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Chinese experience in implementing renewable energy sources as a possible scenario for the Krasnoyarsk Territory

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Abstract
Renewable energy is a rapidly developing area of the modern economy. As many experts forecast, global electricity consumption will double by 2050, while the share of renewable sources in energy generation will be 50%. For most states, the main incentives for the development of renewable energy are the ability to eliminate the consumption of fossil fuels and reduce the level of emissions of pollutants, while ensuring sustainable development of the country. At the same time, Russia, which has significant reserves of natural resources, is in no hurry to switch to the use of energy from renewable sources since it is believed that the country's subsoil can provide it with cheap energy resources for many generations to come. Therefore, introduction of renewable energy sources that are unable to compete with traditional energy without a developed energy infrastructure and established production is impractical. In our study we try to evaluate the efficiency of the introduction of renewable energy sources in the Krasnoyarsk Territory of Russia using the example of the Chinese experience.

Keywords: renewable sources of energy, sustainable development, emissions of pollutants, Chinese experience.

JEL: L94, Q42, R58.

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Introduction

A few years ago, experts predicted that by 2030, renewable energy costs would equal the cost of electricity from traditional sources, but the cases of advanced countries show the future has come and renewables can compete with fossil fuels. However, it is still uncertain whether the introduction of renewable energy can be effective in Russia. The purpose of this work is to use the Chinese experience as an example for evaluating the efficiency of introducing renewable energy sources in the Krasnoyarsk Territory of Russia. The research and statistics of the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA), as well as analytical reviews of consulting companies, were mainly used as a theoretical and informational base for comparing the countries. Statistics for the Russian Federation was taken from the database of the Federal State Statistics Service and its department for the Krasnoyarsk Territory. As a methodological base, the authors used the study "Clean Energy Sources: Insights from Russia" devoted to assessing the potential and demand for electricity from renewable sources, and the study by the Ministry of Housing and Public Utilities of the Krasnoyarsk Territory on assessing the potential of renewable energy in the region. Many works of scientists devoted to specific types of renewable energy were also analysed, as well as materials from Forbes magazine were studied to identify barriers to the development of renewable energy in Russia.

1. Renewable energy development dynamics in the world and in China

Between 2010 and 2019, the installed capacity of renewables worldwide increased by 107.4% — from 1223.3 to 2536.9 GW[1]. The growth is even more impressive compared to 2000, at the end of which the total installed capacity of renewables was only 753.3 GW (236.6%).

For the first time the increase in installed capacity of renewable energy exceeded that of traditional energy in 2012, accounting for more than 50% of the volume of the newly installed capacity. In subsequent years, with rare exceptions, renewable energy sources were steadily increasing their share among new power plants, and by 2019 this figure exceeded 70%. As a result, the share of renewable energy in the total installed capacity of the energy sector accounted to 34.7%.

More than half of all installed capacity, namely 51.7%, is accounted for by hydropower, but this renewable energy industry is developing much slower than the rest: during the period from 2010 to 2019, the capacity increased by only 28.6%, from 925.1 to 1189.4 GW, while that of solar energy, the leader in terms of development rate, increased by 1311.7% — from 41.5 to 586.4 GW.

The success of solar energy is ensured by rapid technological progress in the field of photovoltaic (PV) generators. Encouraged by the reduction in the cost of generating

[1] International Renewable Energy Agency. Renewable energy prospects: China. https://www.irena.org/publications/2014/Nov/Renewable-Energy-Prospects-China

energy, the installed capacity of PV modules increased more than 14 times — from 40.3 to 580.1 GW. As a result, solar energy has become one of the most important sources of renewable energy, taking third place after hydropower and wind energy in the rating of renewable energy by installed capacity.

The previously mentioned wind energy has also developed rapidly. Its growth for the period from 2010 to 2019 amounted to 244.3% — from 180.8 to 622.7 GW. The most significant contribution to the growth in the popularity of wind energy was made by onshore power plants — their capacity increased by 416.6 GW, or 234.3%. However, offshore wind farms are developing much faster — from 3 to 28 GW, or by 826.4%. Solar and wind energy accounted for 90% of the total renewable energy capacity installed in 2019. Due to their versatility, SPPs and wind farms can be placed almost everywhere where the wind blows and the sun shines, and technological progress and industrial development make them more and more effective every year.

The remaining types of renewables, although their installed capacity has increased many times over 2010–2019, have an insignificant share in the total renewable energy capacity — only 5.5%, or 138.3 GW. Of these, 123.8 GW is bioenergy, which is mainly used for energy supply to consumers without access to the central grid; 13.9 GW is geothermal energy, which can be used only in special places; and 0.5 GW is ocean energy, which is still not commercialized and represented by experimental power plants.

Thus, the most promising and universal RES are solar and wind energy. Hydropower is gradually losing its popularity and, even in absolute terms, the increase in its capacity is inferior to rapidly developing renewable energy sources. However, its weight in energy production is still significant and the potential is not exhausted.

The undisputed leader in the sphere of renewable energy is China — the installed capacity of power plants in its territory is 30% of the world level. China ranks first in terms of capacity of hydroelectric power plants, solar power plants, wind farms, and bioenergy power plants.

There are countries where the share of renewable energy sources in energy production is much higher than that indicated above. Thus, Norway receives 97.5% of its electricity from renewable sources, and in the energy structure of Brazil, 82.5% is obtained from renewable energy sources. However, almost all renewable energy in these countries is generated by hydroelectric power stations, since the energy potential of the rivers in these countries makes it possible to cover all their demand for electricity.

Since such countries did not encounter problems that other states introducing renewable energy have, their experience will not be considered in this work. Further research will focus on the experience of China since its practice of introducing renewable energy sources is much more indicative.

Over the past decades, China's economy has developed rapidly, and along with it, electricity consumption has grown. From 1990 to 2017, the country's energy consumption increased from 453.9 to 5537.2 TWh — more than 12 times[2]. This has made China the largest energy consumer accounting for a quarter of the world's total energy consumption.

