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Geothermal Energy: Comparative Characteristic of the USA and Russia

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ABSTRACT
The article gives an overview of geothermal energy in the USA and Russia. To compare the efficiency of using geothermal power stations, the criteria and methodology for their calculation are identified. There are such tools as swot-analysis, comparison on certain criteria as the proportion of areas suitable for geothermal energy, the share of electricity generation in the total and posed the problem of the need to determine the correction factor. The result is the degree of development of alternative energy in each region and the definition of risks.

Keywords: *Geothermal energy, Heat sources, Isolated energy systems.*

1. A LITERATURE REVIEW

The Alternative energy sources are becoming increasingly popular, and many developed countries are attempting to completely replace traditional sources and thereby improve the state of the environment. Despite the fact that the most widely used sources of alternative energy are solar, wind and hydropower, the government and scientists are actively developing geothermal sources, biomass and others. For example, the regulation and possibilities of use in Russia studied by V.A. Butuzova [1], S.V. Alexeenko [2], E.I. Boguslavsky in the monograph "The development of thermal energy" [4], M.I. Kalimillin [5], and on the experience of foreign countries S.V. Levinson [6]. The works of the following authors on the study of the economic and technical component were cited in: V.A. Butuzov [7] and others [8], [9]. In the analysis of geothermal energy the works of Jefferson W. Tester, Koenraad F. Heer, which revealed in detail the energy of the United States. Ozan Sen, Omer Faruk Guler, Ceyhun Yilmaz came to the conclusion that geothermal energy has economic benefits due to natural and technological factors. The strategies of sustainable development of each state and the documents of the U.S. Government on the management of mineral resources and the Energy Strategy of the Russian Federation until 2030 were studied. Nowadays Russia has a branched general power generation system working on fossil fuels and nuclear power. The development of geothermal energy will allow to differentiate the sources of energy supply and stimulate off-grid system generation, which is necessary for isolated areas, for example, Chukotka, Sakhalin region, several energy districts of Kamchatka. The latter has been using alternative energy for a long time. To assess the development of the region and the possibility of developing geothermal energy, the aim is to determine the indicators of development and conduct a comparative analysis of the two countries: the USA and Russia. As well as to assess the risks that accompanies both the development of energy and the lack of the necessary development.

2. MAIN BODY

The alternative energy is gaining a place in the energy mix of countries. According to BP statistical review of the global energy, the total production was 7.4 TWh, hydropower – 4.3 TWh, solar – 856 TWh. Geothermal energy production, according to Irena data, has reached 92.05 GWh, with an average growth rate of 3 % since 2014, the year when the Paris Agreement was signed. The high share of geothermal energy in some countries is due to natural limits and regions with high ground heat. Iceland, for example, mainly heats with this method because of its geophysical capabilities.

There are several factors leading to an increasing share and efficiency of geothermal heat sources. Firstly, there is a tendency that the temperature of the earth is growing every year. Secondly, the need for electricity is rapidly expanding, despite the trends of sensible

consumption. Finally, the tendency of countries to achieve carbon neutrality at the lowest cost.

2.1. Methodology

The methodology of the study will be the use of comparative analysis of the two countries, highlighting the key criteria. Conducting an analysis of the stations used in the context of each country and determining the current and possible risks.

Two types of criteria according to the methodology are used for the comparison. Macroeconomic indicators, such as generating total capacity at Geo power stations and the regions where the stations are located. They show the general position of the country in the world energy market and the interest in the development of this industry. Second, estimated indicators such as the proportion of areas with a high concentration of ground temperature to the total territory of the country, the proportion of regions with installed power generation capacity from geothermal sources to all regions in the country, and the proportion of electricity generation from geothermal sources to the total. The indicators have been defined as core because they completely encompass the countries' geothermal energy development activities and are not difficult to calculate, thus reflecting the accuracy of the calculations to a certain extent. However, not exhaustively determines the predisposition of the country to develop alternative energy, due to different conditions.

An analysis of each country was conducted separately. On the basis of existing plants was considered approach to their management. Technical analysis of the plants of the countries studied, which on some sample reveals the general degree of development of the industry at the microeconomic level. A SWOT analysis was made, which revealed the prospects for the use of energy and the risks if the basic strategy is not followed.

