evident not only in Europe, but worldwide. The introduction of stricter environmental and climate-related standards and requirements is a challenge for Russia [59,60]. At the same time, according to A. Usachev, Director of the Russian Association of Solar Energy Companies, "autonomous energy generation in our country has a large development potential in decentralized energy supply areas, while development of skills in this area opens plenty of opportunities for entering external markets with similar conditions."

Energy generation from various types of waste is growing all over the world, and includes solid domestic waste (SDW), agricultural and animal farming waste, water treatment sediments, and other types of waste. During the forthcoming decades, the amount of SDW is expected to grow at a higher rate than urbanization, reaching 4.2 bn tons a year by 2050 [61]. In Russia annual generation of SDW is in the range of 27–54 mln tons (or about 130 mln m^3). Most of it is disposed at garbage dumps: more than 80 bn tons of solid waste has accumulated in the country, out of which about 16 bn tons is SDW [62]. Today over 14 700 legal landfills occupy the territory of 4 mln hectares (comparable with the territory of Switzerland and Netherlands), and they annually grow by 400 000 ha (which is 40% more than the territory of Luxemburg).

Making use of it would allow Russia to significantly reduce the amount of harmful emissions from burning more expensive fuel, and save fuel in many industries such as metallurgy, cement production, etc. Given that up to 300 L of synthetic oil can be produced from 1 ton of SDW, the accumulated amount of domestic waste is sufficient to produce up to 3.8 bn tons of synthetic oil, which is equivalent to 46.3% of Russia's internationally confirmed oil reserves. Annually generated domestic and agricultural waste (about 300 mln tons in dry weight) is enough to produce up to 90 bn m^3 of gas.

The growing role of information and communication technologies (ICT) leads to active development of smart grids and networks for centralized, distributed, and individual energy supply of industrial and household consumers. The digitalization of energy infrastructure based on cloud computing and Big Data systems is expected to reduce energy costs and create backup end-user capacities [63,64]. Many countries are engineering national-level smart grids with active participation of generating and distributing companies, and consumers in energy transmission and distribution. All Russian grid companies are developing smart energy systems. In particular, Federal Grid Company of the Unified Energy System (FGC UES) is implementing major pilot smart grid projects such as North-Western Smart Grid and Eastern Smart Grid [44,65]. The 'Energy.Net' National Technology Initiative (NTI) was launched to support the leading Russian companies that offer smart electricity solutions to be tested in cities of Kaliningrad and Sochi [66].

Among other technological trends is the development of energy storage solutions (new types of accumulators and batteries, etc.), and relevant infrastructure (charging and power output systems). The already available stationary and portable energy storage systems can provide additional advantages for the low-carbon technologies. Given the increased efficiency and service life, lower production and running costs, and reduced need for standby capacity energy storage systems[1] . could significantly increase the efficiency of numerous centralized and decentralized generation systems, including solar-, nuclear-, wind-, geothermal, etc. Major barriers hindering the development of energy storage systems in Russia include their high costs and the legal uncertainty surrounding their use in the energy system.

[1] Revolutionary changes in data storage and processing systems are expected due to the development of photonics, which imply using light instead of electricity and can create a $20 billion market by 2030 [120]"

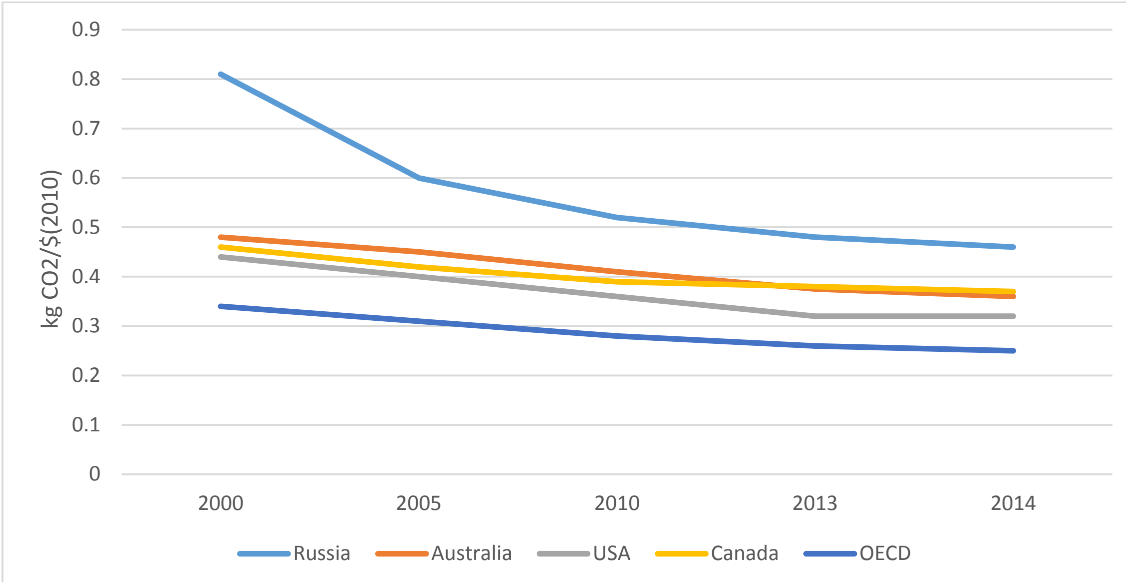

Fig. 2. CO_2 emissions from fossil fuel combustion per $1,000 of GDP (in 2010 prices) (purchasing power parity), by country (kg). Source: [37].

Social trends related to the energy industry and worthy of special note include persistent sickness and mortality rates caused by the environment pollution occurring over the course of the production and combustion of hydrocarbons, and accidents at energy generating facilities (anthropogenic disasters). A study of energy generation-related disaster risks for 11 types of energy sources based on extended data series (1874–2014) revealed 1,100 such accidents which have caused more than 210,000 deaths, and economic damage of almost $350 bn [67]. The World Health Organization asserts that 92% of the world population live in regions where the WHO pollution limits are not observed. These emissions from fuel extraction and combustion cause 7 mln premature deaths [68].

As to the value trends, the emergence of corporate and household energy saving culture should be noted [69]. This tendency is reflected in the global GDP energy intensity decline by 1% per year (on average in 2010–2013), and a drop in 2014 by 2.3%. In the OECD and BRICS countries (except Brazil and Russia), this indicator decreased by 15–20% in ten years' time (2004–2014) [119]. Analysis shows that about 65% of the existing potential to increase energy efficiency (while ensuring a good return on investments) is located in developing countries. Exploiting this potential over the next 12 years would require investing $90 bn a year, about a half of the sum developing countries would have spent on upgrading their energy infrastructure to meet the growing demand [71].

Russia remains very much behind developed countries, including Northern ones, in terms of GDP energy intensity. To narrow this gap, the Federal Law #261 “On Energy Saving and Increasing Energy Efficiency” was passed in 2009, accompanied by a relevant national program, following which all Russian regions approved regional energy efficiency programs. Though it will not be possible to reduce the energy intensity of Russian GDP by 40% by 2020 compared with 2007[2] as planned earlier, projects to upgrade the heating systems are being implemented all over the country that should help Russia meeting the target. Investing in the reduction of energy intensity pays back: on the macro-level, it may increase annual GDP growth by up to 2% [72]. Major steps are also required to reduce the energy intensity of the Russian energy industry: for example, Russian grid companies' basic energy efficiency figures are 30%–50% lower than that of the leading international companies'; the efficiency factor of Russian gas-powered thermal power plants is 20%–30% lower, while in terms of the Nelson complexity index, the gap in certain cases is as large as 200% [73].