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2 IRENA. Data and statistics. https://www.irena.org/Statistics

However, with the growth of the economy, CO_2 emissions also increased. Over the period 1990–2017, carbon dioxide emissions in China increased 4.5 times — from 2089 to 9258 million tons, which is 30% of global CO_2 emissions. A significant part of greenhouse gas emissions is generated by coal-fired power, which produces 70% of all Chinese electricity.

But in the same period, there was an increase in the environmental efficiency of the Chinese economy. In 1990, the level of CO_2 emissions per unit of GDP was 2.3 kg, and in 2017 — only 0.9 kg[3].

Such a significant reduction in greenhouse gas emissions was achieved, among other things, through the implementation of renewable energy sources. According to the data for 2016, the share of renewable energy in China's electricity is 25.4%. Although this may not be the best indicator, the use of renewable energy allowed to avoid 1494 million tons of CO_2 emissions[4].

Chinese renewable energy has developed rapidly over the past decades, with an average growth rate of 13% from 2000 to 2019. Solar and wind energy developed faster than others, and from promising but underdeveloped sources of energy they turned into the cornerstone of the Chinese economy. Their share in renewable energy is 55%, and the lion's share of the solar and wind energy market belongs to Chinese companies.

The rapid growth of renewable energy in China was also encouraged by the lack of coal to meet the demand and low efficiency of energy generation at coal-fired power plants, which made it easier for renewables to compete with fossil fuels.

Such a rapid development of renewable energy is impossible without competent actions of authorities (Nikonorov & Baraboshkina, 2018). Fortunately, the Chinese government was ready to experiment: first, small projects were launched in certain territories, the efficiency of various legislative measures was checked, and then, if the experiment was successful, the innovation was applied throughout the country.

One of these successful experiments was the Law on Renewable Energy adopted in 2005, which laid the foundation for the development of renewable energy in the country. This law made renewable energy a priority area for energy development. In addition, research and industrial development in the sphere of renewable energy were identified as the preferred area for the expansion of high-tech industry in the national program.

The Law "On Renewable Energy Sources" also empowered the State Council to regulate the development and use of renewable energy sources at the national level. The State Council sets medium-term and long-term goals for the total development of renewable energy and consequently prepares national plans for their achievement. In designing these goals and plans, it interacts with regional and local governments in order to adjust the plan to regional differences.

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[3] IEA. Data and statistics. CO_2 emissions by energy source. China (People's Republic of China and Hong Kong China). https://www.iea.org/data-and-statistics?country=CHINA

[4] IRENA. Energy Avoided calculator. https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Avoided-Emissions-Calculator

The law also regulates the interaction of authorities, energy producers and network owners: developers of projects related to renewable energy should receive administrative permission for their implementation. If several applications are submitted for the same project license, an open tender is held, the winner of which will receive a guarantee of connecting his project to the power grid, gas pipeline or heat pipe, depending on the products being produced. The entire issue can be sold to the owner of energy grid, who is obliged to purchase it at the price established by the results of the tender. In turn, the energy grid owner can compensate for his losses by increasing his own tariffs.

In 2009, this law was finalized by setting four tariffs for renewable energy distribution. The tariff for each case is selected depending on the quality of resources, the cost of the project, and several other parameters that affect the cost of energy. As technology advances and renewable energy becomes cheaper, the government lowers the tariffs.

Another measure to promote the development of renewable energy in China is the establishment of a specialized fund which covers the difference between renewable energy tariffs and the cost of electricity received from coal-fired power plants.

In 2016, in order to avoid overproduction of low-efficiency renewable energy sources, minimum power factor requirements for wind and solar were introduced at the provincial level.

Likewise, in order to control household demand for electricity, the Chinese government introduced a system of "raising block tariffs" in 2012. According to this system, when energy consumption is low (0–240 kWh per month), electricity charges are subsidized covering about 80% of the cost, thus ensuring that the population receives a basic amount of electricity. Moreover, the poor can get a certain amount of energy for free.

The price of the second power unit (241–4400 kWh per month) is set at such a level as to offset all costs.

The price for the third power unit (more than 4400 kWh per month) increases and, in fact, fines consumers for excessive energy consumption and for the resulting excessive greenhouse gas emissions. Similar measures are applied to enterprises, and that motivates consumers to save energy thereby increasing the energy efficiency of the economy.

However, for the country's transition to renewable energy sources, encouraging their production and saving energy is not enough. One of the difficulties that the Chinese government faced on the path to sustainable development was an outdated grid[5].

A significant part of Chinese energy producers is located in the north-west of the country, while the main consumers are concentrated in the south-eastern part. Transition to renewable energy also imposes many requirements on the grid. Economic growth and uneven spatial distribution of energy generators can lead to local overloads and blackouts in outdated power grid. Moreover, such grids support only one-way interaction between producers and consumers of energy, which limits the potential of generators installed by the consumer and capable of providing energy not only to their owner, but also supplying excess to the grid. Another problem is inability of this grid to monitor supply and demand

[5] The Wall Street Journal. China Wants Smart Grid, But Not Too Smart. https://blogs.wsj.com/chinarealtime/2010/09/29/china-wants-smart-grid-but-not-too-smart/

in the network in real-time and promptly change the energy production level to meet the demand.

To solve these problems, the Chinese government decided to create a smart grid that will also be able to supply energy over long distances with minimal losses. It is planned to spend about $128 billion on this goal from 2016 to 2030, which demonstrates the importance of improving energy infrastructure for the implementation of renewable energy sources.

Thus, the successful experience of China is very indicative and allows us to draw conclusions about what steps should be taken to develop renewable energy.

2. Renewable energy implementation in Russia

As for Russia, over the past two decades, RE in our country has practically not developed. Between 2000 and 2019, installed capacity increased by just 24.6%, from 44.3 to 55.2 GW[6]. At the same time, almost 88% of all newly installed capacity is accounted for by hydroelectric power plants, which produced 17.1% of all Russian energy in 2017.