2.2. Technological analysis

Principal schemes of geothermal power stations, depending on the scheme of the organisation and the conditions of application. There are three schemes of power generation using hydrothermal sources:

1. Direct – usage of dry ground steam;

2. Indirect – usage of saturated water steam;

3. Mixed – usage binary cycle. [4]

Geothermal power stations are classified according to the heat transfer: single separation, with two separation pressures, steam expansions, and binary cycles. Generally, geothermal power stations operate on superheated steam, the binary system helps to use the energy of the earth even at low temperatures, which makes it possible to increase the heat output and use in regions that are less suitable for the application of geothermal stations. [7]

The advantage of using this type of plant is the ability to develop an off-grid system, that is, use in isolated power systems without connection to generic electric lines. Despite this, the location of the plant for its greatest energy output and heat output should correspond to one of the following sources of geothermal energy. This source classification was compiled by the International Energy Agency and includes:

- Geothermal dry steam reservoirs, plants currently use heat from these sources because of the lowest costs;
- Sources of wet steam, their use increases technological costs due to the possibility of corrosion of equipment and the need to clean condensate;
- Geothermal waters, a notable example of their usage is iceland;
- Dry hot rocks located at a depth of 3 km or more;
- Magmas.

In Russia, wet steam sources and hot rocks are the most common. The latter add technological difficulties leading to expensive drilling. So at a depth of 10 km – the cost will cost 1–2 bln. rubles, which is more than 60 % of the total capital costs. Short life time of wells with heat extraction efficiency up to 5 % of reserve. [6]

In total 613 geothermal power units operate in the world, in 2020 in Russia the installed capacity of plants is 74 MW, and in the USA – the largest producer of geothermal energy – the capacity of plants is 2 587 MW, with a global capacity of 14 thousand MW.

Summarizing the given characteristics of geothermal plants, we can say that the industry does not stagnated and tends to create such equipment which will have high efficiency of use. Examine each country separately in the context of types of station use and approaches to their management.

2.3. Geothermal energy in the United States

The composition and development of geothermal energy in the United States. The U.S., like Russia, are countries with large reserves of fossil fuels and are interested in maintaining a certain balance in the demand for these fuels. However, America is not neglecting other sources, so there is geothermal plants in 7 state. In Nevada such production reaches 10 % of total US geothermal power generation. (Table 1)

Table 1. American states with geothermal plants in 2020

State	Share of geothermal energy in the state	Share of geothermal energy in the U.S.
California	70.5%	6.1%
Nevada	24.5%	10.2%
Utah	2.1%	0.1%
Hawaii	1.2%	2.2%
Oregon	0.9%	0.2%
Idaho	0.5%	0.5%
New-Mexico	0.3%	0.2%

Made by author using data of US Bureau of Land Management

The increase in installed capacity since 1990 was negative and was 326 MW (from 2,913 MW to 2,587 MW). It can be assumed that the state put in a certain number of plants and only maintained their capacity. Also on the website of the US Bureau of Land Management there is information about the state of the plants, as well as documents on their completed and impending sale. This shows the privatization of the industry and the possibility of agile management. For example, since the signing of the Paris Agreement capacity has increased by 73 MW.

Comparing the information by region and the map with geothermal energy sources (Figure 1), we can see that America has engaged most of the regions, these states are marked in white on the map. Not involved such regions as Arizona and Colorado with high potential to benefit from the earth.

Consider a few geothermal power plants, California has the two largest geothermal reservoirs in the United States, the Salton Sea and Geysers resource area, with an estimated generation capacity of 644 MW and 100 MW. The geothermal lease is for a 10-year period, with 50 percent of the funds paid to the state, 25 percent paid to the respective county, and 25 percent retained by the U.S. Department of the Treasury.

Utah has two geothermal power generating facilities, Cove Fort and Roosevelt Hot Springs, located in the central and southwestern part of the state. Both sites offer redevelopment and expansion of their respective geothermal resources.

Thus, in the U.S. geysers dispose to the construction of power plants with low costs, and even with the private ownership of the plant, the return goes to the government budget.

