The Effect of Energy Generation Mix on Air Quality in the Siberian Regions

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***Abstract* — Production of electricity and heat makes a significant contribution to environmental pollution. The article shows that key factors behind the negative impact of this type of activity on air quality are the power generation mix and the type of fuel used. In order to address environmental issues facing the Siberian regions it is necessary to expand the use of natural gas and introduce the best available technologies of coal combustion at existing thermal power plants in order to reduce emissions of the most hazardous pollutants.**

***Index Terms*: electricity and heat production, fuel combustion, air pollution, urban environmental issues, air quality.**

I. Introduction

As of 2020, 38% of the population of Siberia lived in cities with high and very high levels of air pollution, and in some regions the share of this population exceeded 60% (Table 1).

A significant contribution to air pollution is made by electricity and heat production: the share of pollutant emissions from the activity referred to as «Provision of electricity, gas, and steam» in total emissions in Russia in 2019 was about 17%. At the same time, the sector accounted for 36% of particulate matter emissions, 25% of sulfur dioxide emissions, and 46% of nitrogen oxide emissions. In Siberia, these figures were even higher. Table 2 presents the share of emissions of the most common pollutants from fuel combustion for electricity and heat generation in the total emissions of these substances in the region. The data are presented for 2017: the metric was not calculated for subsequent periods. In some regions, the share of the sector is more than 90% because there are no other large industrial enterprises that are sources of pollution. Furthermore, fuel combustion makes the greatest contribution to emissions of particulate matter and nitrogen oxides, which are most reliably associated with negative impacts on human health.

Thus, a significant share of environmental issues of Siberian cities is associated with the production of electricity and heat. Because this type of activity is an indispensable component of critical infrastructures, it is important to determine which generation parameters contribute to adverse impacts on the environment and can be changed in order to improve the air quality in cities.

II. Literature Review

In terms of adverse impacts on the air quality, the thermal power industry holds a principal place in the energy generation mix. With this in mind, in [2], the authors provided performance metrics of the environmental efficiency of different methods of energy production and calculated the value of the overall comprehensive index of adverse impacts on the environment and human health. Combustion of coal, oil, and gas contributes the largest amount of greenhouse gases and harmful substances emission into the atmosphere. The comprehensive index of adverse impact for coal was 65.2 points, for oil and gas – 26.4 points. For comparison: nuclear power and hydropower scored 16.1 and 16.5 points, respectively. It is also worth noting that there is not only the gap between thermal power and other types of energy generation but also a significant difference in the types of fuel used. When coal is burned, a significant amount of sulfur dioxide, nitrogen oxides, and particulate matter is emitted, which contributes to the formation of acid rain and smog, and have an adverse impact on human health. The role of coal as the main fuel has been well-researched, including from the point of view of the impact on human potential. The authors found that in 2006 the use of coal in power generation prevailed in 6 out of 10 regions of the Russian Federation with the lowest human development index [3]. The type of fuel also affects the eco-intensity metric. Paper [4] demonstrated that the expansion of the electric power industry in Trans-Baikal territory in 2006–2016 falls in the zone of «brown» or

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Table 1. Air Quality in the Regions of Siberia in 2020

Region	Level of air pollution (H – high, VH – very high)	Cities	Share of population living in cities with high and very high levels of air pollution
Altai Republic	-		-
Tuva Republic	VH	Kyzyl	68%
Khakassia Republic	VH	Chernogorsk	69%
	H	Abakan	
Altai Krai	H	Barnaul	48%
Krasnoyarsk Krai	VH	Kansk, Minusinsk, Norilsk	58%
	H	Krasnoyarsk, Lesosibirsk	(Taimyr Autonomous Okrug – 99%)
Irkutsk Oblast	VH	Vikhorevka, Zima, Svirsk, Usolie-Sibirskoe, Cheremkhovo, Shelekhov	70%
	H	Angarsk, Bratsk, Irkutsk	
Kemerovo Oblast	H	Kemerovo, Novokuznetsk	47%
Novosibirsk Oblast	-	-	0%
Omsk Oblast	-	-	0%
Tomsk Oblast	-	-	0%

Source: Yearbook «The state of air pollution in cities in Russia for 2020» [1]

Table 2. Share of Pollutant Emissions from Fuel Combustion for Electricity and Heat Generation in Total Emissions in the Region in 2017, %

	Particulate matter	Sulfur dioxide	Nitrogen oxide	Carbon dioxide
Siberian Federal Okrug	78.0	25.8	74.6	32.1
Altai Republic	92.8	96.0	100.0	96.7
Tuva Republic	94.8	99.6	96.0	98.7
Khakassia Republic	46.6	54.3	74.8	16.7
Altai Krai	77.5	91.4	87.9	69.8
Krasnoyarsk Krai	60.2	4.9	65.7	23.6
Irkutsk Oblast	69.2	90.9	44.7	15.7
Kemerovo Oblast	59.9	66.3	75.0	23.7
Novosibirsk Oblast	79.8	98.0	86.8	63.3
Omsk Oblast	87.2	87.9	84.5	74.3
Tomsk Oblast	31.6	92.5	73.4	18.0