The installed capacity of the remaining renewable energy sources has grown many times over this period. Wind and solar energy were created virtually from nothing, and in recent years their growth has accelerated significantly. However, in absolute terms, the growth is insignificant, and for 2017, only 0.3% of the total energy produced was obtained from renewable sources, excluding hydropower.

The foundation for the development of renewable energy in Russia was laid in 2007 with amendments to the Federal Law "On the Electric Power Industry"[7]. Initially, the law did not contain provisions on renewable energy, however, the definition and types of renewable energy were introduced, as well as a mechanism for supporting renewable energy. Projects for the construction of renewable energy plants are selected through a tender, after which a contract for power distribution in the wholesale market is concluded with the winner. The price under this agreement is determined by the government of the Russian Federation.

In 2013, a Government Decree approved pricing rules for renewable energy capacities, which allowed companies in the renewable energy industry to profit not only from electricity distribution, but also from the capacity of plants. At the same time, the limits of the installed capacity of projects applying for this supporting measure were determined: a minimum limit of 5 MW was set for solar PVs and wind farms, and from 5 to 25 MW for small-scale hydropower plant[8].

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6 IRENA. Data and statistics. https://www.irena.org/Statistics

7 Ministerstvo energetiki Rossijskoj Federacii. Ob otrasli (The Ministry of Energy of the Russian Federation. About the industry). https://minenergo.gov.ru/node/489

8 Postanovlenie Pravitel'stva Rossijskoj Federacii ot 28 maya 2013 g. No. 449 (red. ot 10.03.2020) "O mekhanizme stimulirovaniya ispol'zovaniya vozobnovlyaemyh istochnikov energii na optovom rynke elektricheskoj energii i moshchnosti" (Decree of the Government of the Russian Federation of May 28, 2013 No. 449 (as amended on 10.03.2020) "On the mechanism for stimulating the use of renewable energy sources in the wholesale market

In 2015, in order to reduce the risks of investment projects in the field of renewable energy, the government made amendments to the previously specified procedure for determining the price of the capacity of renewable energy facilities: when calculating the price of the capacity, a correction factor was used to determine a fairer cost of financing the project using foreign currency. Investors were also given an opportunity to defer fulfilment of capacity deployment obligations[9].

In 2009, a Government Decree (8th January, No. 1-p) also determined the marginal capital expenditures for the construction of renewable energy facilities, which became an incentive for renewable energy companies to develop technologies and increase the efficiency of projects. Approved indicators are provided in Table 1.

Table 1. Limit values of capital costs for the construction of renewable energy powerplants *(thousand roubles per 1 kW of installed capacity)*

RE type	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind power	65,8	110	109,9	109,8	109,7	109,6	109,5	109,3	109,2	109,1	85
Solar PV	116,5	114,1	111,8	109,6	107,4	105,3	103,2	101,1	99,1	65	65
Small-scale hydropower	146	146	146	146	146	146	146	146	146	146	146

Source: http://docs.cntd.ru/document/902137809 (Appendix 4).

This Decree also set targets for the newly installed RE capacity that are presented in Table 2.

Table 2. Target indicators of the amount of commissioned installed capacity of renewable energy powerplants *(MW)*

RE type	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
Wind power	-	51	50	200	400	500	500	500	500	500	214,7	3415,7
Solar PV	35,2	140	199	250	270	270	270	162,6	162,6	240	238,6	2238
Small-scale hydropower	-	-	-	20,7	-	49,8	16	24,9	33	23,8	41,8	210
Total	35,2	191	249	470,7	670	819,8	786	687,5	695,6	763,8	495,1	5863,7

Source: http://docs.cntd.ru/document/902137809 (Appendix 1).

These indicators were set in such a way as to give manufacturers of renewable energy equipment time to get a return on investment in their projects, but at the same time to support competition in the long term in order to reduce the cost of equipment.

of electric energy and power"). http://www.consultant.ru/cons/cgi/online.cgi?req=doc&base=LAW&n=347433&fld=134&dst=1000000001,0&rnd=0.23295776881821317#08851836037191898

9 Postanovlenie Pravitel'stva Rossijskoj Federacii ot 28 maya 2013 g. No. 449 (red. ot 10.03.2020) "O mekhanizme stimulirovaniya ispol'zovaniya vozobnovlyaemyh istochnikov energii na optovom rynke elektricheskoj energii i moshchnosti" (Government of Russia "On measures to stimulate the use of renewable energy sources in the wholesale market of electric energy and power"). http://government.ru/docs/20510/

Nevertheless, it must be pointed out that if we compare the presented targets with the statistics of the newly introduced installed capacity of renewable energy sources, we can see that in most cases the plans were not implemented sufficiently.

In order to encourage the development of high-tech production in Russia, this Decree specified target indicators for localization of renewable energy facilities commissioned in the period from 2020 to 2024. For wind and small hydropower plants this indicator is 65%, and for solar power plants — 70%.

In 2015, the government adopted Decree No. 47 (23th January), due to which renewable energy companies received support in the retail electricity markets, as well as in off-grid areas: energy grid companies must purchase energy from renewables at established tariffs. Requirements for capital costs and localization were also established for renewable energy companies participating in the retail market.

Another measure to support the renewable energy industry is to cover half of the cost of technological connection of generating facilities with a capacity of up to 25 MW through subsidies from the federal budget (Alikerimova & Ninalalov, 2019).

The support measures described above for companies in the renewable energy sector are already yielding the results. Even though not all targets were achieved, in the period from 2016 to 2019, it was possible to deploy a significant amount of renewable energy capacities, as well as to reduce the average cost of capital for solar and wind power plants that are presented in Table 3.