Renewable power generation costs are rapidly falling, making these energy sources competitive with conventional ones. Even in the short term, electricity generated from solar radiation is forecasted to become the cheapest in many regions of the world [74]. An analysis of technical potential of renewables and existing financial opportunities to fully meet the European Union's energy demand by using renewables, revealed that if advanced energy storage and transfer technologies are used, and provided that certain industries' demand for energy resources changes, this would be possible. Remarkably, energy from renewables will cost consumers less than a combination of fossil energy resources and nuclear energy [75].

The problem of getting access to reliable and inexpensive electricity sources is a global one: about 1.1 bn people (approximately 15% of the planet's population) are living without a centralized electricity supply [76]. In remote areas not connected to the centralized supply systems, electricity is typically produced with diesel generators, which explains the high energy costs and dependence on external fuel supplies [48,77]. In the near future solar and wind energy, as well as hybrid energy facilities (such as solar-wind, solar-geothermal, wind turbines and fuel cells) will satisfy the energy demand in such areas [78,79]. Russia has substantial territories and multiple remote settlements, where the use of renewables is economically justifiable today [80].

In solar industry, the costs of crystal silicon photoelectric cells have fallen exponentially (from $76 in 1997 to $0.30 in 2015) (Liebreich, 2016). The price of PV-generated electricity show similar dynamics: in just five months of 2016, the tariff offered by certain generating companies in the UAE has dropped by 25%, from $0.029 to $0.023 per kWh. Non-material costs are expected to decline by 85% between 2015 and 2030 [81]. Solar electricity already costs

[2] Decree of the President of the Russian Federation № 889 “On Certain Measures to Increase Energy and Environmental Efficiency of the Russian Economy” dated June 4, 2008.

$0.05–0.10 per kWh in Europe, China, India, South Africa, and the US. In 2016, at the solar generation capacities auction in Dubai, the price of $0.03 per kWh was offered [82]. The installed capacity costs for energy companies in the next 20 years are expected to fall by 25%–40% (Fig. 3) [1,74]. Since capital expenditures make the bulk of solar energy costs, wholesale prices can be expected to drop proportionally (Fig. 4). Wind generation shows a more modest cost reduction (Fig. 5). All this suggests there is potential for a further increase of efficiency and a reduction of costs.

About 10 years ago, it was expected that by 2050, biomass would provide close to 15% of primary energy [84], but already in 2015, it became clear that its potential was much greater [85]. In Russia, the main sources of energy biomass are organic agricultural waste (energy content is up to 80 mln toe a year); forest industry's organic waste (provided advanced forestry and wood processing technologies are applied - up to 1 bn toe per year); urban waste; peat (in total 60 bn toe per year); and energy crops (at least 270.9 mln toe per year) [86].

Renewables (excluding large hydro) amount to only 1.5% of centralized energy generation in Russia. This is contrary to global trends and does not match the country's high technical potential [87]. One obvious explanation to this fact is the abundance of fossil fuels that guarantee short-term economic and energy security. In 2013, the combined share of oil, gas, and coal in the total primary energy supply was 90.6%, or 731 mln toe (Fig. 6). However, by 2040, hydrocarbon exports will no longer be able to yield either comparable revenues, or a similar share in the national budget. Even if the Russian energy industry increases absolute hydrocarbon production output, it will not be able to serve as the main source of economic growth even for the next two decades [17].

The trends listed above may represent both opportunities and challenges to Russia and its energy industry and are not likely to develop at the same pace. The cost of energy technologies in many cases seems to be the main uncertainty factor, since it determines their competitiveness. This applies to the development of high-temperature superconductors, cold nuclear fusion, and hydrogen energy technologies that can lead to breakthroughs in various applied research areas, from energy storage to computer technologies.

The main uncertainty factors affecting the development of the renewable energy sector are future national and international regulations [15], the extent of energy systems readiness to integrate large amounts of renewable energy, and emergence of new energy sources, economic growth and energy consumption patterns in the US, China, and India, the adoption of cleaner energy technologies in the developing and poor countries [49], the probability of adopting a coherent, evidence-based climate policy [89]. Unclear is the progress in certain areas of research and development (R&D) and a persistent gap between energy research and commercial development of its outcomes.

Despite the available estimates of fossil fuels' undiscovered reserves, it is difficult to establish their actual volume [49] and what amounts are commercially recoverable. It remains unclear whether it will be possible to unfold the infrastructure for the capture, storage, and use of carbon dioxide that will make a significant contribution to decreasing the anthropogenic impact on climate [90]. Another major area of uncertainty concerns the dynamics of energy prices [91,92].

Finally, a key uncertainty factor is the emergence and wide application of cheaper and more advanced renewable energy technologies (such as tidal power plants, wave energy solutions, and fuel cells), as well as fundamentally new energy sources, such as controlled nuclear fusion, geothermal energy from hot dry rocks, energy of the dark matter [93] and more.

4. Scenarios for the Russian renewable energy industry

Changes in the Russian and global economy significantly affect possible development paths for the renewable energy sector and its place in the Russian energy industry. The scenarios imply various

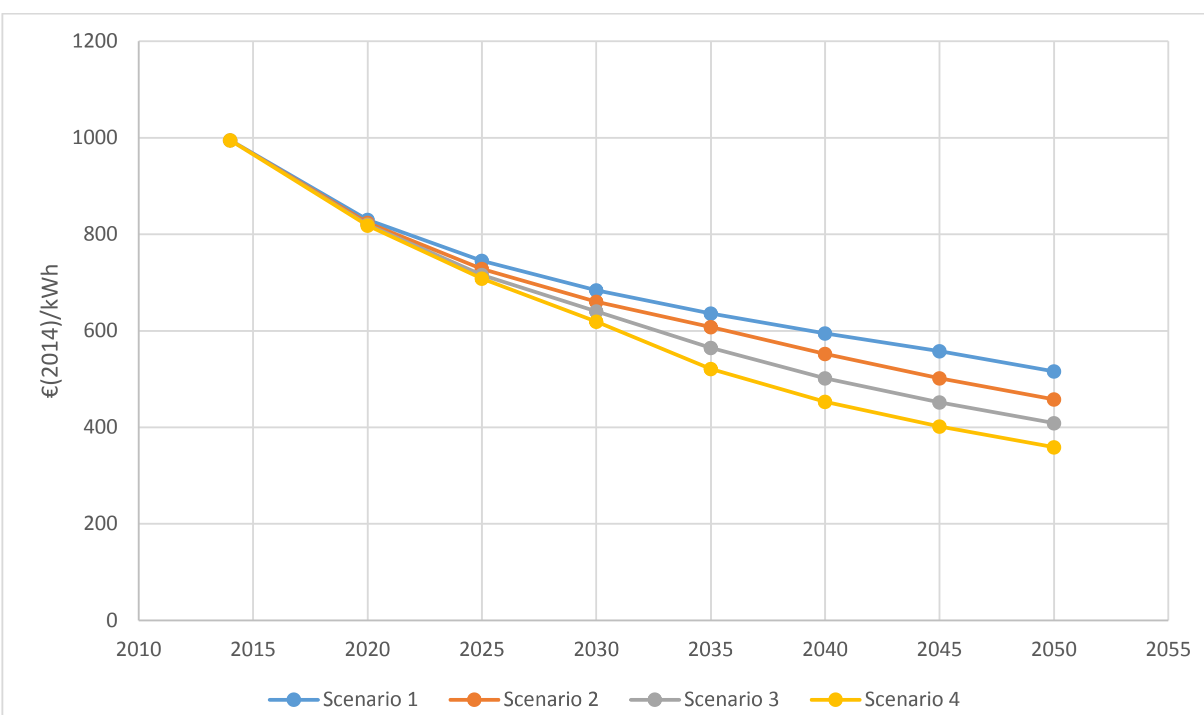

Fig. 3. The projected installed PV capacity costs (EUR per 1 kWh). Source of data: Fraunhofer ISE, [74].