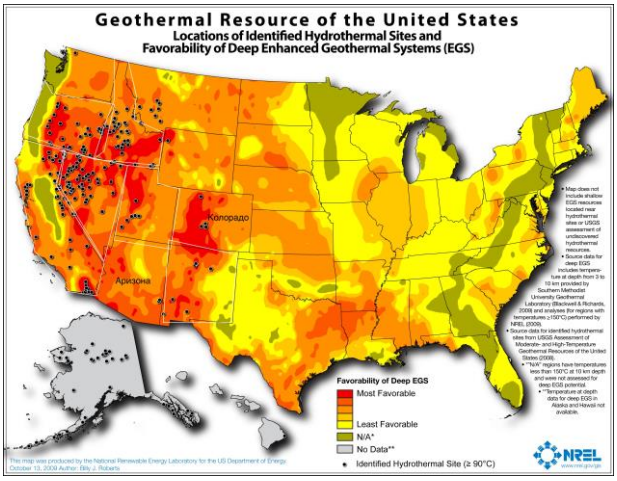

Figure 1 Regions with established and potential geothermal energy use in the United States highlighted white lines. Potential regions: Colorado, Arizona. Made by the author according to NREL and US Bureau of Land Management data.

Based on the information described earlier, compare the results achieved at the micro- and macroeconomic levels and the risks associated with them. (Table 2).

Table 2. SWOT- analysis of geothermal energy in the U.S.

Strengths	Opportunities
- sustainable growth of geothermal energy production - the development of new projects is issue for the state level - no costs for the transportation of electricity - low capital costs	- the presence of natural hydro sources of heat, like geysers - Following the Paris Agreement - creating a sustainable energy balance - reasonable consumption of fossil fuels - private generation of energy for own needs - independence from fuel prices
Weaknesses	**Threats**
- A tender for exploiting the site - private business with majority share of payments to the state budget	- uncertainty in electricity demand - loss of additional profit

Made by author

Advantages and possibilities of use in America outweigh the disadvantages. Thus, geological and technical conditions allow further development of the technology. In the absence of appropriate measures in the country, “weaknesses” and “threats” can outweigh the positives, not by quantity, but by degree of impact. On the external side, the threats are climate change, leading to hot summers and a sharp rise in the demand for electricity both privately and nationally. There is

increased stress on current plants and increased fixed and variable costs in the form of downtime of additional equipment and increased demand for fossil fuels. The availability of plants using geothermal sources would help even out the load on plants and reduce dependence on fuel prices.

The controversial practice of applying private business with government participation in the organization of the power plant enterprise leads to more negative consequences. It is a lack of flexibility for businesses and a limitation in financing and development since most of the proceeds go to the state. With a lack of subsidies from the state or participation in development, the industry is in a holding pattern. The solution would be either a complete transfer of rights to private business and external control of the state, or equity participation, the creation of a venture capital enterprise.

2.4. Geothermal energy in Russia

In Russia the use of geothermal sources is not so widespread: since 1990 the capacity has just increased from 11 MW to 74 MW. Nowadays, there are 5 plants in operation, the largest is Mutnovskaya GeoPP with a capacity of up to 80MW. (Table 3)

Table 3. Main geothermal power plants in Russia and their characteristics

Power station	Capacity	Location	Technology
Pauzhetskaya GeoPP	12–17 MW	West coast of Kamchatka	binary power module
Verkhne-Mutnovskaya experimental-industrial geopower station	12 MW	Southeast Kamchatka Peninsula	3 modules per 4 MW
Mutnovskaya GeoPP	50 MW (80 MW is planned)	Southeast Kamchatka	Using the energy of geysers
Ocean GeoPP - decommissioned	2.5 MW	Iturup Island in the Kuril Islands	Two “Tuman-2A” power modules
Mendeleevskaya GeoTPP - work in progress	3.6 MW – 7.4 MW	Yuzhno-Kurilsk	No data

Made by author

The process of plant operation in Russia using as an example of the Mutnovskaya GeoPP. The site selection required drilling 100 wildcats. A number of equipment was engineered specifically for this power station. Due to these technical features, it has environmental safety, as there is no contact between the geothermal coolant and the environment, protection from corrosion and deposition of salts. The particular feature of small plants is the construction of blocks, which reduces the time of commissioning of the plant and in the future can be supplemented to meet additional needs.