Table 3. Average planned capital costs based on the results of tenders of renewable energy projects *(thousand roubles per kW of installed capacity)*

RE type	2013	2014	2015	2016	2017	2018	2019
Wind power	115,7	111,6	122,8	-	112,5	78,2	49,8
Solar PV	64,9	-	155,1	136	102,9	67,6	64,9
Small-scale hydropower	-	146	174	-	163,9	174,5	175,9

Source: https://minenergo.gov.ru/node/489

Production of equipment for renewable energy plants has also increased: from 140 MW of installed capacity per year in 2012 to 900 MW per year in 2019. Thus, it can be noted that the measures to support renewable energy used in Russia are generally similar to those of the Chinese government (Nikonorov & Baraboshkina, 2018). Of course, the success of Chinese renewable energy is incomparably brighter than the Russian one, but China had a powerful incentive — the high cost of coal-fired energy, while in Russia it was the other way around.

Renewable energy in Russia has significant potential[10]. The average level of insolation in the southern and south-eastern parts of Russia is 3.5–4.5 kWh per day, or 1200–1500 kWh

[10] IRENA. (2017). Remap 2030 Renewable Energy Prospects for Russian Federation, Working paper, IRENA, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Apr/IRENA_REmap_Russia_paper_2017.pdf

per year, per square meter, which is higher than in many countries where solar power is already actively used.

Russian wind power has the highest potential in the world, its possible energy production is 2571.8 PWh per year. Just 0.03% of this energy would be enough to cover the need for electricity throughout Russia. At the same time, wind energy is distributed more evenly throughout the country than solar energy.

The best zones for placing wind farms are the northern and south-western territories of the country where the wind speed at an altitude of 100 meters often exceeds 8 m/s.

In general, the economically feasible potential volume of electricity generation from wind power is estimated by experts at 260 TWh per year which is approximately 30% of the country's electricity consumed. However, one cannot fail to notice that these calculations were made back in 2016, and since then the cost of generating energy at wind powerplants has decreased, so now even a larger share of Russian energy consumption can be provided by wind energy.

Hydropower also has great potential. Russian water resources are considered to be among the richest in the world. The volume of economically feasible energy generation using hydroelectric power plants is almost 5 times the current capacity, which is approximately 150% of the electricity consumption of the country. The central and eastern parts of the country have the greatest potential.

A significant difference in water levels during high and low tides in the White and Okhotsk Seas amounting to about 10 meters, as well as in many other territories with a high difference in water levels during the day, provides Russia with a potentially high level of electricity generation when using ocean energy. In general, the potential generation of electricity through a TEC is estimated at 90 GWh per year.

Geothermal energy has significant potential, too. Many regions have reserves of hot geothermal fluids. The potential installed capacity of geothermal power plants is estimated at 2 GW.

Finally, Russia has enormous potential in all types of bioenergy — from by-products of the forest industry and peat to organic waste and urban waste. The Russian Federation possesses 20% of the world's forest resources, which the forest industry can potentially use to produce a huge amount of solid biofuel (wood chips, wood pellets, etc.). Organic agricultural waste amounting to 625 million tons per year can be used in the production of biogas, which, in turn, can be used to generate electricity. 165 million tons per year of urban waste can also be used for biogas production. In total, it is economically feasible for Russia to produce about 830 TWh of electricity per year from bioenergy.

At the same time, renewable energy can solve the problem of energy shortages in isolated areas. The main source of electricity in these regions is diesel power plants, which have many shortcomings:

1) Poor technical condition of the equipment that leads to frequent breakdowns and low efficiency of energy generation;
2) Dependence on fuel shipments from remote areas via a poorly developed transport network that implies a high cost of energy generation and the possibility of obtaining fuel only under suitable weather conditions;

3) Dependence on state financial support since without it energy generation in isolated areas is not economically feasible. However, it is worth noting that at the same time, companies generating electricity in such areas have no incentive to replace diesel generators with renewable energy sources since their costs are compensated from the state budget.

These generators produce about 2.5 TWh per year, and the cost of the electricity they produce varies from 60 to 80 roubles per kWh, and in some cases reaches 120 roubles. In such regions, renewable energy sources may not just be competitive — they will become a salvation for residents. Therefore, the government pays special attention to the development of renewable energy in isolated regions.

Thus, even without considering solar and geothermal energy, Russia has the potential to provide 300% of its energy consumption (according to 2017) using RES alone and, moreover, to supply isolated areas with clean and cheap energy. But at the same time, there are many factors that impede the development of renewable energy in Russia.

The first barrier is high competition from conventional energy. While transition to renewable energy was economically and strategically beneficial for countries that do not have sufficient reserves of fossil fuels on their territory, the opposite is true for Russia. The presence of huge reserves of fossil resources allows our country to not depend on external supplies and create many jobs, as well as significantly reduces the cost of electricity produced by traditional energy, thus increasing its competitiveness.

At the same time, the cost of generating energy from solar and wind power in Russia is not dropping as fast as the global average. The following factors influence the cost of renewable energy in Russia:

1) A low level of mastering the production of equipment for powerplants since companies from the renewable energy sphere entered the Russian market relatively recently. At the same time, due to localization requirements, companies are forced to incur significant costs for creating production in Russia in a short time, which are then distributed to a small volume of output;
2) The remoteness of power plants construction sites from equipment manufacturing centers, which, along with poorly developed transport infrastructure, seriously increases the cost of transporting equipment. In addition, the best places for energy generation are often located far away from consumers of electricity, which increases transmission losses and requires improvement of existing infrastructure;
3) Climatic characteristics of the country. The cost of building electricity generation facilities based on renewable energy sources often increases due to the need to consider significant temperature drops during the year or frozen soil;
4) Insufficient elaboration of technical regulation in the field of renewable energy[11]. Russian standards of technical regulation do not take into account the specifics

[11] Kalanov, A. (2018). Vozobnovlyaemaya energetika v Rossii: Stoyat' na meste ili sdelat' pervyj shag. *Forbes* 18.04 (Kalanov, A. (2018). Renewable energy in Russia: To stand still or take the first step. *Forbes* 18.04). https://www.forbes.ru/biznes/342905-vozobnovlyaemaya-energetika-v-rossii-stoyat-na-meste-ili-sdelat-pervyy-shag

of renewable energy powerplants, therefore irrelevant requirements are often imposed on them, and approval of construction, the process of obtaining certificates of compliance with technical requirements, which begins only after the facility is commissioned, and integration into the power grid can last several years;

5) High risks. The dependence of the Russian renewable energy industry on external supplies of equipment for the production of generators along with an unstable exchange rate, as well as the influence of the above factors, leads to a significant increase in risks for investors, which implies an increase in the cost of capital for companies from the renewable energy sector.