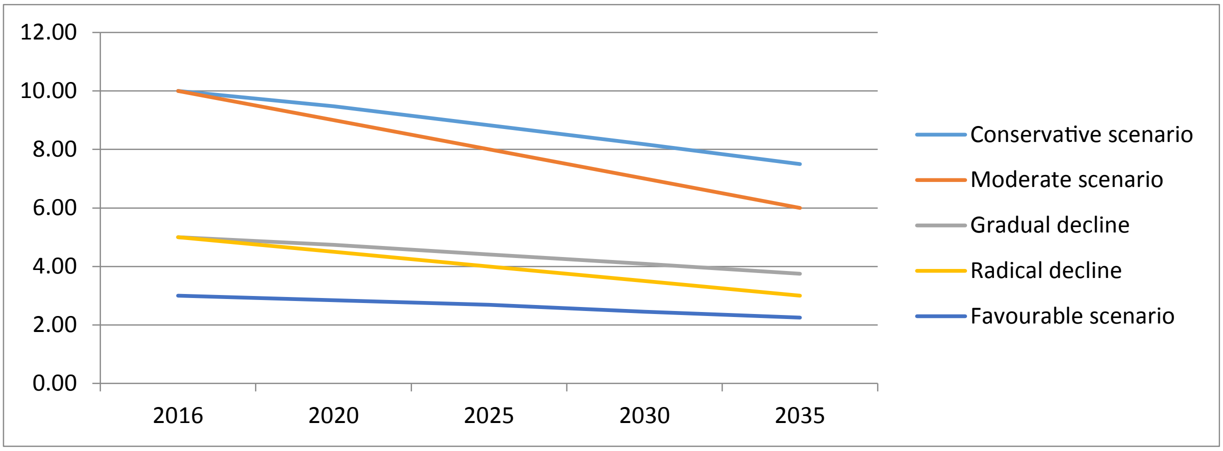

Fig. 4. Forecasted wholesale prices of solar PV electricity (USD per 1 kWh). *Sources*: IRENA, [82]; BP, [1]; HSE research.

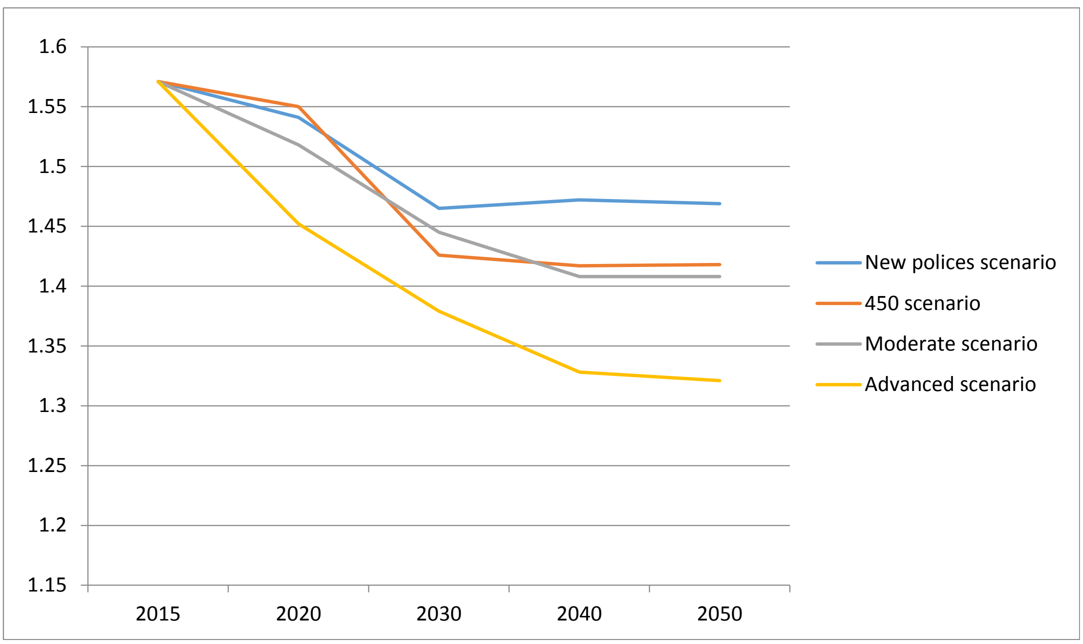

Fig. 5. Levelized cost of electricity from wind energy (EUR cent per 1 kWh). Source of data: GWEC, [83].

trend combinations and their impact on the Russian renewable energy sector. They outline probable development paths for the Russian renewable energy sector until 2035, and highlight major differences and potential interconnections between them. The main quantitative indicators describing developments in the three selected research areas, and key external factors affecting the application of renewables in Russia are outlined.

4.1. Scenario 1: new energy paradigm (3D)

The "New energy paradigm (3D)" scenario implies moving towards green growth through de-monopolization, disintermediation (eliminating unnecessary intermediaries), and decentralization. This development path would be possible if the Russian economy steadily grows, is diversified, the domestic and foreign policy frameworks are favourable, the investment climate improves, and energy companies have access to financial resources and advanced technologies on international markets. Combined, these conditions would promote the steady technological development of the Russian renewable energy sector.

The first stage of this scenario implies the catch-up development that will lead to domestic technological modernization of engineering systems, the wide application of smart energy technologies, consumer friendly approach, increased quality and reliability of services, and advancement of international R&D cooperation. The successful implementation of the first stage will prepare the ground for moving on to the new technology paradigm in the Russian energy industry.

