Directions for Transition to Low-Carbon Energy in the Baikal-Khuvsgul Transboundary Territory: Background, Conditions, Effects

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Abstract — **The joint development of transboundary territories of Russia and Mongolia primarily focuses on a unique natural formation, the Baikal-Khuvsgul basin. These territories are a promising area for the expansion of cooperation in the field of environmental protection, tourism and energy. The existing energy system, however, does not provide the appropriate conditions for this, as it is characterized by low reliability and the impossibility of connecting new large consumers. Heat is supplied to consumers from numerous coal-fired and wood-fired boiler houses of small and medium capacity with outdated equipment. In the context of energy supply problems and a focus on environmentally attractive low-carbon technologies, this study examines the use of renewable energy and conversion of municipal boilers to gas. An analysis of the available resources in the territory showed a high solar energy potential for the development of generation based on photovoltaic converters. Another way to use RES in the Baikal-Khuvsgul area is to replace low-capacity coal-fired boilers with heat pump units. Conversion of boiler houses to gas does not solve completely the issue of decarbonization, since CO2 emissions, although to a lesser extent, occur during the gaseous fuel combustion. At the same time, it will significantly reduce the human-induced environmental impact through the elimination of particulate matter and sulfur dioxide emissions, and ash and slag waste. The paper presents a feasibility study of solutions for the development of electricity and heat supply with a minimum emission of greenhouse gases and pollutants in the Baikal-Khuvsgul transboundary territory.**

Index Terms: **power supply systems, environmental assessment, greenhouse gases, emissions of pollutants, ash and slag waste.**

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http://dx.doi.org/10.38028/esr.2022.02.0003
Received June 18, 2022. Revised July 11, 2022.
Accepted July 30, 2022. Available online August 31, 2022.

I. Introduction

The key areas of interaction between Russia and Mongolia are the joint development of the infrastructure in the transboundary territories and cooperation in the field of environmental protection, tourism, and energy (An agreement between the Government of the Russian Federation and the Government of Mongolia on support of interregional and cross-border cooperation of 03.09.2019, Ulaanbaatar).

The central part of the transboundary territory of Russia and Mongolia is occupied by a unique natural formation – the Baikal-Khuvsgul basin. The Lake Khuvsgul basin, which is one of the main stable feeding sources of the Selenga river and, consequently, that of Lake Baikal, is virtually not yet affected by human activities. Lake Baikal is recognized as the oldest and deepest lake on the planet with the largest volume of fresh water [1]. It is included in the list of UNESCO World Heritage Sites.

The Baikal-Khuvsgul transboundary territory is a favorable area for the development of international tourism. It includes the Khuvsgul aimak of Mongolia and three districts that are part of the constituent entities of the Russian Federation (the Okinsky and Tunkinsky districts of the Republic of Buryatia, and the Slyudyansky district of the Irkutsk Region) [2]. Within the boundaries of the territory at issue, there is the Tunka national park, the Khuvsgul national park, many sanatoriums, recreation centers, and places for tourism and recreation. Lakes Baikal and Khuvsgul are connected by a road passing through the Tunka Valley. The area is dominated by mid-mountain relief, and there is the highest peak of the Sayan Mountains – Mount Munku-Sardyk – on the Russian-Mongolian border, which is a popular sports tourism destination [3].

Currently, specially protected natural areas (SPNA) are actively involved in ecotourism and integrated into the socio-economic development [2]. One of the conditions for the successful sustainable development of ecotourism in the transboundary area is the creation of an environmentally friendly infrastructure to minimize environmental impact. This direction is consistent with the goals of the Strategy for the socio-economic development of the Russian Federation with a low level of greenhouse gas emissions until 2050 (Strategy for socio-economic