The introduction of renewable energy sources is also hindered by excessive electricity production. In 2017, only 760.8 GWh (or 70%) out of 1,094.2 GWh of generated energy was consumed. And introduction of new generating facilities will only increase the imbalance. Another problem is the outdated grid. As noted earlier, it is difficult to integrate renewable energy generators into a conventional grid, and a significant part of their potential remains unexploited. The natural monopoly on the energy infrastructure, in particular, the grid, also complicates the competition of renewables with fossil fuels and makes it difficult to connect renewable energy sources to a single energy system[12].

Thus, as can be seen in Table 4, in 2014, the levelized cost of electricity from renewable sources significantly exceeded the same indicator of traditional energy sources.

Table 4. Levelized cost of electricity in Russia, 2014

Powerplant type	**Fuel cost** (RUB/ GJ)	**Lifetime** (Years)	**Capital cost** (RUB/ kW)	**Operation & maintenance cost** (RUB/kW per year)	**LCOE**	
					Discount rate 10% (RUB/ kWh)	**Discount rate 12%** (RUB/ kWh)
Coal-fired	62,4	60	86 400	3504	2,4	2,4
Gas	132,96	30	38 400	2064	1,92	2,4
Solar PV	-	30	114 122	2448	12–16,8	13,92–19,2
Wind	-	30	110 000	1680	4,32–6,24	4,8–7,2
Small-scale hydropower	-	40	146 000	2928	5,28–5,76	6,24–6,72

Source: Kalanov, A. (2018). Vozobnovlyaemaya energetika v Rossii: Stoyat’ na meste ili sdelat’ pervyj shag. *Forbes* 18.04 (Kalanov, A. (2018). Renewable energy in Russia: To stand still or take the first step. *Forbes* 18.04). https://www.forbes.ru/biznes/342905-vozobnovlyaemaya-energetika-v-rossii-stoyat-na-meste-ili-sdelat-pervyy-shag

[12] Ernst & Young. Obzor elektro-energeticheskoj otrasli Rossii (Overview of the electric power industry in Russia). https://www.ey.com/Publication/vwLUAssets/EY-power-market-russia-2018/$File/EY-power-market-russia-2018.pdf

3. Efficiency of introducing RE in the Krasnoyarsk Territory

The Krasnoyarsk Territory is one of the largest subjects of the Russian Federation (after the Republic of Yakutia). The land area of the region is 2.36 million km^2 — 13.9% of the country's total territory[13]. Its length from north to south is almost 3000 km, and from west to east it reaches 1250 km.

According to a study conducted by the Ministry of Housing and Public Utilities of the Krasnoyarsk Territory and the Siberian Federal University, renewable energy sources have significant potential[14].

30 out of a total of 44 municipal entities, located mainly in the southern part of the region, have conditions suitable for sustained operation of photovoltaic generators. In another 11 districts located in the central part, operation of photovoltaic generators is possible, however, generation of energy will not be so efficient. 3 northern regions are unsuitable for solar power plants.

Using data on the gross insolation of the districts, calculations of the potential power generation in these municipalities were made, the results of which can be seen in Appendix 6. Data on the efficiency of Hevel PV modules were used for calculations[15] since this is the only company in Russia that has own production of these plants and therefore it is the most preferred and probable supplier of equipment for solar power plants, given the localization requirements and the government's commitment to develop high-tech production in Russia.

As for another technology of utilizing solar power for electricity production — concentrated solar energy — application of this technology is advisable only near the equator, and therefore it cannot be used in the Krasnoyarsk Territory.

To determine the potential energy production using wind turbines located onshore, we used data on the average wind speed in the most suitable locations of wind farms in the entities, as well as indicators of the Ulyanovsk wind farm built by Fortum.[16] The calculation of the electricity generated by one generator per year was carried out according to the following formula (Aubakirov, 2016):

$$E_{annual} = (\eta * WEUR * \rho * V^3_{av.a.} * \pi * D^2)/8, \quad (1)$$

where η — generator's efficiency; *WEUR* — Wind Energy Utilization Ratio; ρ — air density, kg/m^3; $V_{av.a}$ — average annual wind speed, m/s; D — the diameter of the blades of the generator, m.

Since in this case we used the example of the Ulyanovsk wind farm and the characteristics of its equipment, the only variable is the wind speed. Thus, wind energy in the region does not have as much potential as solar energy, but it can be used in areas isolated from the

[13] http://www.krskstate.ru/about

[14] Ministerstvo promyshlennosti, energetiki i zhilishchno-kommunal'nogo hozyajstva Krasnoyarskogo kraya. Investicii v vozobnovlyaemuyu energetiku (The Ministry of Industry, Energy and Housing and Communal Services of the Krasnoyarsk Territory. Renewable energy investments). http://gkh24.ru/pages/view/61 /

[15] https://www.hevelsolar.com/catalog/solnechnye-moduli/

[16] https://www.fortum.ru/vetryanaya-elektricheskaya-stanciya-v-ulyanovskoy-oblasti

central network where the level of insolation is insufficient. These include the Taimyr and Turukhansky municipal entities — their insolation rates were the lowest, while the level of electricity generation with the help of wind generators was the highest.