This scenario implies increased investments: rapid construction of renewable power plants for centralized, distributed, and individual energy supply and implementation of cluster territorial development projects, with integrated energy supply based on renewable and local energy sources. Efficient technologies to convert renewable energy into power, heat and cooling; biomass into biofuel; and energy storage technologies will be applied. These changes will assure better physical access to more affordable energy for the population, improved environmental and climate situation, increased quality of life and positive effects for people's

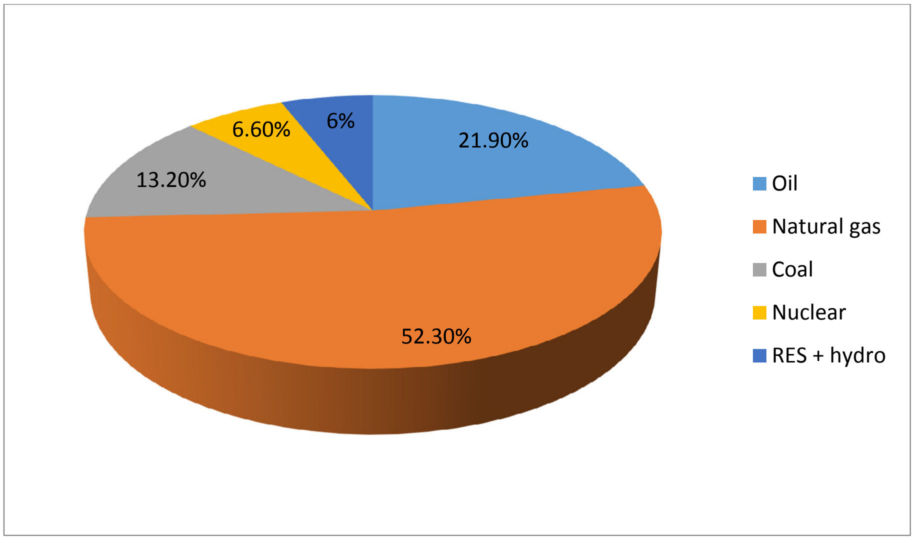

Fig. 6. Total primary energy consumption by fuel in Russia: 2017 (%). Source of data: Statista, [88].

health.

The increased share of renewables will be accompanied by application of improved energy systems, such as macro and micro smart grids. Due to reduced unemployment and increases in average wages and pensions, the share of energy-efficient households with a surplus of self-generated power will increase, leading to active consumers playing a more important role in distributed generation.

The share of renewables in the energy balance will depend on gas and electricity prices. Moreover, a substantial impetus will be given by government programs for the promotion of renewable energy, policy support tools to increase resilience and safety of energy systems with a high share of renewable power generation.

There will be an increasing number of vehicles operating on biofuel and electric engines based on advanced efficient energy technologies (in particular, electric and hydrogen cars will become less expensive and more efficient); new transport infrastructure will be put in place, and new legislation will be adopted.

The increased efficiency of traditional energy companies in the medium term will allow cutting costs and promoting full-cycle solutions (exploration, extraction, transportation) with reduced tax preferences. Lowering costs and the retention of production output volumes will open financial opportunities to diversify business activities and support R&D, including those related to renewables.

The successful implementation of reforms requires the involvement of organizations at municipal level in managing the sector (including tariff policies and sustaining the infrastructure). Also, programs and projects will be designed to promote energy supply and manage centralized, distributed, and individual renewable power plants [94,95].

4.2. Scenario 2: relying on hydrocarbon exports

The “Relying on hydrocarbon exports” scenario implies a continuation of the trends observed in 2015–2016 and the conservation of problems against the background of a stagnating economy. No structural reforms are anticipated. The main source of national income (that provides close to half of federal budget revenues) will be the export of raw materials, predominantly oil and gas (60%). A significant proportion of development programs, including those in the renewable energy sector, will directly or indirectly (through R&D programs, subsidies, tax preferences, and business competition for electricity consumers) depend on the revenues generated on hydrocarbon markets.

The prospective development of the industry will mostly be based on the growth of gas, solar, and wind power generation (due to lower levelized costs). The shares of nuclear and coal generation will drop, while oil products’ use for energy generation purposes will remain unchanged [96]. Accordingly, demand for gas will increase, and its supply to European consumers will continue. Next-generation highly flexible gas-turbine and steam-gas power plants will help meeting peak loads and electricity shortages during unforeseen power downturns of solar and wind power plants, due to the complementarity of these energy sources.

The independent domestic manufacturing of energy equipment will require significant financial resources and highly skilled personnel together with well-thought corporate management and planning strategies that will not receive additional incentives under this scenario. Instead, policy tools will be put in place to integrate Russian energy companies into global value chains. The cost reduction of hydrocarbon extraction and processing equipment (necessary for the further development of the Russian energy industry) will be achieved by steady localization of its manufacturing in cooperation with top international companies. To make such localization more attractive, the Russian energy industry will have to implement several transformations including measures to increase competition on the domestic gas market, reforms in the industry, and tariff regulation. This development path implies the gradual removal of international and domestic limitations on the supply of technologies and equipment.

4.3. Scenario 3: the worst forecast comes true

This scenario is based on more pessimistic macroeconomic indicators than the Russian Ministry of Finance’s conservative forecast [97]. The main prerequisite for this development path is the end of the long high oil price period by 2015, and the beginning of their long-term decline combined with increased competition on the global markets, among other factors due to an increased supply of LNG [98].

The decline of oil prices will be followed by reduced volumes of oil production: if the current oil and gas industry remains unchanged, in 20 years’ time oil production in Russia may drop by 46%

[44]. At the same time, federal budget revenues, largely based on hydrocarbons exports, determine the government's ability to promote new technology projects and set special tariffs for renewable energy at the initial stage of this market development. The diffusion of renewables on global markets over the next few decades will increase, with many countries switching to electric cars, while the Russian energy industry will lag far behind.

The Russian gas industry is totally different from the oil industry: the amount of reserves and production potential here are not that important, but there are difficulties with entering international markets. According to BP's estimates, the prime cost of supplying gas to Europe is about \$130 per 1,000 m^3. There is a probability that LNG supplies on the European market at just over \$100 per m^3 will replace a certain share of the Russian gas [99].

The deteriorating economic situation and a weak rouble would hinder the modernization and growth of Russian mechanical engineering companies and the Russian energy companies will continue their dependence on imported machinery, materials, technologies, and software.

The renewables growth rate in Russia's energy balance will be at its lowest and will not affect gas consumption. The existing Russian national programs on promoting renewable energy until 2024 may be reconsidered. A few low capacity renewable energy power plants will still be constructed only in a few remote regions where it will be economically feasible.

There will be a gradual decline of the industry's economic performance, along with consistent curtailing of development programs for green and conventional energy generation, and in the medium term their effective freezing, resulting in very low probability to switch to the "Centralized diversification" scenario. The main danger of this scenario is not just an inability to advance the energy industry to a higher technological level, but its significant deterioration: the degradation of tangible and intangible assets, increasing frequency of human-induced accidents, a higher rate of bankruptcies, the loss of technological and financial stability, ultimately leading to a new round of economic decline.

4.4. Scenario 4: centralized diversification

The "Centralized diversification" scenario implies the accelerated development of the renewable energy sector with the leading role of the state and a monopolized energy market. The main prerequisites include the depletion of traditional hydrocarbon reserves and a significant decline in global demand for them. This would create the need to restructure the industry by increasing the share of renewables to make energy more accessible and reduce tariff pressure on end users, lower Northern regions' dependence on government subsidies, and make energy tariffs less dependent on volatile hydrocarbon prices.

Under this scenario, the state sets target indicators and selects territories for promoting energy supply from renewables, with a particular focus on decentralized energy supply areas that cover about 70% of the Russian territory, with a population of between 10 and 20 mln, and centralized energy supply areas experiencing major shortages of capacities, high expenditures, substantial technological problems with connecting to power grids and district heating networks, and significant losses due to frequent and large-scale power cuts. The increased use of renewables in combination with gas-based generation will provide an efficient mechanism for improving the environmental situation and preserving the climate, and also serve as a priority national project with a high inter-industry multiplicative effect.