All geothermal plants are managed by RusHydro, a key shareholder is the Russian Federation. According to their data, geothermal plants are perspective for Kamchatka region, they do not consider projects in other regions. The decision was influenced by the unsuccessful experience with Okeanskaya GeoPP. It was shut down because of the inappropriate usage and instability of the plant. Moreover, its construction term exceeded the useful life.

The second plant in the same area, the Mendeleev GeoPP, had great success, but due to difficult climatic conditions and improper use has periodic problems with autonomous operation.

Consider the peculiarities of the Russian power industry using the SWOT analysis. (Table 4)

Table 4. SWOT-analysis of geothermal energy in Russia

Strengths	Opportunities
- usage of a unique binary cycle technology - successful experience of using the station in Kamchatka region - independence of Kamchatka region from fossil fuels	- availability of potential consumers - isolated energy areas - accelerated transition to carbon neutrality - many economically and technically suitable territories - independence from fuel prices
Weaknesses	**Threats**
- low development of the industry - high cost of equipment - availability of qualified personnel	severe continental climate

Made by author

Distinctive features of the Russian energy sector are the country's large territory needed of a steady supply of electricity in harsh climatic conditions, which reduce the useful lifecycle of equipment and increase capital and operating costs. Despite this, actions have already been taken on the part of scientists and the state, such as the invention of the binary cycle, which increases heat output from the ground, and the support of plants by state companies like RusHydro.

By not developing this industry, the state is deprived of potential opportunities and thus revenue. For example, the main advantage of alternative energy sources is the possibility to reduce fuel transportation

costs and losses on power lines. The second advantage is the availability of not only electric energy, but also thermal energy. The advantages results in a high potential of using geothermal energy in remote areas and in areas with weakly branched energy network. (Figure 2).

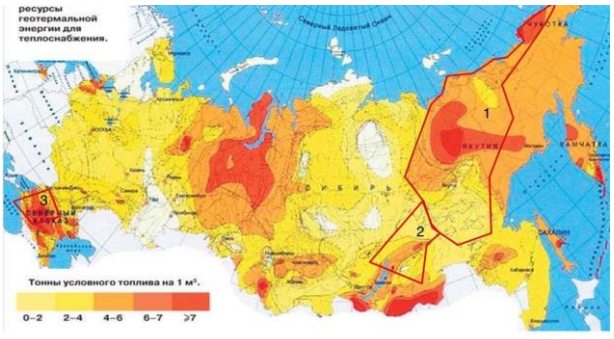

Figure 2 Comparison of energy regions and potential geothermal sources. 1 – Yakutsk and Chukotka. 2 – Mamsko-Chuysky and Bodabinsky energy districts of the Irkutsk energy system. 3 – Southwestern power district of the Kuban energy system made by the author based on data from the Ministry of Energy of the Russian Federation.

Figure 2 shows that Russia has potential consumers to use this method of electricity generation. Areas such as Chukotka and Yakutia have a cold climate and the availability of additional thermal energy without the use of fuel would be economically attractive. Along with this it is necessary to carry out additional technical research to increase the durability of the equipment and increase their useful life, as well as to develop a unified method of maintenance of the equipment. For this purpose it is necessary to invest not only in improvement of the equipment, but also in potential personnel.

2.4. Comparative analysis of geothermal energy development in the USA and Russia

After reviewing the methodology of using GeoPPs in each country and determining their effectiveness at the microeconomic level, we will identify criteria for their comparison at the national scale. From the generalizing indicators we can distinguish: the total power generated by GeoPPs; the share of regions in the total territory of the country, where power plants are used. Also use the following proportions: the share of geothermal resources in the energy balance and the share of electricity generation from geothermal sources in the total. (Table 5) Additional indicators are needed to determine a country's predisposition to use this type of electricity and to make a preliminary assessment of the equipment needed and its cost. The second indicator measures a country's independence from fossil fuels and its commitment to carbon neutrality.