Source: Calculated according to official statistics

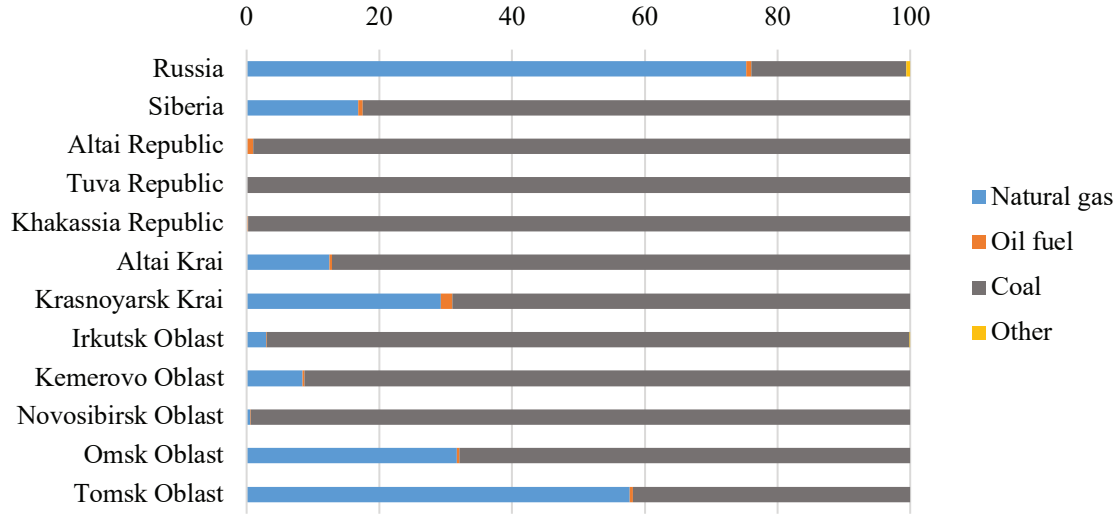

Fig. 1. Structure of electricity generation by types of power plants in 2021, %. Source: Calculated according to official statistics.

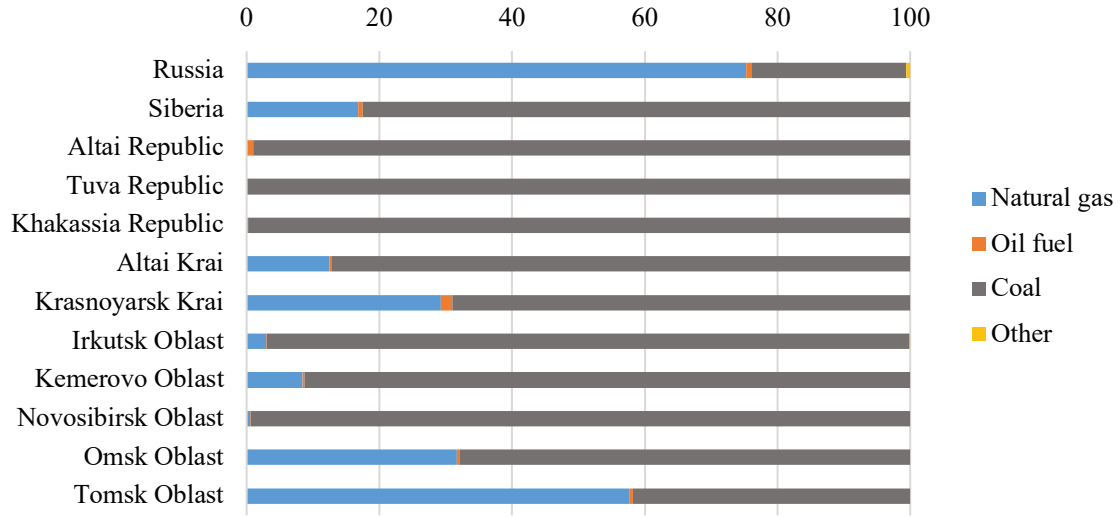

Fig. 2. Fuel consumption at power plants and boiler in 2020 by type of fuel, %. Source: Calculated according to official statistics

«black» growth, i.e., it was characterized by an increase in environmental impacts, while in Russia as a whole, in recent years it has gravitated towards «green» growth. The authors attributed this difference to the fact that in the Trans-Baikal Territory electricity and heat are supplied by coal-fired plants. The need for gradual replacement of coal-fired thermal power plants with more environmentally friendly energy sources was discussed in [5]. It was noted that nuclear power is a promising type of power generation for Siberia due to the availability of enterprises for the production and enrichment of uranium ore, as well as capacities for storing spent fuel.