According to the official targets for the industry and valid legislation, industrial clusters will be established by 2024 for manufacturing of advanced equipment based on technology transfer with a capacity of at least 500 MW a year for wind energy, 270 MW for solar energy, and 160 MW for hydropower. These clusters will cover companies and R&D centers in power mechanical engineering, electrical engineering, electronics, material science, etc. They are expected to facilitate the establishment of science schools, improve product quality, and increase output and unit capacity, extend the scope for equipment application, attract strategic investors in green technologies, and contribute to the growth of GDP. This, in turn, would require the government to step up generation from renewables, prolong programs and fulfil international climate change obligations, as well as support exporting green energy services and equipment to third countries.

Accomplishing the above objectives would require an improved renewable energy management structure. The newly established Federal Renewable Energy Agency would be responsible for shaping and implementing the relevant government policies. State corporations responsible for the science and technology (S&T) basis for primary and secondary renewable-based generating equipment will support the changes and facilitate international S&T cooperation. A number of energy companies, including oil and gas firms, will be instructed by the government to diversify their activities by producing a wide range of high value added products and increasing generation from renewables that will cover own energy consumption, energy demand in their home regions, and the development of new territories. Federal and regional programs are expected to be approved to promote the construction of renewable energy power plants and relevant support systems.

Measures to promote the development of conventional and renewable energy generation will be coordinated. The standardization and quality control agencies responsible for the renewable energy sector will begin to operate. An increased level of technology transfer from developed countries to Russia is foreseen due to the saturation of their domestic markets. If the country faces a serious economic crisis, the development of green energy technologies will be rolled back, but, in keeping with the global move towards clean energy and Russia's membership in the relevant international organizations, global cooperation in this field will help the country to overcome these difficulties.

4.5. A comparative analysis of the scenarios

A comparative analysis of the key external and internal factors and indicators describing economic development in general, and the renewable energy sector in particular, both globally and in Russia, was conducted in the scope of this study for each of the above scenarios (Table 1).

The "New technology paradigm (3D)" and "Centralized diversification" scenarios imply the most active development of the renewable energy sector and a significant reduction of power and heat generation costs. Renewable energy sources will become economically viable for Russian companies (under the first scenario, private firms, under the fourth – public ones). The "Relying on hydrocarbon exports" scenario presumes high hydrocarbon prices, which would also contribute to the use of renewables because competing fossil resources would be too expensive. At the same time the fossil fuels exporters would be trying to increase production of conventional energy sources.

The "New technology paradigm (3D)" scenario seems to be the most promising one for Russia. It implies the best opportunities for making use of the country's substantial renewable energy potential [106–108,114]. The implementation of this scenario will increase energy security through the diversification of energy resources, fossil fuel savings, and the creation of a new, high-tech green energy sector.

"Relying on hydrocarbon exports" implies preserving the

Table 1
Key factors and indicators of the development scenarios for the Russian renewable energy industry until 2035.

Factors/indicators	Scenario 1: New energy paradigm (3D)	Scenario 2: Relying on hydrocarbon exports	Scenario 3: The worst forecast comes true	Scenario 4: Centralized diversification
Economic situation (macroeconomic characteristics)				
Annual global economic growth, %	≈ +3.5	≈ +3.0	≈+2 … +2.5	≈ +3.5
Annual growth of the Russian economy, %	+2 … +4 GDP increased by 30%–44% by 2030	−1 … 0 … +1 GDP recovers to the 2014 level in 2020	−1 … −4[a] GDP recovers to the 2014 level in 2035	+1 … + +1.5 GDP recovers to the 2014 level in 2020
Implementation of economic reforms in Russia	Structural reforms and the diversification of the economy. Russia's switch to the green growth model	Limited structural reforms, privatization of energy monopolies, abandoning the "project-based" public funding model in the energy industry and manufacturing, major tax cuts, and a reduced regulatory burden	No structural reforms	Some structural reforms, while preserving the leading role of the state in the energy industry and in the overall economy
Renewables share in the energy balance, %				
Globally	25	20	17	25
In Russia	10	5	3	8
Energy intensity of the economy, toe per $1,000 of GDP				
Globally	0.11	0.11	0.11	0.11
In Russia (in purchasing power parity terms)	0.27	0.32	0.35	0.29
Oil industry indicators				
Oil prices (USD per barrel)	70–90	80–120	45–55	70–90
ORF б %				
Globally	50	40	30	50
In Russia[b]	35	30	25	30
Global oil production, mln barrels per day	98.9	108.75	76.5	98.9
Global gas production, bn m3	4858	5220	4035	4858
Growth of Russian oil production and exports	Gradually declining production, reduced exports	Production gradually declines to 364 mln tons a year (not counting condensate), according to operators' consolidated plans, reduced exports	Significant decline of production to 332 mln tons a year (not counting condensate); significantly reduced exports	Gradually declining production, reduced exports
Conversion of solar energy into electricity				
Share in the total global energy production from renewables, %	15.2	13	9.5	14
Share in the global FEB, %[c]	8 (PV – 7, CSP – 1)	4 (PV)	5-6 (PV)	4 (PV – 3, CSP – 1)
Production costs, USD per kWh	0.05–0.30	0.07–0.35	0.07–0.35	0.05–0.30
Installed capacity costs, USD per W (in 2014 prices)	0.3–0.4	0.4–0.6	0.4–0.6	0.3–0.4
Global installed capacity, GW[d]	1400–1600	500	900	1000
Generation, tWh per year[e]				
Globally	1389	680	680	951
In Russia	24–38	10–17	14–21	24–38
Installation rate (growth rate) in Russia gWh	1.3–2.1	0.55–0.92	0.75–1.13	1.3–2.1
Government support	Full implementation of all approved national programs, gradual shift to market instruments (e.g., tax breaks, soft loans). Stricter environmental policies.	Full implementation of all approved national programs. No new government programs.	Incomplete implementation of approved national programs.	Full implementation of all approved national programs. New government programs adopted after 2024. Directive-based market regulation.
Conversion of biomass[f] into heat and electricity				
Global demand for biomass-generated energy, EJ per year	115–161	115–161	115–161	115–161
Global install electricity generation capacity (all biomass types), GW	340	274	250	340
Electricity costs, USD per kWh	0.06–0.10	0.10–0.25	0.10–0.25	0.06–0.10
Heat costs, USD per kWh	0.025–0.060	0.04–0.09	0.04–0.09	0.06–0.10
Development of bioenergy industry in Russia	Biomass amounts to about 50% of the total global renewables application	The state of the bioenergy industry remains unchanged, including regulatory and economic barriers hindering development of fuel-based bioenergy and application of discarded bio-waste	Possible comeback of inefficient, "dirty" but cheap energy technologies such as the direct burning of peat	Reforms in the forestry and wood processing industries including the development of in-house generation and the sale of electricity to utilities

(*continued on next page*)

Table 1 (*continued*)

Factors/indicators	Scenario 1: New energy paradigm (3D)	Scenario 2: Relying on hydrocarbon exports	Scenario 3: The worst forecast comes true	Scenario 4: Centralized diversification
End product output and its growth in Russia (all biomass types)				
Biofuel's share in production of heat and electricity, %	3	1.0–1.5	1.0–1.5	2
Growth of biofuel production, %	70[g]	30	20	60
Capacity installation rate (growth rate) in Russia, %				
Biofuel-based electricity generation	5	4	3	4
Biogas-based electricity generation	1	0.4	0.2	0.4
Liquid biofuel (transport)	10	5	7	7
Biofuel (industry)	16	13	10	13
Biofuel (buildings)	13	11	8	11
Government support	R&D funding. Market-based support tools (e.g., tax breaks, soft loans). Stricter environmental policies.	Tax breaks, soft loans	No government support	Adoption of government and federal programs. Administrative regulation of companies' activities. Directive-based market regulation.