Table 5. Comparative characteristic of the USA and Russia

Indicator	USA	Russia
Total generation of stations, GW	18 364	432.68
The share of electricity generation using geothermal sources in the total amount	0.43%	0.04%
The share of regions in the total territory of the country where power plants are used	14%	2.4%
The share of geothermal resources in the energy sector	44%	69%

Made by author

The share of regions in the total area of the country where power plants are used is calculated as the number of regions with an active geothermal power plant and divided by the total number of regions. The share of geothermal resources is a rather complicated indicator to calculate accurately, the numerator is the area of land with a temperature that allows economically to obtain energy.

A comparative analysis has shown that the United States has less potential for developing than Russia, despite the fact that the share of regions using natural energy is higher and the total generation of plants is 42 times greater. The opportunity to develop geothermal sources is conditioned not only by the predisposition to heat, but also by the surface geographical conditions and the population of the region. Although Russia has 69% of the territory from which energy can be obtained, not all of it is achieved by installing inexpensive equipment. In contrast, smaller areas in the U.S. have higher heat output and require less capital outlay to generate energy. Thus, an adjustment factor that incorporates the limitations described above should be developed for a more accurate comparison and evaluation of the region.

The share of power generation from geothermal sources in the total U.S. was 0.43 %, which relative to Russia (0.04 %) is quite high.

Thus, the comparative characterization has shown that each country has its own characteristics and ways of development. The U.S. is at the point where it has utilized the capacities and is aimed at future development through the implementation of government programs and modernization of the current plants. Russia is at the initial stage of development and although there are a lot of scientific publications, the government sets other development priorities. Since the development of geothermal energy is handled by one state-owned company, RusHydro, there is no proper leverage from the outside.

Each country has its own unique characteristics of development and management. The most effective solution would be to use the mutual experience of both countries and apply the practices in their perspective.

3. CONCLUSION

Analysis and comparison of energy of the two countries in the article led to the following conclusions. Such factors as the increase in the earth's temperature by 1°C per year and the countries' desire to transition to a low-carbon economy increase the competitiveness of geothermal energy among alternative energy sources.

A SWOT-analysis was conducted for each country, a technical analysis was done on the example of some plants and associated risks and risks of missed opportunities were identified. This revealed trends and specifics of each country's development.

For the U.S., national indicators such as the amount of generating capacity, the number of geothermal power plants lead the world market. However, the approach to operation through leasing to bidding companies results in low economic viability, as revenue only goes to the budget. Government involvement supports current plants but does not announce upcoming projects.

Russia has identified many opportunities along with the complexity of using them. Which is subject to further economic research. Although there are technologies for producing geothermal turbines and equipment, a world-class geological and scientific school and engineering schools for design and operation, the vector of development and application of skill in practice in the geothermal industry is lacking due to various reasons. Technical analysis led that the harsh climate prompts better calculations and proper maintenance of the stations, otherwise will lead to faulty station operation and a negative attitude towards the industry. The recommendation would be to conduct additional test work with a focus on the effects of the environment on the equipment.

It was also found possible to apply and install GeoPPs in territories isolated from the general power grid, like Yakutia and Chukotka. This would give the region’s independence from the central distribution electricity lines and provide extra sources of heat.

A comparative analysis showed the potential of each country and the extent to which land resources are used to generate electricity. Although Russia has a larger cites suitable for the heat energy, the U.S. exploits 14 % of the total land area and generates 0.43 % of the total energy production. This methodology of analysis can be used to present a cross-section of the country's geothermal energy use separately.

4. FUTURE RESEARCH PERSPECTIVES

The work uncovered various aspects of the use and responsibility of the state in the development of geothermal energy and identified areas for further study. Such as the development of a corrective factor in assessing the predisposition of the country to industrial use of land heat. It should include the complexity of the development of the region, the influence of climatic conditions, the method of obtaining heat.

The second direction is to make economic estimates for a detailed study of the region where the geothermal plant will be used. They should include the cost of equipment and duration of construction works in comparison with the useful life and the cost of annual maintenance of the plant.

The development of the industry requires proper attention as it can sufficiently provide towns and villages without harming the environment. It is necessary to initiate the construction of even small, powerful plants, the design of which is becoming increasingly popular in Russia, such as small nuclear power plants. And to perform additional calculations about potential locations and methods of their arrangement, it is worth considering not only for the USA, as the largest producer of geothermal energy, but also for other countries, like Iceland. The latter is associated with geothermal energy, as the main source of energy is the heat of the ground.

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