Despite the formation of a thick layer of ice on the rivers of the region in winter, the potential for developing small-scale hydropower plants in the region is very high: due to the fact that many settlements, including energy-deficient ones, are located near rivers, small hydropower can be used to supply these settlements with electricity. The construction of such plants in these settlements would not only solve the problem of their energy shortages, but also create an opportunity for them to develop an industry based on the processing of taiga resources.

Calculation of the potential and economic efficiency of full-scale hydropower plants is very difficult due to the lack of necessary data in the public access and high dependence of indicators on the individual characteristics of the project. In this regard, further study will only use their energy generation cost which averages about 32 kopecks.

Bioenergy in the region is geographically tied to certain agricultural and woodworking enterprises and peat deposits. In this regard, the development of this energy sector is feasible only in several municipal entities of the region. Biogas production can be carried out in areas with developed livestock farming. The list and potential of this areas is presented in Table 5.

Table 5. Biogas potential in the Krasnoyarsk Territory

Municipal entity	Electricity generation potential (MWh per year)
Berezovsky	21 495
Emelyanovsky	16 728
Nazarovsky	82 281
Uzhursky	30 010

Source: The Ministry of Industry, Energy and Housing and Communal Services of the Krasnoyarsk Territory. Renewable energy investments. http://gkh24.ru/pages/view/61/

Thus, these areas have significant potential for biogas energy. As for the other areas of bioenergy, despite the presence of significant peat reserves and a developed woodworking industry, the use of these resources is extremely difficult due to the remoteness and inaccessibility of peat deposits, and, in the case of the woodworking industry, due to the use of its waste for other purposes.

Geothermal energy cannot be used either for energy generation, or for heating buildings as there are no geothermal resources in the region that are close to the surface and have a high temperature for energy generation, and the use of heat pumps can only be feasible in places with an average annual air temperature from +4.5 C^0 to +5 C^0, while the average annual temperature even in the southern part of the region is +1.6 C^0.

The use of ocean energy in this territory is also very difficult since the Kara Sea and the Laptev Sea that wash the region belong to the Arctic Ocean basin, and therefore the bays where ocean energy powerplants can be located are covered with ice for most of the year. At the same time, consumers are often located far away from such places and that makes the use of ocean energy for electricity production even more difficult. For the same reasons, the use of offshore wind power is also difficult.

Thus, further research on the effectiveness of RE implementation will concern the use of solar energy, wind energy, small-scale hydropower, and biogas.

To calculate the cost of energy generation by renewables, we used the indicator of Levelized Cost of Electricity (LCOE) which is actively used in similar calculations by international agencies, including IRENA.

There are many variations of calculating this indicator, but in this work its basic version is used:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}, \quad (2)$$

where I_t — investment costs in year t; M_t — operating costs in year t; F_t — fuel acquisition costs in year t; E_t — electrical energy generated in year t; r — discount rate; n — expected lifetime of powerplant.

Investment and operating costs for wind farms, solar power plants, small-scale hydropower and biogas, the limit values of the corresponding costs per 1 kW of installed capacity were taken from the Decree of the Government of the Russian Federation (July 28, 2015 No. 1472-p)[17]. The data on the capital and operating costs of thermal power plants were taken from the article by VYGON Consulting[18].

The cost of fuel for a solar power plant, wind farm and small-scale hydropower plant is zero — it is simply not required for these types of stations. For biogas plants, fuel costs are also accepted as zero, since they use livestock waste. For thermal powerplants, fuel costs were determined based on the average cost of coal supplied to Russian power plants.

The generated energy volume of solar and wind power was calculated based on the previously determined potential volume of electricity generation, set for 1 kW of power. For a small-scale hydropower plant, electricity generation was determined based on the indicators of the RusHydro project[19]. To calculate the energy production by biogas power plants, data on the company BioEnergoSila[20] products were used.

The discount rate for renewable energy sources was determined based on the average level of rates for green bonds taken from the Moscow Exchange website. It amounted

[17] Pravitel'stvo Rossijskoj Federacii. Rasporyazhenie ot 28 iyulya 2015 g. No. 1472-r. (Government of the Russian Federation. July 28, 2015 No. 1472-r). http://static.government.ru/media/files/goomAd8bkYkAzjAwAOpRJ5pt2mjqbviW.pdf

[18] https://vygon.consulting/upload/iblock/7f1/vygon_consulting_power_plants_modernization.pdf

[19] PAO "RusGidro". Opredeleny postavshchiki gidrosilovogo oborudovaniya dlya Krasnogorskih MGES (PJSC RusHydro. Suppliers of hydraulic power equipment for the Krasnogorsk SHPPs were identified). http://www.rushydro.ru/press/news/110853.html

[20] http://www.bioenergosila.ru/services/biogas/

to 10.3%. The discount rate for thermal powerplants was set at 8.54% based on the average coupon rate for bonds of Enel Russia. This company is chosen for calculation due to the fact that it is the only energy company that has only thermal power plants in its assets and has issued bonds on the Moscow Exchange[21]. The discount rate for renewable energy sources, as expected, turned out to be higher due to increased risks for investors.

The data on the service life of the facilities were taken from the IRENA study indicated earlier, and, in the case of biogas plants, from the product description on the corresponding company's website.

Further, the maximum and minimum indicators were identified for various types of power plants: for solar PVs and wind farms — based on the resource potential of the entities; for small-scale hydropower and biogas plants — based on their installed capacity; for thermal power plants and large-scale hydropower, only an average indicator was calculated. Thus, the following results were obtained in Table 6.

Table 6. Levelized cost of electricity

Powerplant type	**LCOE** (RUB/kWh)	
	Min	**Max**
Solar	10,96	17,47
Wind	1,73	525,63
Small-scale hydropower	4,59	10,76
Biogas	2,92	4,60
TPP	3,28	
Large-scale hydropower	0,32	

Source: authors' calculations.

The results are generally similar to the previously indicated IRENA data on the normalized cost of electricity in Russia, however, one can note a rise in the cost of thermal powerplants energy generation due to rising coal costs and inflation, and, at the same time, LCOE conservation for solar PVs and a decrease for small-scale hydropower that is a consequence of improved technology and the gradual establishment of equipment production.