Note: indicator values are given for 2035 (unless other year is specified).
[a] Recession until the international hydrocarbon market stabilizes followed by a prolonged stagnation.
[b] 20%–27% in 2015.
[c] PV – direct solar energy conversion technology (photovoltaic), CSP – concentrated solar power.
[d] Until 2030. According to the Global Wind Energy Council's forecast, by 2020 global installed wind generation capacity will exceed 790 GW (in 2015, 430 GW).
[e] Until 2030.
[f] Mainly peat and wood pellets, agricultural and industrial waste, SDW, etc.
[g] Russia can produce about 3 mln tons of bioethanol from biomass; 730 mln m^3 of biogas from manure, and more than 1 bn m^3 from bioethanol production waste; 300,000 tons of biofuel equivalent from sawdust, and 800,000 tons of pellets (fuel granules) from forest industry waste, which is comparable with annual oil, coal, or natural gas outputs (Russia's annual energy balance is in excess of 1,600 mln toe). Russia is the eighth largest pellet producer in the world. In 2014, the output was 891,500 tons (31% growth). This is about 3% of global output. The global monopolists are the US and Canada: they account for almost half of the global wood fuel turnover and for about 38% of its global exports.
Sources: Russian Ministry of Energy, [44]; Pantskhava et al., Pantskhava et al., [100]; Russian Energy Agency, [86]; Smith, [101]; BP, [1]; GWEC, [83]; GWEC, Greenpeace, GWEC, Greenpeace, [113]; FAOSTAT, [102]; IMF, [103]; OECD/IEA, [116,96,104]; U.S. EIA, [49]; ERI RAS, Analytical Center, [17]; Association of Solar Energy Companies [105]; HSE research.

previously set development vectors and priorities for the energy industry, increased competition on global energy markets, and geopolitical rivalry over the control of the production and transportation of fossil energy resources. It involves addressing numerous threats, including terrorism, local conflicts, the risks of the Russian energy industry lagging behind others, and the moral and physical deterioration of assets. Under this scenario, Russian producers will have to find ways to integrate themselves into the existing international value chains in the energy sector.

The implementation of the "The worst forecast comes true" scenario would prevent the Russian energy industry from advancing to a new technological level. It would also not allow maintaining the actual positions: sustaining and upgrading tangible and intangible assets, avoiding anthropogenic disasters, retaining the technological and financial stability of energy companies, and improving the quality of their management. Following this development path could lead to a further downturn of the national economy. It would significantly limit the scope for the Russian energy industry's development until 2030, making its modernization or securing new niches on the global market impossible.

Under the "Centralized diversification" scenario, unlike the "New energy paradigm (3D)" option, the industry would remain highly monopolized, with the state playing a lead role in the renewable energy sector's development. This scenario does not imply advanced management models for the industry and increased competitiveness, so, in the long term, it is unlikely to yield sustainable outcomes.

5. Policy implications and conclusions

In recent years, various pieces of legislation were adopted in Russia, which were designed to promote the accelerated development of the renewable energy sector. Several strategic documents are currently being agreed upon by the relevant government agencies. In particular, an updated Russian S&T Foresight 2030 is being finalized; an S&T Foresight for the Russian Energy Sector 2035 was completed and approved [109]. These documents identify trends, markets, products, technologies, and promising R&D areas relevant for the development of the renewable energy industry. The draft Russian Energy Strategy 2035, the main strategic document for the industry, sets the goal of "advancing the country's energy sector, through its structural transformation, to maximize its contribution toward the dynamic socioeconomic development of the Russian Federation" [44]. The document targets from 0.7 GW of renewables per year in the conservative scenario to 1.5 GW/year in optimistic scenario. The previous version of the Strategy until 2030 had a much more ambitious goal of 3.2 GW/year. At the same time there is a discrepancy with the General Development Plan of the Russian Power Sector previews only 0.5 GW/year by 2035 (Table 2).

The Russian Government Decree № 861-r (2013) that aims at increasing the energy efficiency of the electrical energy industry through the application of renewables until 2020, and the Russian Government Regulation № 449 (2013) that aims at promoting the application of renewables in the wholesale electric power and capacity market constituted the first legal mechanism for allowing the trade in renewable energy sources on the wholesale electricity market. The Russian Government Regulation of January 23, 2015 № 47 introduced tools to support biogas, energy biomass, landfill gas, and other renewables on retail electricity markets, including the definition of regulated long-term prices (tariffs).

A roadmap was designed in 2016 to promote the development of seven smart grid and Internet of Energy markets (called Energy.Net) in the scope of the National Technology Initiative, proposed by the Russian President as a long-term public-private partnership

Table 2
Official renewable energy targets in the Russian Federation.

Russian strategy documents (name and date of adoption)		Renewable targets
November 2009 [118]	Energy Strategy until 2030	Up to 25 GW
July 2015	The basic provisions of the energy policy by the Russian Government	4.5% until 2024 (wind up to 25 GW, solar up to 50 GW)
June 2017	General Development Plan of the Russian Power Sector until 2035	11.6 GW
February 2018	Energy Strategy until 2035 (draft)	Increase the volume of power from renewables 20 times to 46 bn kW/hour

program. It is expected that Russian companies will occupy leading positions at global markets by 2035 and offer solutions for domestic smart grids and distributed energy systems, including renewable energy technologies [110].

An important event, which marked Russia's inclusion on the international renewable energy agenda was the country's becoming a member of the International Renewable Energy Agency on July 22, 2015, thus opening direct access to the best relevant international R&D practices and their application.

However, several factors significantly reduce generating and grid companies' interest in solar, wind, and small-scale hydropower. First of all, there is a surplus of installed capacity in the country (the load-to-installed-capacity rate is 0.69). Installing more capacity would only aggravate the situation further, despite the plans for dismantling inefficient outdated coal-fired heat and power plants. Secondly, the predominant traditional management views are to have 100% back-up facilities for renewable-based power plants, conventional power plants' flexibility must be stepped up (such as nuclear power plants and older gas-based thermal power plants). At the same time, Russia's national grid faces a problem of unloading power plants at night-time and summer time, as well as low capacity factor at heat power plants (less than 49% of calendar time). Thirdly, the insufficient density of electric grids significantly limits the scope for a free flow of electricity.

5.1. Proposed management tools for Russian companies

The corporate management tools Russian companies could use under each of the scenarios described above depend upon their development strategies and available resources, and on combined socioeconomic and political factors. Suggestions for companies presented below are structured into the following groups: technological innovations, new products and services, new competences, organizational changes, infrastructure upgrades, and financial matters. Some of the suggested steps and technological solutions are the same for all four scenarios, while the choice of other solutions depends on the scenario conditions.

Under the "New energy paradigm (3D)" scenario multiple innovations will be applied (Table 3). This will result in the appearance of new products and services, such as construction materials and designs based on photo converters, wind turbines for the Arctic zone and permafrost, with various capacity and design (horizontal and vertical axis) and various kinds of biofuel to substitute diesel fuel. We also expect the development and upgrade of smart systems for monitoring and controlling renewable energy facilities, and integrating them into the unified energy system.