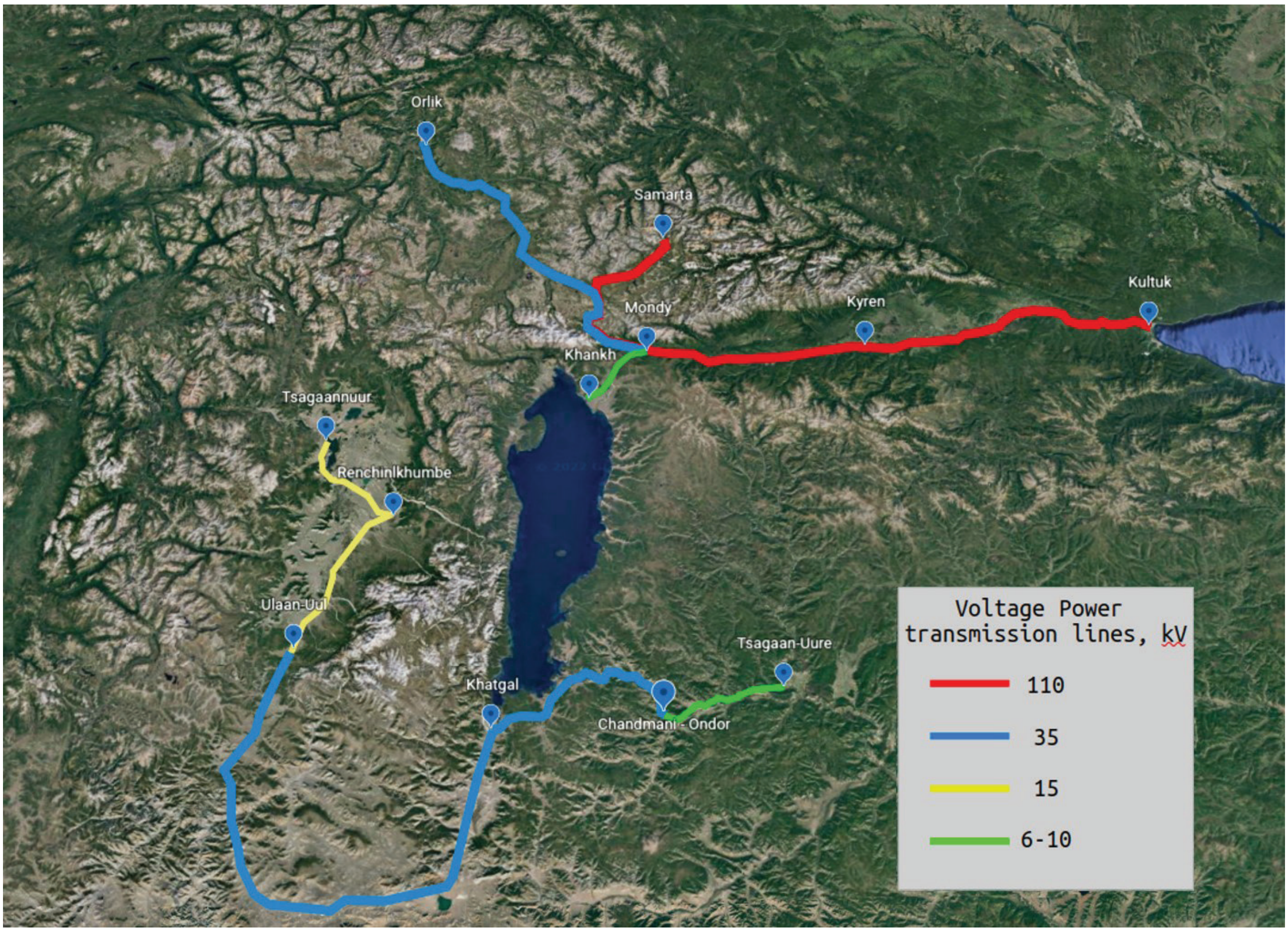

Fig. 1. Situational plan of power supply systems.

development of the Russia Federation with a low level of greenhouse gas emissions until 2050, approved by the Resolution of the Government of the Russian Federation No. 3052 of 29.102021.). The strategy measures involve replacing part of coal-fired generation with carbon-free and low-carbon ones; increasing electricity generation to meet the needs of the economy through carbon-free generation; reducing emissions from existing coal-fired generation plants through the introduction of advanced technologies.

Numerous works examine the strategies for low-carbon development of the ecotourism industry and minimization of anthropogenic impacts on protected areas. He et al. [4] models a low-carbon ecotourism system and a set of activities, including the municipal solid waste processing aimed at minimizing negative impacts on the ecosystem. Heshmati et al. [5] considers strategies for combining the development of ecotourism and the protection of natural resources using a SWOT analysis. The main proposed measures include regular patrolling and limiting destructive activities (poaching, arson, plastic waste dumping).

In [6], the findings statistically confirm a relationship between the development of tourism and the reduction in pollution. One of the key factors is the introduction of renewable energy sources. In [7], an improved decision-making tool is proposed for the technical and economic analysis of multi-energy microgrids for energy supply to infrastructure facilities in ecotourism development areas. Minaei et al. [8] consider the issue of developing energy supply to remote settlements located in protected areas, national parks and reserves, the preservation of which is essential for the sustainable development of territories and minimization of climate impacts. The electricity production based on fossil fuels and the construction of electrical networks pose a potential threat to the ecosystem in such areas. Therefore, the study considered the use of solar technologies for energy purposes.

The review of the studies shows that they focus on the identification of the influencing factors and development of a policy for low-carbon development of tourist areas and protected areas. Some investigations deal with the creation of low-carbon power supply systems.

This paper presents a study into the avenues for the transition to low-carbon energy in the Baikal-Khuvsgul transboundary territory, including a feasibility study of solutions for the development of electricity and heat supply with minimal emissions of greenhouse gases and pollutants.

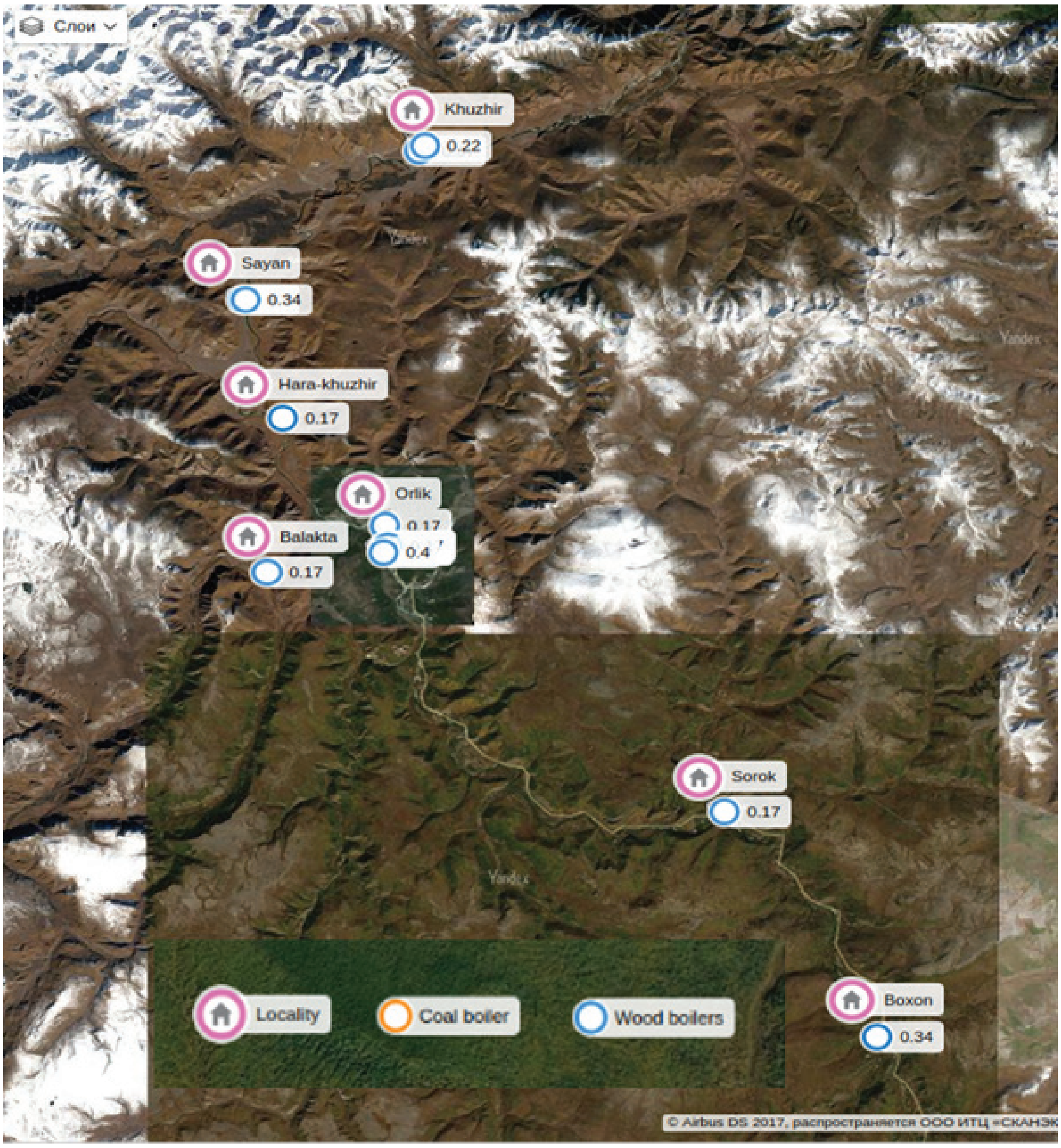

Fig. 2 Location of boiler houses in the Okinsky district with indication of installed boiler capacities, Gcal/h.