To assess the efficiency of RE implementation in the Krasnoyarsk Territory, three scenarios will be considered: an initial one that illustrates the current situation; a 10% increase in the share of renewable energy sources, according to which renewable energy sources will be introduced everywhere; and optimal deployment of renewable energy sources, in which the share of renewable energy sources increases by 10% only in those areas where it is economically feasible (Papenov & Nikonorov, 2017).

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[21] https://www.moex.com/s3019?utm_source=www.moex.com&utm_term=%D1%81%D0%B5%D0%B3%D0%BC%D0%B5%D0%BD%D1%82%20%D0%B7%D0%B5%D0%BB%D0%B5%D0%BD%D1%8B%D1%85

To compare the scenarios, the Krasnoyarsk Territory was divided into two zones:

1. Having a central power grid. It includes the southern part of the region, as well as the city of Norilsk and part of the Taimyr Region.
2. Isolated from the central grid. This area includes remote areas in which diesel generators are used to generate energy.

The efficiency assessment itself will be carried out according to the following parameters:

1) Investment costs for the introduction of RES;
2) Expenditures for the capacity supply contracts;
3) Energy generation cost;
4) Air pollutant emissions.

Scenarios will be compared based on the data for 2018 (data on diesel generation is taken for 2014).

According to the initial scenario, the current situation in the Krasnoyarsk Territory remains unchanged, and RE powerplants are not introduced. In this case, the cost of implementing the scenario is zero.

In the zone with central energy supply, the average normalized cost of electricity is 1.54 RUB/kWh. In the isolated zone there is no certain level of cost of electricity generation. It is set individually for each locality due to the high and variable costs of transporting diesel fuel. Since most points cost in the range of 60–80 RUB/kWh, in this study we will use the average value of 70 RUB/kWh.

Thus, the average normalized cost of electricity in the whole region is 1.74 RUB/kWh.

The level of all emissions of pollutants is 529.1 thousand tons[22], 229.4 account for the energy sector. At the same time, emissions from diesel generators which are not considered in regional statistics are added to them. Their volume accounts for additional 13.3 thousand tons.

In the case of a 10% increase in the share of renewable energy sources, in order to replace TPPs, it is necessary to introduce plants capable of generating 5.6 billion kWh per year in a zone with central energy supply, 983 million — in a separate power grid of Norilsk and part of the Taimyr Region, and 160 million kWh per year — in an isolated area.

Renewables will be deployed in such a way as to try to achieve the minimum cost of electricity, thus four biogas power plants will be commissioned in the zone with central energy supply since this type of facility has the lowest cost of generating electricity. Their total generation will amount to 150.5 million kWh per year, which will require the introduction of 18.6 MW of capacity. Capital costs for their construction will amount to 3.3 billion roubles for investors. Of course, biogas power plants will emit CO_2 in the course of work, however, due to the fact that at the same time they process livestock waste polluting the atmosphere, in this work the emission from these greenhouse gas stations will be considered as zero (Klochkova & Harlamova, 2015).

[22] Ministerstvo ekologii i racional'nogo prirodopol'zovaniya Krasnoyarskogo kraya. Gosudarstvennyj doklad «O sostoyanii i ohrane okruzhayushchej sredy v Krasnoyarskom kraev 2018 godu» (Ministry of Ecology and Environmental Management of the Krasnoyarsk Territory. State report "On the State and Environmental Protection in the Krasnoyarsk Territory 2018". http://mpr.krskstate.ru/dat/File/3/Gosdoklad%20.pdf

Another 60 million kWh will be generated using small-scale hydropower deployed in 30 entities with a total capacity of 17.8 MW, which will cost potential investors 2.6 billion roubles.

The remaining energy could be provided by wind farms located in the Achinsk Region, which is the most suitable for such power plants in the southern part of the Territory. However, to generate 5.39 billion kWh, it would require deploying a power plant with a capacity of 3376.8 MW produced by 1350 generators. Given that such a power plant would require a huge area, which is unlikely to have enough space with high wind speed, this project is not feasible. Therefore, for further research, the maximum wind farm size for the southern regions will be set at 35 MW, which corresponds to the largest wind farm in Russia — Ulyanovsk.

Thus, wind farms will be built in 4 entities: Achinsky, Bogotolsky, Nazarovsky, and Uyarsky. Their total capacity will be 140 MW, energy production — 191.7 million kWh per year, and the average LCOE — 9.31 RUB / kWh. It will require 15.3 billion roubles of investments.

Since further introduction of wind farms is impractical, the remaining energy will be generated by solar powerplants, the most expensive renewable energy source according to the LCOE. The installed capacity of the required power plant will be 4.3 GW, and generated energy — 5.2 billion kWh per year. It will occupy the territory of the Ermakovsky entity with an area of 2588 hectares (excluding the space between solar panels) and require investments in the amount of 463 billion roubles.

Norilsk and the Taimyr entity will be supplied with energy by a huge wind farm capable of generating 983 million kWh per year since this is much more realistic in this area than in the Achinsky entity. This will require an installed capacity of 135 MW, 54 wind generators, and 14.7 billion roubles of investments.

To provide isolated areas with RE, it will be necessary to place power plants in each of them due to their large size and low population density. Data on powerplants in these areas is provided in Table 7.

Thus, the average LCOE of renewable energy in isolated areas will amount to 10.82 RUB/kWh, which is significantly less than the current cost of electricity. LCOE in entities supplied by central energy grid will account for 9.29 RUB/ kWh, and in the whole region — for 9.34. The average cost of generation, including all energy sources, is 64.08, 2.49 and 3.15 roubles per kWh, respectively.