The new competences required for these developments include designing of local solar power installations and solar settlements, control systems for renewable energy power plants and net metering systems, the ability to predict renewable power plants' operation modes and more. The development of biomass energy requires extending competences in relevant disciplines such as thermochemistry and chemical thermodynamics, organic chemistry and biochemistry, chemical engineering.

Among the multiple organizational changes expected under this scenario are the liberalization and de-monopolization of electricity markets, reduction of the government involvement in energy distribution and generation companies, establishment of independent generation companies and private heat supply companies, appearance of active consumers/individual energy producers. Companies will be able to develop projects meeting CO_2 emissions certification requirements in the scope of the Kyoto Protocol Clean Development Mechanism.

The required infrastructure upgrades include the flexible energy transmission, distribution, and storage systems of various scales to optimize energy supply and consumption; extending connections between regional energy systems; and unveiling of the national smart grid. Measures need to be taken for improving relay protection, automation, and accident prevention systems given the growing share of distributed power plants.

Under the scenario "Relying on hydrocarbon exports" only the cheapest and fast pay-off technological solutions will be implemented, such as the development of cheap solar spectrum photo converters with high efficiency factor and long working life in a wide range of capacities and sizes, with concentrators and without them, for application in diverse climatic conditions; R&D aimed at reducing wind turbines' costs, increasing their strength, reducing mass and fatigue, cutting maintenance costs and frequency of major components' failures; and technologies to grow high-output biomass crops. Similarly, the most simple and affordable products will find their way to the market, such as standardized household energy supply systems and energy generating installations based on domestic and industrial waste. The most wanted specialists under this scenario will have to be able to design renewable energy power plants; management, prediction, monitoring and control systems.

Organizational changes will not be multiple. There will be limited structural reforms, including the privatization of some of the energy monopolies. Energy companies should plan for gradual diversification through the application of technologies to convert solar energy into electricity, wind energy into electricity, and biomass energy into heat and electricity, to support their mainstream activities, supply energy to domestic regions, and develop new territories. The regional (possibly national) standards will be adopted for the interactions between smart grids and industrial equipment.

Infrastructure upgrades should be aimed at modernizing and replacing the old equipment for minimizing the losses. It is advisable to design flexible energy transmission, distribution, and storage systems of various scales to optimize energy supply and consumption. The companies will also benefit from a set of measures to promote the integration of renewables into the grid: automation, increasing the capacity of energy systems and intersystem links, designing frequency control techniques to cope with the increased share of renewables.

On the financial side infrastructural conditions to attract investments in the renewable energy sector will be maintained. The investors will be provided guarantees for returns on investments made in the scope of federal and regional targeted programs aimed at building renewable energy power plants in Russian regions.

Under the "The worst forecast comes true" scenario a limited number of new technological issues will be tackled, such as the

Table 3
Technological innovation to be applied by the Russian companies under the “New energy paradigm (3D)” scenario.

Conversion of solar energy into electricity	Conversion of wind energy into electricity	Conversion of biomass into heat and electricity
• The development of cheap photo converters with extremely high efficiency factor and long working life, utilizing the full solar spectrum, based on amorphous, polycrystalline, organic, perovskite and rectenna-based structures, in a wide range of capacities and sizes, with concentrators and without them, for use in a wide range of climatic conditions • The development of a new component base to increase efficiency and reduce unit costs of installed capacities (the development of next-generation organic elements, quantum dot elements, etc.) • The application of techniques for integrating solar energy installations into the energy system, including a more efficient mode of management and energy storage technologies. More efficient and safe energy electrochemical storage systems for hydraulic storage plants; the development and application of other storage system types (e.g., capacitor-based accumulators, chemical energy storage based on production of fuel, gravitational solid-state mechanical storage systems, thermal energy accumulators) • Energy supply solutions for spacecraft, satellites, and geolocation devices	• R&D in advanced materials and key components, for a wide range of climatic conditions, to increase productivity, reliability, and the service life of products • The development of new architectures for more powerful and lightweight wind turbines, with reduced mass (and hence costs) and better performance (large rotors, high towers, better system characteristics, higher efficiency factor) • Research aimed at reducing wind turbines’ costs, increasing their strength, reducing mass and fatigue, cutting running costs and frequency of major components’ failures (such as blades, gear boxes, generators, and power drives) • The application of high-temperature superconductor-based generators • The application of new structural materials • New wind monitoring technologies (wind measuring equipment), providing more accurate data for higher-quality and more efficient modelling and new project design	• The development of new technologies to grow high-output biomass crops; creating highly efficient microorganisms • The development of technologies for utilizing power plants’ CO_2 emissions to produce energy biomass • The development of technologies to produce biomass through artificial photosynthesis • The development of efficient technologies for biochemistry-based production of biogas from vegetable matter of various origins, on the basis of bioengineering advances including the creation of highly efficient microorganisms • The development of new technologies to produce liquid motor fuels including aviation kerosene and their components from vegetable matter • The development of new technologies to produce high value added chemical products from biomass (such as bioplastics, etc.) • The development of new technologies to transform biomass into high-quality solid fuels • The development of biomass burning technologies, for use in power plants • The development of environmentally safe technologies of biomass gasification, for use in power plants • The development of new biochemistry-based technologies to produce high-quality motor fuels from CO_2 without the use of photosynthesis • Creating new types of environmentally safe, genetically modified microorganisms to efficiently produce motor fuel components • Bioprocessing technologies: developing chemical processes, modelling technological processes, automated enterprise control systems

development of new architectures for more powerful and lightweight wind turbines, with reduced mass (and hence costs) and better performance (large rotors, high towers, better system characteristics, higher efficiency factor) and the development of biomass combustion technologies for use in power plants. New equipment will be limited to items that quickly pay-off (i.e. efficient land-based wind turbines connected to the grid in regions with high wind speed) or solve the existing problems, such as waste accumulation (i.e. energy generation installations based on the utilization of domestic and industrial waste). The renewable energy specialists will be mainly required to design facilities and settlements with renewable energy supply systems, and design management and control systems for renewable power plants.

Nearly no organizational changes, structural reforms and infrastructure upgrades are expected. It is advised to focus on the retention of existing solar, wind, and biomass-based power plants. Companies may be involved in the construction of individual small-capacity renewable energy power plants in territories where it is more economically efficient than connecting to the grid or gas pipeline. In some areas it will be economically beneficial to switch to first-generation biofuel for heating.

The range and direction of technological innovations in the “Centralized diversification” scenario will resemble those in the “Relying on hydrocarbon exports”. Companies should expect limited structural reforms in Russia, continued government regulation and public funding of the energy and manufacturing industries. As a result, the list of new products and services designed by the Russian companies will be much smaller than in the “3D” scenario. These will include charging stations for electric cars, energy supply systems and multipurpose systems (SCADA EMS), and offshore wind turbines. Grid companies will have to improve relay protection, automation, and accident prevention systems, given the growing share of distributed power plants.

Besides the general set of competences, outlined in the “Relying on hydrocarbon export” scenario, companies will have to create training opportunities for solid-state physics, physical electronics, power electronics curricula; focus on semiconductor physics and chemistry programs at universities. Specialists in applied thermochemistry and chemical thermodynamics, organic chemistry and biochemistry, chemical engineering will be in demand. Renewable energy engineers will also be required to design and implement models to predict operation modes of renewable energy facilities.