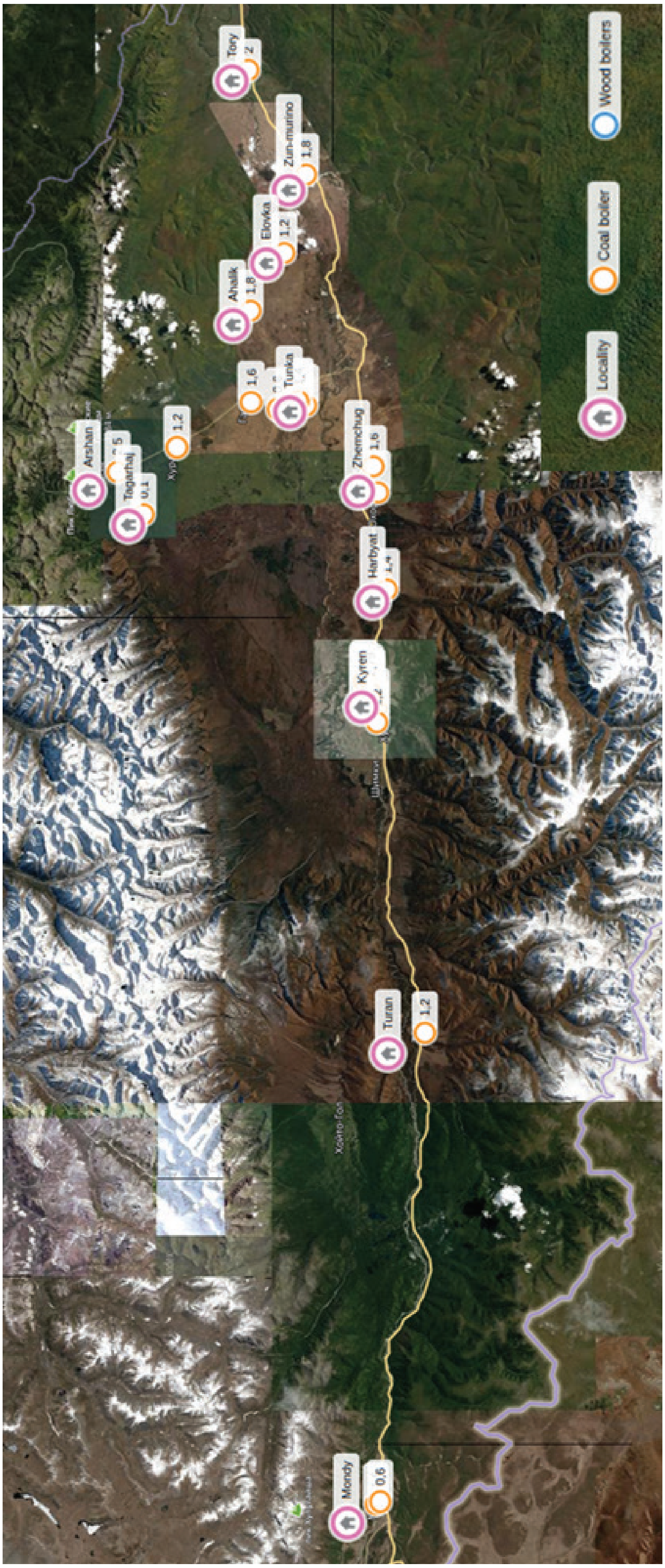

Fig. 3. Location of boiler houses in the Tunkinsky district with indication of installed boiler capacities, Gcal/h.

Table 1. Estimated emissions of pollutants from municipal boilers, t/year.

Current state	District	Emissions					
		Total	Particulate matter	SO_2	NOx	CO	Greenhouse gases (CO_2)
	Okinsky	217	73	-	14	130	-
	Tunkinsky	1 516	1 236	119	15	146	10 000

II. The current state of power supply systems in the studied area

A. Power supply systems

The situational plan of a system for power supply to consumers in the Baikal-Khuvsgul transboundary territory is presented in Fig. 1. A detailed analysis of the current state of the power supply systems in this territory is given in [9–10].

Consumers in the Russian part of the territory receive power through a long single-circuit 110 kV power transmission line (TL) Kultuk - Kyren - Zun-Murino - Mondy - Samarta. Consumers located in the territory of the Khuvsgul National Park are supplied with electricity through the 10 kV interstate transmission line Mondy-Khankh, 35 km long (see Fig. 1). Power supply to consumers in the territories adjacent to Lake Khuvsgul from the eastern, western and southern sides is carried out from the central power system of Mongolia through the 110/35 kV power line Bulgan-Muren-Khatgal, 298 km long, and further through 6, 10, and 15 kV distribution networks.

Power transmission lines are characterized by significant wear and tear and frequent long outages. In the event of a long-term power outage, diesel power plants (DPPs) at some substations (for example, Orlik and Soroka substations) are used to supply consumers with power.

The large length of power lines also causes the problem of low voltage levels for consumers. The connection of new consumers in the territory at issue is limited due to the inability to provide an acceptable voltage level at remote substations.

Within the boundaries of the considered territory, there are also remote, hard-to-reach consumers, mainly tourist sites and cattle breeders, which are supplied with electricity from DPPs.

B. Heating systems

This study considers the current state of heat supply to the Baikal-Khubsugul territory focusing on the Okinsky and Tunkinsky districts of the Republic of Buryatia, which are adjacent to the Mongolian border from the Russian side. The populated settlements of the districts are mainly located along the highway, which is used to provide the population with the basic essentials. The main consumers of thermal energy from municipal boiler houses in these settlements are kindergartens, schools, administration buildings, and other social facilities. The population is supplied with heat from individual furnaces that burn mainly firewood.