The introduction of RES will also require the support of their owner. Under the renewable energy supply contract, their owners will be able to receive payment for electricity generated by the plants at an increased rate. This rate strongly depends on the individual characteristics of powerplants, however, based on the fact that 1.5 GW of renewable capacity was constructed under the capacity supply contracts which cost consumers 43.7 billion roubles over 5 years, we can assume that the cost of maintaining 4.7 GW of capacity will amount to 27.3 billion roubles a year, but will decrease every year.

Another cost item is the placement of a power grid capable of realizing the potential of renewable energy in an area with a centralised energy distribution. The infrastructure

Table 7. Energy supply of isolated areas

Municipal entity	RE type	Installed capacity (kW)	Energy generation (kWh per year)	Investments required (million roubles)	LCOE (RUB/kWh)
Abansky	Small-scale hydropower	6,24	21 000,00	1,87	10,76
Balakhtinsky	Small-scale hydropower	2,66	8960,00	0,80	10,76
Boguchansky	Small-scale hydropower	0,03	100,80	0,01	10,76
Yeniseisky	Small-scale hydropower	449,61	1 512 940,00	134,88	10,76
	Solar	2061,40	2 105 488,00	221,42	12,94
Ermakovsky	Small-scale hydropower	6,58	22 130,00	1,97	10,76
Idrinsky	Small-scale hydropower	7,88	26 530,00	2,37	10,76
Kezhemsky	Small-scale hydropower	136,01	457 690,00	40,80	10,76
Motyginsky	Small-scale hydropower	37,30	125 530,00	11,19	10,76
North Yeniseisky	Solar	17,47	17 650,00	1,88	13,08
Taseevsky	Small-scale hydropower	4,44	14 950,00	1,33	10,76
Turukhansky	Wind	2257,50	5 309 650,00	247,58	5,86
Evenkisky	Solar	6760,21	6 222 420,00	726,11	14,35

Source: authors' calculations.

improvement project in the Krasnoyarsk Territory has already begun, and the expected investments required to modernize the network are 6.5 billion roubles for the southern part of the region[23].

Also, technological connection of plants to the power grid will require additional investments. However, due to the fact that the cost of connection is calculated individually for each project, it is impossible to estimate investments for connecting to the power grid, as well as subsidies from the state budget that cover part of the costs of connecting renewables.

As for environmental efficiency, thanks to reducing fuel consumption of TPPs and diesel generators by 24.2% and 10%, respectively, emissions will be reduced in the amount of 56.7 thousand tons.

According to the scenario of optimal development of renewable energy, the share of renewable energy will be increased by 10% only in those areas where this will lead to a decrease in the cost of electricity.

As follows from the scenario considered earlier, the introduction of renewable energy plants is advisable only in isolated areas. The Taimyr entity will also be added to those indicated in Table 7, however, now it will only include settlements isolated from the central grid and using diesel generators.

[23] https://neftegaz.ru/news/powernetworks/193394-mrsk-sibiri-planiruet-zavershit-sozdanie-2-y-tsifrovoy-podstantsii-v-krasnoyarske-uzhe-v-avguste-201/; https://tass.ru/ekonomika/6515200

According to this scenario, the average levelized cost of electricity in the entire region will be 1.72 roubles. The amount of investments needed to deploy the generators will be 1.4 billion roubles. The expenditures for the capacity supply contracts will be about 71.3 million roubles per year.

At the same time, reducing the cost of energy generation will save up to 1.15 billion roubles a year. We can state that the return period of investments is just over a year; however, these funds will not be received by investors themselves, but by the entire economy, since the cross-subsidization method is introduced to compensate for excessively high tariffs in some regions by aligning them with tariffs in other. This method led to an increase in electricity tariffs for the enterprises in the Central Federal District, thus making them pay for isolated areas (Chugunov, 2019).

Investments in the improvement of the power grid will not be required since each settlement will be connected to its own power plant which has all the necessary equipment to create local smart grid. Under this scenario, the emission of pollutants into the atmosphere will be reduced by 1.33 thousand tons. Thus, it is possible to compare the scenarios. The summary of this comparison is presented in Table 8.

Table 8. Summary of the scenarios overview

Scenario	Initial	10% increase in the share of renewables	Optimal introduction of renewables
Investments required (billion roubles)	0,0	506,8	1,5
Expenditures under capacity supply contracts (million roubles per year)	0,0	27 300,0	71,3
Average LCOE in central grid areas (RUB/kWh)	1,5	2,5	1,5
Average LCOE in isolated areas (RUB/kWh)	70,0	64,1	64,1
Average LCOE (RUB/kWh)	1,74	3,15	1,72
Emission of air pollutants by the industry (thousand tons)	242,7	186,0	241,4
Total emission of air pollutants (thousand tons)	542,4	485,7	541,1
Cost of electricity reduction efficiency (RUB/kWh for 1 billion roubles)	-	–0,003	0,014
Emission reduction efficiency (thousand tons for 1 billion roubles)	-	0,112	0,917

Source: authors' calculations.

Thus, as can be seen in the table above, the introduction of renewable energy in the isolated areas of Krasnoyarsk is the most economically and environmentally efficient solution as it will provide a reduction in both emissions and the average cost of electricity.

Conclusion

Renewables are rapidly developing. Its technologies are improved every year, the installed capacity of power plants is growing, and the cost of electricity generated by them is decreasing. Russia's application of the successful practices of China, a pioneer of renewable energy, creates the basis for the development of renewables, but existing barriers hold back their potential. The Krasnoyarsk Territory has the same problem — the region has significant potential, but it is difficult to utilize it.

The study reveals that in the current conditions, the massive introduction of renewable energy in the Krasnoyarsk Territory is inefficient since this will require huge investments that will lead to sufficient reduction of pollutant emissions but increase the average cost of energy generation. However, the use of renewable energy in isolated areas is much more appropriate: this will significantly reduce the cost of energy generation in remote settlements, lessen the burden on all energy consumers, and lower the amount of air pollutant emissions. Thus, we can conclude that the introduction of renewable energy in the Krasnoyarsk Territory can prove effective.

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