A number of fuel and energy companies will have to diversify and restructure. New public green generation companies will be established. Under this scenario companies should plan to create innovative infrastructure for the energy industry, including corporate R&D centers. National energy system standards will be streamlined with the global ones, and other organizational changes similar to those in the 3D scenario will occur.

Companies will benefit from better economic conditions to attract investments in the renewable energy sector, public funding and return-on-investment guaranties. Existing federal and regional programs to build renewable energy power plants and mechanisms supporting the application of renewables in Russian regions will be prolonged.

5.2. Proposed management tools for public authorities

Several years ago a national program supporting renewable electricity generation in Russia was adopted with Capacity Purchase Agreements (CPA) playing the central role. The government has set up 2024 targets for the development of the renewable energy sector, by type of renewables and a mechanism for trading renewable power plants power capacity on wholesale markets in line with the targets, and within the limits set for capital investments (per 1 kW of renewable energy power plants installed capacity, by type of renewables). Capital investment limits take into account currency rate fluctuations. Renewable power plants are compensated up to 50% of technology-related cost for connecting to grid. On retail market network companies are required to cover 5% of their power losses by electricity from renewable energy power plants.

The renewable energy policy agenda that is in place should be extended and continued. Renewable energy producers also believe the basic internal profit margin of the CPA projects should be increased from 12% to 14%, to increase their investment appeal and due to the complex economic situation in the country. Additionally, the authorities may consider increasing installed capacity limits of wind power plants and small hydro power plants that benefit from power supply agreements [111].

Capital expenditures related to the construction of renewable power plants remain high and directly depends on loan costs.[3] Therefore, providing concessional funding for the construction of renewable power plants should become the main government support tool together with subsidies to individual consumers and households to purchase highly efficient renewable energy generating equipment.

The following forms of concessional funding to energy companies should be extended:

- Government-subsidized interest rates for loans provided by commercial banks;
- Loans provided by the Russian Development Bank at lower-than-market rates;
- Making funding available through a special fund or extending the mandate and funding limits of the Industrial Development Fund.

On the strategy level, the renewable energy target share (excluding large hydropower plants) in the country's energy balance should be increased. Federal, regional, and municipal indicator systems will need to be developed to monitor and evaluate the implementation of policies to promote the application of renewables. Pubic support would be required to accomplish this ambitious objective. This can be achieved by explaining the main advantages of clean energy generation to consumers and providing economic incentives that may include tax breaks for households and companies for buying renewable energy generation equipment, and adopting the simplest possible procedure for selling surplus electricity to the grid.

Cross-subsidies in electricity and heating tariffs create additional problems for producers and consumers alike, and should be reconsidered. Firstly, electricity tariffs for the population in different regions vary. Secondly, nuclear energy producers and coal-based generation companies currently do not include in their tariffs the investment component given that they receive subsidies directly from the government budget. Thirdly, preferential duties are applied for the production and export of crude (super-viscous) oil. On top of that, the environmental discount remains in place: the applied fines are insufficient to fully recover the damage and do not provide stimuli for producers to invest in new pipelines.

A specific Northern Regions Supplies program should be designed and approved for northern areas in Siberia, the Far East, and in European Russia (more than a half of them are Arctic regions). A much more efficient and reliable alternative to diesel fuel would be wind- and solar-powered plants, hydrogen fuel (hydrolysis), and various types of hybrid solutions [48,77]: [112].

The application of described policy tools will differ depending on the scenario. Under the "New energy paradigm (3D)" scenario new rules for the electric energy, heat and capacity markets should be adopted. In particular, net metering legislation, and rules for active energy consumers should be put in place. This scenario also requires the development of a system of standards for solar power equipment, wind- and biomass energy power plants, and rules and standards for the installation of such equipment over the course of constructing private housing, residential, administrative, and industrial buildings.

This development path requires periodical audits and updates of legislation that sets the limits for capital expenditures and maintenance costs; methodological guidance on setting tariffs for renewable power; procedures for applying the support mechanism for the renewable energy sector. Rules and procedures will be developed to ensure grid stability on a "demand response" basis; the virtual power plant concept should be officially defined and adopted, along with rules for operating such facilities.

The "Relying on hydrocarbon exports" path will require adopting regional programs to support building renewable-based power plants only in regions where it would be economically viable in the short term; creating infrastructural conditions to attract investments in the renewable energy sector; coordinating steps to promote conventional and renewable energy generation.

If the "The worst forecast comes true" scenario unfolds, legislation and regulations for the renewable energy sector will not be developed any further after 2017. Therefore, plans should be drafted to promote the sector's development in the medium and long term. Continued basic research would be necessary even under this scenario. In a situation of dire financial straits, it would make sense to concentrate on several breakthrough areas.

The "Centralized diversification" option implies that federal and regional programs to install renewable energy power plants will serve as the main policy tools supporting the development of the renewable energy sector in Russian regions. The rules regulating relations between consumers who own power sources and sell power to the grid and retail companies (those that provide energy services to end-use consumers in residential, commercial, and industrial segment) would also need to be adjusted. Legislation may potentially be adopted to ensure grids' stability by managing the load on the demand side and regulating the virtual power plants operations.

Under this scenario, it would be important to switch from normative regulations to market-based stimuli: promote energy generation from renewable sources using tax breaks – tax credits, soft loans, investment subsidies, special tax rates linked to energy consumption, or general taxation depending on the generation type. These measures would also help bringing private investments in the sector. In addition, plans should be put in place for the gradual de-monopolization of the sector. To monitor power generating companies' compliance with their obligations, the introduction of a certification system may be required, to confirm the generation and supply of specific amounts of energy from renewable sources (solar, wind, tidal, hydro, or bioelectricity, liquid or gas biofuel).

The ever-changing economic, technological, political, and social situation in Russia, and the world at large, significantly affect the

[3] Calculations show that reducing the capital costs of solar energy generation to about 50,000 roubles per kW ($790/kW is the IRENA-forecasted average weighted capital unit cost by 2025, globally), combined with 18% CF (in Russian sun-rich regions) and a 5% annual interest rate, would bring electricity cost to RUB2.6 per kWh ("single-rate", covering both investment payback and investor's profit). If the interest rate goes down to 2% (all other parameters remaining unchanged), electricity costs would fall to RUB2 per kWh (approx. 3 dollar cents).

possible development paths for the country's renewable energy sector, and leading to different outcomes: from the major application of renewable energy power plants to their use only at a minimum level, to accomplish narrow power and heat supply-related objectives. The main forks on the Russian energy industry development path have not been passed yet.

Russia's success in switching to a new technology paradigm depends upon numerous factors, including taking timely policy and planning measures, implementing the long-overdue structural reforms in the industry to reduce market monopolization and increase competition and innovation activity of companies. Public and private support of R&D potentially leading to the emergence of new, possibly breakthrough, energy technologies would allow the country reducing its dependence upon imported energy technologies, obtain competitive advantages in certain market segments, and provide an impetus to the overall economic growth.

Advancing the renewable energy sector will not be possible without popular support, and social demand for green and efficient energy technologies: various countries have successfully increased the sector's share to the level of network parity specifically because of public pressure. In Russia, this demand has not yet developed completely, since people do not always understand the advantages of renewable-based generation. However, in the medium to long term these advantages will become obvious.

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