In the Okinsky district, 5.5 thousand people live on an area of 26.6 thousand km^2. There are 18 municipal low-capacity boiler houses (up to 3 Gcal/h) (Fig. 2). The total installed capacity of the boiler houses is 6.9 Gcal/h, they burn 8.8 thousand tons of wood fuel annually.

In the Tunkinsky district, 20.1 thousand people live on an area of 11.8 thousand km^2. There are 24 municipal boiler houses with a total installed capacity of 38.7 Gcal/h, of which only one (in the village of Kyren) is of medium capacity – 5.2 Gcal/h, and the rest are of low capacity (Fig. 3). The main fuel is coal from the Cheremkhovskoye deposit, which is delivered from the territory of the Irkutsk region to meet an annual demand of 6.5 thousand tons/year.

C. Environmental assessment of heat supply systems

Due to the lack of information, environmental assessments in the study are given only for the systems supplying heat from municipal boiler houses in the Tunkinsky and Okinsky districts. It is worth noting that these boiler houses, along with individual furnaces, make the most significant contribution to the environmental situation in the territory, due to the predominance of coal in the fuel balance and the absence of exhaust gas purification equipment.

The emissions of pollutants into the atmosphere, which are among the main environmental characteristics of heat supply systems, were calculated based on the methods approved in Russia [11, 12]. The total emission of pollutants from municipal boilers in the two districts is estimated at 1.7 thousand tons/year, with the predominant contribution of boilers in the Tunkinsky district due to coal combustion (Table 1).

Environmental problems are local in nature and are associated not only with emissions of pollutants but also with the energy production and consumption waste, i.e., ash and slag waste (ASW). The ASW amount is calculated on the basis of existing recommendations [13–14] and makes up 861 tons/year, of which 108 tons are waste from wood fuel combustion in the Okinsky district and 753 tons are ASW from coal combustion in the Tunkinsky district.

The issue of climate change associated with greenhouse gas (CO_2) emissions is acute for thermal power facilities. According to our estimates, the rated carbon dioxide emissions at the current level of coal consumption are 10 thousand tons/year. CO_2 emissions from municipal boilers in the Okinsky district are zero, since carbon dioxide released into the air during combustion is believed to be

Table 2. The main directions and effects of the transition to low-carbon energy in the Baikal-Khuvsgul territory.

Direction	Effect
Electricity supply	
Use of renewable energy sources and reactive power compensation devices	- increasing the reliability of power supply to consumers; - ensuring the level of voltage at consumers according to the State standard requirements; - providing the opportunity to connect new consumers; - reducing diesel fuel consumption
Heat supply	
Replacement of coal with gas fuel	- excluding coal deliveries and combustion in boiler houses of the Tunkinsky district
Use of geothermal heat pumps	- replacing low-capacity boiler houses (load up to 0.4 Gcal/h) in the Tunkinsky and Okinsky districts

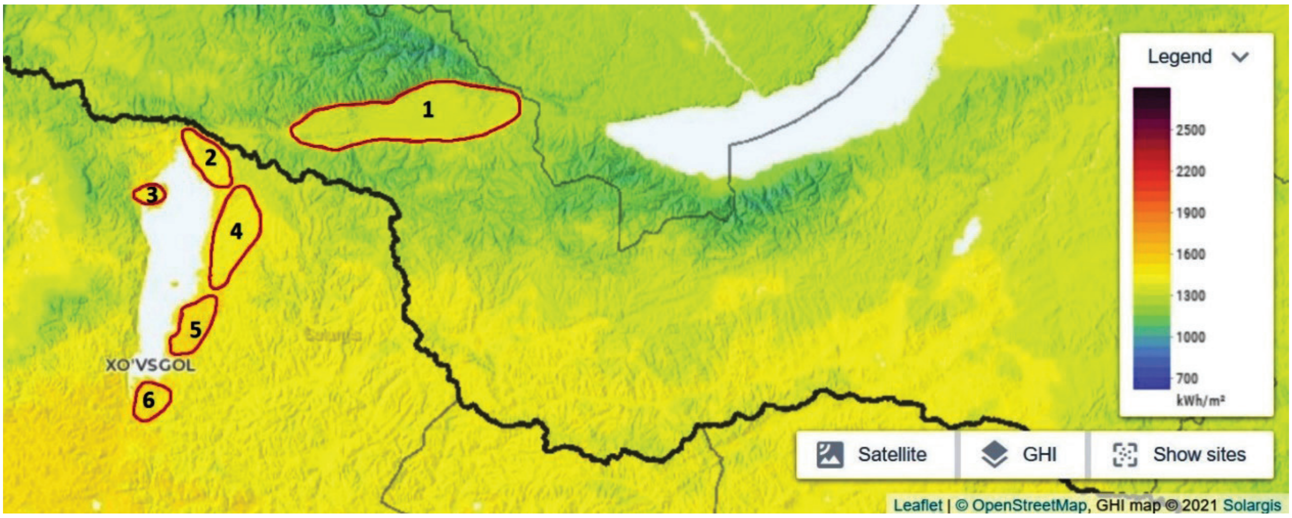

Fig. 4. Total solar radiation incident on a horizontal surface.

previously absorbed from the atmosphere by growing plants (the closed cycle formed does not lead to an increase in CO_2 concentration in the atmosphere) [15–16].

III. Main directions for transition to low-carbon energy

The issues of environmental protection, energy supply reliability and efficiency improvement can be resolved, and the transition to low-carbon energy in the considered areas can be made through the implementation of some measures related to both electricity supply and heat supply. An analysis of possible effects to be gained from these measures is presented in Table 2.

The choice of directions for the transition to low-carbon energy should be based on analysis of resource availability, and environmental and economic assessments of solutions to be adopted.

A. Resources and efficiency of wind and solar energy for electricity supply

Analysis of the wind and solar potential in the region involved geoinformation systems NASA POWER (NASA POWER- URL: https://power.larc.nasa.gov / (accessed 18.04.2022), Global solar atlas (Global solar atlas. – URL: https://globalsolaratlas.info (accessed 18.04.2022), and Global wind atlas (Global wind atlas – URL: https://globalwindatlas.info (accessed 18.04.2022).

High indicators of solar energy potential are observed in the Tunka National Park and on the shore of Lake Khuvsgul (Fig. 4). The Figure shows the areas with the highest solar energy potential. The flux of total solar radiation incident on a horizontal surface in these areas varies from 1 241 to 1 365 kW·h/m^2 per year, and on an inclined surface – from 1 456 to 1 602 kW·h/m^2 per year.

The wind energy potential of the territory is characterized by a low average annual wind speed of 3.3 to 4 m/s at a height of 10 m.

The conditions and results of a comparative analysis of the cost-effectiveness of low-capacity wind power plants (WPPs) and solar power plants (SPPs) are presented in Table 3.

The estimates obtained indicate a promising level of solar energy potential for the development of solar generation in the Baikal-Khuvsgul transboundary territory. The wind energy potential of the territory is, on the contrary, insufficient for electricity supply purposes.

The feasibility of solar energy in the Baikal-Khuvsgul territory has been assessed. The locations and installed capacity of solar power plants have been determined for

Table 3. Comparison of SPP and WPP cost-effectiveness.

Index	WPP	SPP
Specific capital investments, $/kW*	2 500–3 000	1 200–1 400
Operating costs, $/kW/year	75–90	24–28
Installed capacity utilization factor, %	7.5–10.4	18.3–19.7
Discount rate, %	7	
Estimated period, years	30	
Levelized cost of electricity generation, $/kW·h	0.31–0.51	0.07–0.09

Note – * Technical and economic estimates were obtained at a rate of 82 rubles for 1 dollar.

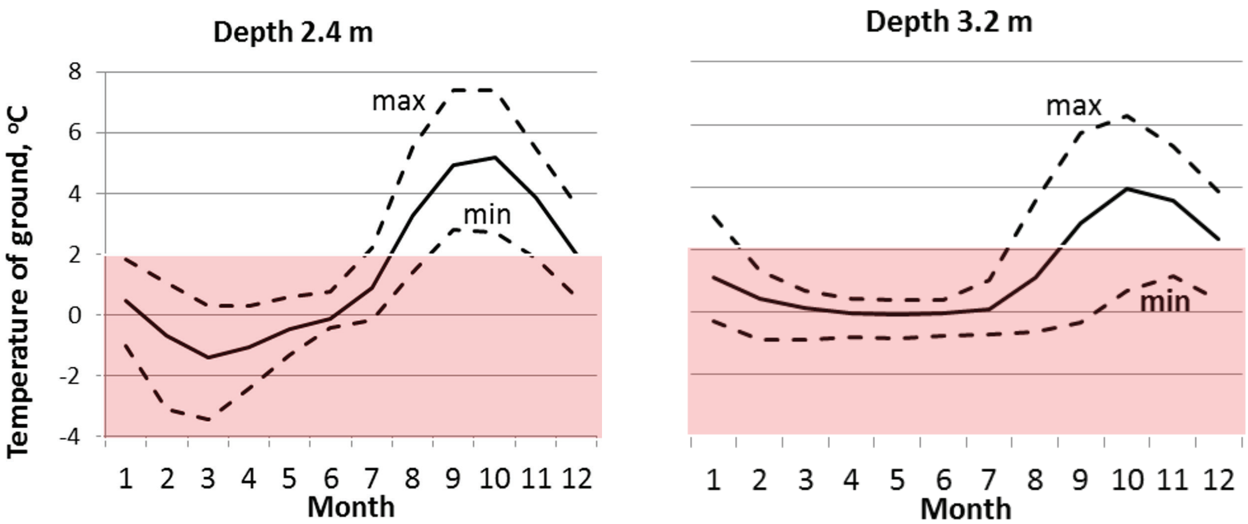

Fig. 5. Graphs of relationships between the ground temperature and the depth in the settlement of Tunka (obtained based on 1974-2012 measurements).

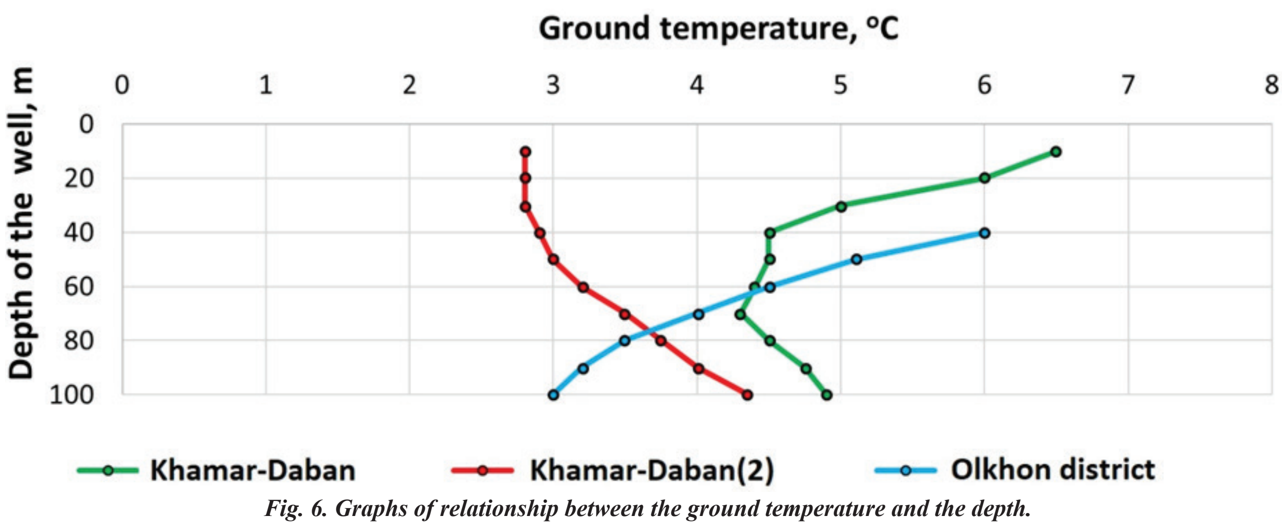

Fig. 6. Graphs of relationship between the ground temperature and the depth.

the zone of centralized power supply. These plants, given the development prospects, will provide acceptable voltage deviations for consumers and high reliability of power supply: in Khuzhir – 1.4 MW, Orlik – 0.2 MW, Forty – 0.2 MW, Police station – 0.1 MW, Mondy – 0.3 MW, and Khankh – 0.2 MW [17].

The optimal power of solar power plants in the zone of autonomous power supply is 7- 60 kW, depending on the load of the consumer, and the total required power for power supply of remote tourist sites is 250–300 kW [18].

In the southern areas of Lake Khuvsgul, it is advisable to use reactive power compensators to provide the required voltage level for the consumer [10].

B. Resources and efficiency of low-grade geothermal energy for heating purposes

The geothermal energy potential in the Baikal-Khuvsgul transboundary territory was analyzed using

Table 4. Characteristics of low-capacity coal-fired boiler houses and electricity supply conditions for consumers in the Tunkinsky and Okinsky districts.

Characteristics	Tunkinsky district	Okinsky district
Boiler houses with a load of up to 0.4 Gcal/h	22 pieces	14 pieces
Fuel type	Cheremkhovsky coal	Firewood
Consumption, tce/year	4 683	6 396 m^3
Fuel price, $*/tce	66.56	92.44
Tariff, $/kW·h	0.04 (population) 0.05–0.06 (others)	
Heat consumers	Schools, kindergartens, military commissariat, other social facilities	

Note - * at a rate of 82 rubles for 1 dollar.

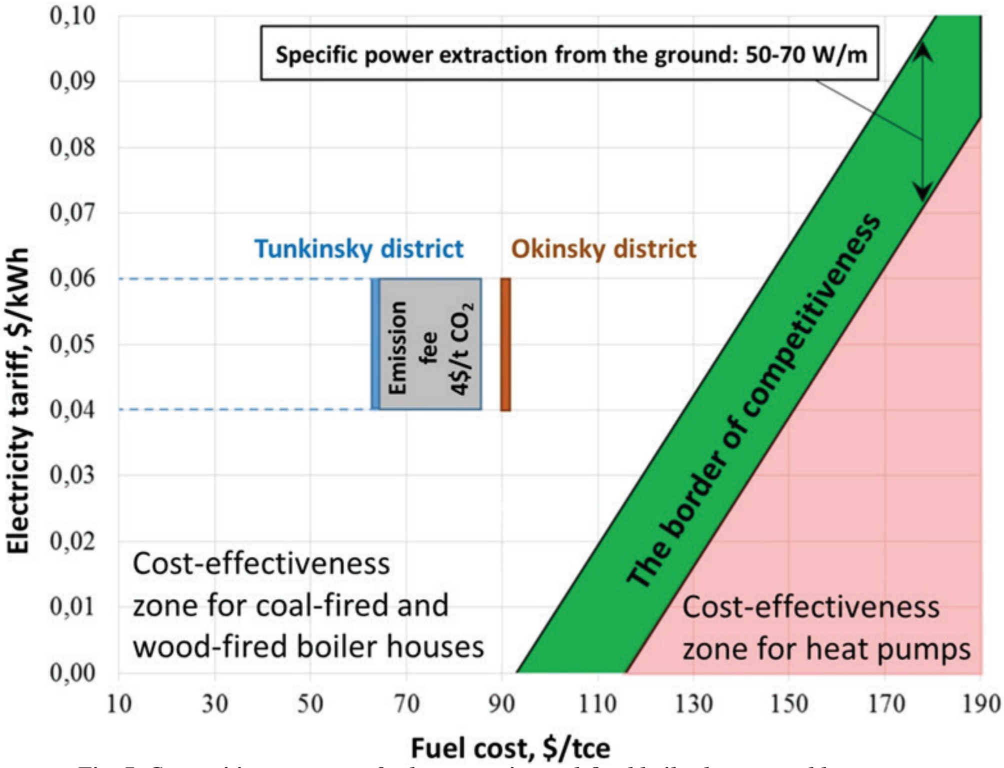

Fig. 7. Competitiveness zones for low-capacity coal-fired boiler houses and heat pumps.

the database «Specialized arrays for climate studies» (Specialized arrays for climate research – URL: http://aisori-m.meteo.ru/waisori/ (accessed 18.04.2022) and data from [19]. Due to the high cost and complexity of temperature measurements at the depth of the earth, the data are limited in terms of both the period and the number of observation points. Figures 5 and 6 show graphs of temperature changes depending on the measurement depth.

The low level of ground temperature allows considering only a limited set of geothermal energy technologies, the most promising of which are low-capacity heat pump units (HPUs).

Low-capacity heat pump units can be used to completely replace coal-fired or wood-fired low-capacity boilers (up to 0.4 Gcal/h). They are highly automated and have virtually no impact on the environment. Their widespread use, however, is limited by high capital costs for the main equipment and the system for extracting heat from the ground.

Three methods of low-potential heat extraction were analyzed for the considered area:

1. Open loop with water intake from the reservoir and subsequent return discharge.
2. Closed horizontal loop at a depth of up to 4 meters with propylene glycol as heat carrier.
3. Closed vertical loop with a borehole depth of up to 100 meters with propylene glycol as heat carrier.

An open loop with water intake from a reservoir is the most cost-effective method due to its relatively low cost [20]. However, a significant limitation is the

Table 5. Results of the feasibility study of alternative heating options.

Parameter	Value [a]
Specific capital investments in the heating system with heat pump, $/kW*	1 085
Specific capital investments in the heating system with heat pump, mln. $/Gcal/h	1.28
Discount rate, %	7
Estimated period, years	30
Discounted payback period of the heating system with heat pump	~50 years
Levelized cost of thermal energy for heat pump, $/Gcal	62.2
Levelized cost of thermal energy for low-capacity coal-fired boilers houses, $/Gcal	41.5

Note – * Technical and economic estimates were obtained at a rate of 82 rubles for 1 dollar.

Fig. 8. The route of the main gas pipeline through the territory of the Tunkinsky district.

inaccessibility of this method in areas remote from Lakes Baikal and Khuvsgul, and the difficulty of assessing the environmental impact of the project.

Heat extraction with the aid of a closed horizontal loop can also have only limited application in the coastal areas of Lakes Baikal and Khuvsgul. In the areas remote from the lakes, the ground temperature at a depth of up to 4 meters is less than 2°C for most of the year (see Fig. 5). At such a temperature of the ground, heat extraction is technically inefficient.

Heat extraction using a closed vertical loop can be implemented almost everywhere. Figure 6 shows that the ground temperature at a depth of up to 100 m in different areas of the Baikal-Khuvsgul transboundary territory is in the range of 2.8–6.5°C all year round.

The approach presented in [20] was used to assess the economic efficiency of heat pump unit to replace low-capacity coal-fired boilers in the territory at issue.

The characteristics of low-capacity boiler houses operating in the studied area are presented in Table 4. Figure 7 shows the competitiveness limits for low-capacity coal-fired boilers and heat pumps.

Table 5 shows the feasibility study results for the alternative heating options.

Based on Figure 7 and Table 5, we can conclude that under the current technical and economic conditions, coal and wood-fired boilers have a significantly higher economic efficiency compared to heat pumps. Only an increase in the fuel cost up to $135/tce will make heat pump equally economical with coal-fired boilers. The heat pump cost-effectiveness can also significantly rise with an increase in fees for emissions of pollutants into the atmosphere or the introduction of a carbon tax. Figure 7 indicates that the conditions of the Tunkinsky district approach the border of competitiveness at an emission fee of 4 $/t CO_2.

Table 6. Emissions of pollutants and greenhouse gases at conversion of boiler houses to gas in the Tunkinsky district, t/year.

Conversion to gas	Emission into the atmosphere					
	Pollutants					Greenhouse gases (CO_2)
	Total	Particulate matter	SO_2	NOx	CO	
	9.5	0	0	2.5	7	4 000

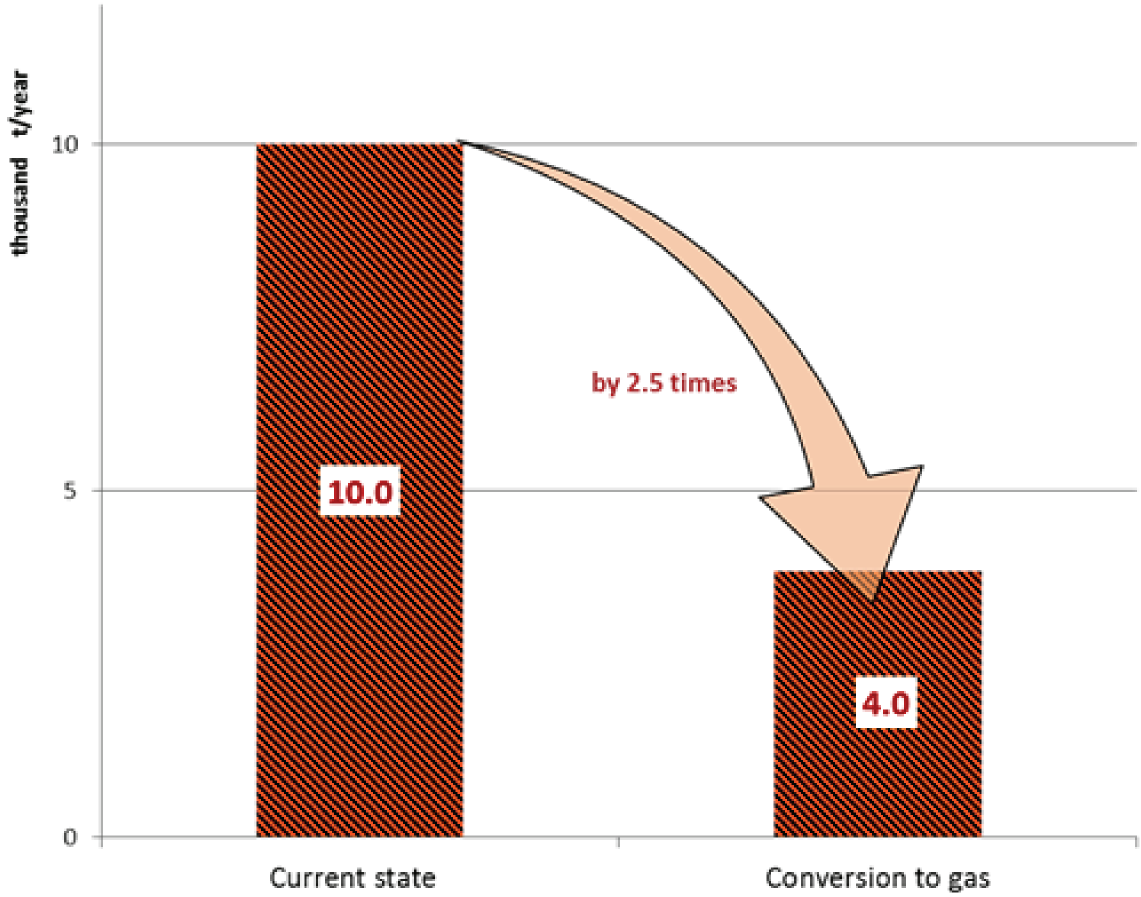

Fig. 9. Reduction in carbon dioxide emissions by converting boiler houses to gas in the Tunkinsky district.

C. Prerequisites for and efficiency of converting consumers to gas in the Tunkinsky district

One of the possible ways to reduce emissions of pollutants and greenhouse gases in the Tunkinsky district may be the transition to more environmentally friendly energy sources, namely, natural gas. As shown above, CO_2 emissions from municipal wood-fired boilers in the Okinsky district are considered to be zero.

The main preconditions for converting the Tunkinsky district to gas can be the plans of PJSC Gazprom to build the Power of Siberia 2 gas pipeline to China through Mongolia and the presence of specially protected natural areas (the Tunka and Khuvsgul national parks), where economic activity should be carried out according to the special nature management rules to meet some restrictions, especially for the areas adjacent to Lake Baikal, which is regulated by the Law on the Protection of Lake Baikal [21–22].

In accordance with the prospects for the development of the gas transmission system in the eastern regions of Russia, the main gas pipeline will pass through the territory of only four municipal districts of the Republic of Buryatia, including the Tunkinsky district. Fig. 8 presents the gas pipeline route running through the territory of the Tunkinsky district according to the assignment for engineering surveys for the project «Rationale for the investments in the construction of a gas pipeline to the People's Republic of China through Mongolia» [23].

An analysis of current prices for coal used in municipal boiler houses in the Republic of Buryatia, according to [24], shows that the Tunkinsky district has one of the highest prices among the districts of the Republic, along with the Barguzinsky and Bauntovsky districts. The assessment of competitive prices for natural gas when switching from coal to gas confirmed the effectiveness of this measure for small municipal boiler houses in the Tunkinsky district. With the

Table 7. Quantitative indicators of environmental effects.

A decrease in key environmental indicators compared to the current state, t/year	District			
Indicator:	Tunkinsky			Okinsky
	Main lines of decarbonization			
	Construction of solar power plant	Conversion to gas	Heat pump units	Heat pump units
Emissions of pollutants	12	1 507	1 091	207
Formation of ash and slag waste	-	753	542	103
Greenhouse gas emissions (CO_2)	409	6 010	7 205	-

price of coal for boiler houses of $38-44/t, competitive prices for natural gas are estimated at $146-170/1 000 m^3.

The basis for the transition to low-carbon energy should still be environmental, social, and climate effects. Estimates of the reduction in the anthropogenic load on the environment during the transition of the boiler houses to gas in the Tunkinsky district are given in Table 6.

Conversion of boiler houses to natural gas will completely eliminate emissions of particulate matter and sulfur oxides into the atmosphere, and the total emission of pollutants will be reduced by 159 times or by 99% compared to the current state. The emission of carbon dioxide will decrease by 2.5 times, from 10 to 4 thousand t/year (Fig. 9).

Moreover, a significant environmental benefit of converting to gas is the complete elimination of ash and slag waste in the Tunkinsky district.

IV. Environmental effects for various directions of transition to low-carbon energy

The implementation of the recommended directions for the transition to low-carbon energy in the Baikal-Khuvsgul transboundary territory makes it possible to gain some environmental effects associated with a reduction in the anthropogenic pressure on the natural environment. The construction of a solar power plant to replace part of diesel power plants will provide an opportunity for the Tunkinsky district to cut down diesel fuel consumption, which will decrease pollutant emissions by 12 t and carbon dioxide emissions by 409 t, yearly.

Conversion of municipal boiler houses in the Tunkinsky district to gas will reduce pollutant emissions by 1.5 thousand tons/year, greenhouse gas emissions by 6 thousand tons/year and eliminate the ASW formation. The most significant measure in the context of low-carbon energy development in the Tunkinsky district is to introduce heat pump units to replace 22 small boiler houses. As a result, only two boiler houses will supply pollutants, greenhouse gases and ASW to the elements of the natural environment. In general, the reduction in pollutant emissions will decrease from 1.5 to 0.5 thousand tons/year, CO_2 emissions - from 10 to 2.8 thousand tons, and ASW – from 753 to 211 tons/year (Table 7).

From a scientific perspective, it is of interest to compare the environmental effects for various lines of transition to low-carbon energy. The comparison for the Tunkinsky district shows that the greatest reduction in CO_2 emissions can be achieved by using heat pumps instead of numerous low-capacity boiler houses (with a load of up to 0.4 Gcal/h): heat pumps can reduce the existing emission of 10 thousand t/year by 7.2 thousand t/year, while the conversion of all heat sources in the district to gas – by 6 thousand t/year. However, conversion to gas wins when it comes to the emissions of pollutants into the atmosphere and the ASW production.

To reduce the anthropogenic pollution of the natural environment in the Okinsky district, it may be quite justified to use heat pumps instead of low-capacity boilers (only 4, out of 18, wood-burning boilers will remain in operation). Studies have shown that in this case, the emission of pollutants will decrease from 217 to 10 tons/year (22 times) and the production of ASW will drop from 108 to 5 tons/year (22 times) (see Table 7). In general, the environmental impact in this area will be virtually eliminated.

V. Conclusion

The Baikal-Khuvsgul transboundary territory is an advantageous area for the development of recreational activities and tourism. The existing energy system does not provide adequate conditions for this. The power system is characterized by low reliability and inability to connect new large consumers. Heat is supplied to consumers from many coal-fired and wood-fired boilers of small and medium capacity, which are characterized by low performance and have an inefficient exhaust gas purification system.

To improve the reliability and environmental efficiency of energy supply to consumers in the Baikal-Khuvsgul transboundary territory, the research involves studying the challenges of transitioning to low-carbon technologies. The use of RES and conversion of municipal boiler houses to gas are considered as the main avenues.

An analysis of the resources available in the territory showed a high solar energy potential for the expansion of generation based on photovoltaic converters. The levelized cost of electricity generation from low-capacity solar power plants is estimated to lie in the range of $0.07–0.09/kWh. This cost is comparable to the electricity tariff for the population of the considered territories, which reaches $0.06 /kWh. The placement of solar power plants at remote substations offers a combination of benefits: an increase in the reliability of power supply, opportunity to connect new consumers, reduction in pollutant emissions from backup diesel power plants, and elimination of fuel import and storage.

Another way of using RES in the territory at issue is to replace low-capacity coal-fired boilers with heat pumps. The geothermal energy potential is sufficient, but the capital cost of a heat pump-based heating system is high, which is why this option can be considered only if there is a significant increase in air pollution charges or a carbon tax is introduced. The levelized cost of thermal energy production from heat pump unit is \$62/Gcal, which significantly exceeds the value of this indicator for the boiler house (\$41.5/Gcal).

Conversion of municipal boiler houses to gas can become an important alternative to the transition to low-carbon technologies in the Tunkinsky district, but it will not completely resolve the issue of decarbonization, since burning of gas fuel causes CO_2 emissions too, albeit to a lesser extent. However, the implementation of this direction will significantly reduce the environmental impact from the municipal boilers: the emissions of particulate matter and sulfur dioxide will be eliminated and no ash and slag waste will be produced. This is a very important point for the creation of acceptable conditions for any type of activity in the territory of the Tunka National Park, which is a zone of special nature management. It should be emphasized once again that conversion to gas is possible only under certain conditions, if the main gas pipeline runs through the territories at issue.

However, decarbonization technologies can play an important role when they are aimed at jointly solving environmental, social, and climate problems.

The findings of the study have enabled us to make important conclusions, some of which should be highlighted:

1) The greatest environmental effect for the Tunkinsky district, as a zone of special nature management, can be provided by converting municipal boiler houses to gas;

2) The greatest decarbonization effect can be obtained by eliminating the combustion of fossil fuels;

3) It is advisable to solve the environmental problems in the considered territories by combining various avenues and technologies.

Acknowledgment

The research was carried out under State Assignment Project (no. FWEU-2021-0004) of the Fundamental Research Program of the Russian Federation 2021–2030 using the resources of the High-Temperature Circuit Multi-Access Research Center (Ministry of Science and Higher Education of the Russian Federation, project no 13.CKP.21.0038).

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SPIN 6445-7531. Hirsch index 10.

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