Obviously, in addition to the type of fuel burned, many other factors, such as the local climate conditions, the location of pollution sources, and the technologies used, contribute to adverse impacts on the atmosphere during the production of heat and electricity. The risks are due to the extreme continental climate with low capability of the atmosphere for self-cleaning and dominant use of coal as the fuel of choice. The proximity of sources of pollution to housing areas has the most negative impact on the air quality in cities and the health of the population [3]. Through a case study of the Irkutsk region, it was shown that one of the reasons for the adverse impact of thermal power plants on the atmosphere is the low level of emission treatment. At the same time, in the case when large CHPPs are equipped with ash collectors, most small boiler plants located in close proximity to the housing and social infrastructure facilities operate without emissions [6]. The possibility of upgrading existing thermal power plants and boiler plants in order to reduce pollutant emissions was discussed in [7]. The authors showed that the innovation-driven development of the energy sector, based on the expansion of the use of natural gas and the use of the best

Table 3. The Main Generating Enterprises of the Krasnoyarsk Territory and Their Contribution to Air Pollution in 2020

№	Eenterprise	Cities and settlements – heat consumers	Location	Share of enterprise emissions in the total emissions of the municipality, %
		Thermal power plants of power companies		
1	Berezovskaya GRES	Sharypovo, Dubinino	Sharypovsky district	90.9
2	Nazarovskaya GRES	Nazarovo	Nazarovo	92.7
3	Krasnoyarskaya CHPP-1	Krasnoyarsk, Berezovka	Krasnoyarsk	13.0
4	Krasnoyarskaya CHPP-2	Krasnoyarsk	Krasnoyarsk	14.1
5	Krasnoyarskaya CHPP-3	Krasnoyarsk	Krasnoyarsk	6.3
6	Krasnoyarskaya GRES -2	Zelenogorsk, Orlovka	Zelenogorsk	19.6
7	Kanskaya CHPP	Kansk	Kansk	16.0
8	Zheleznogorskaya CHPP	Zheleznogorsk, Sosnovoborsk	Sosnovoborsk	N/A
9	Minusinskaya CHPP	Minusinsk, Zeleny Bor	Minusinsk district	80.6
		Power plants of industrial enterprises		
10	CHPP JSC RUSAL-Achinsk	Achinsk	Achinsk	N/A
11	CHPP LLC Teplo-Sbyt-Servis	Kansk	Kansk	N/A
		Norilsk-Taimyr Energy District		
12	Norilskaya CHPP-1	Norilsk	Norilsk	N/A
13	Norilskaya CHPP-2	Talnakh	Norilsk city district	N/A
14	Norilskaya CHPP-3	Kayerkan	Norilsk city district	N/A

Source: compiled from the data presented in the Government Report «On the State and Protection of the Environment in Krasnoyarsk Krai in 2020» [8] and the Program for Expansion Planning of the Krasnoyarsk Territory Electricity Sector for 2022–2026 [9].

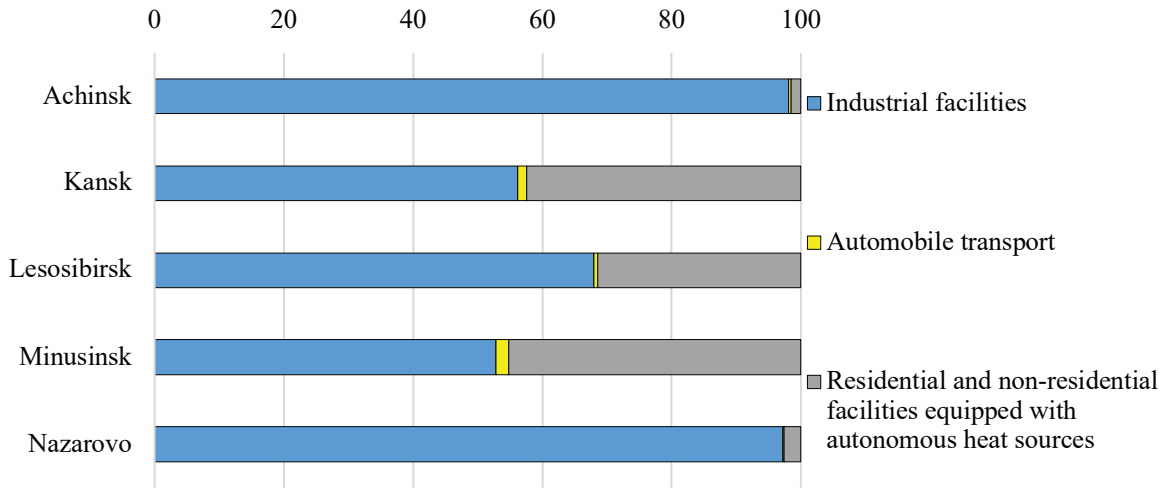

Fig. 3. Atmospheric air pollution in the cities of Krasnoyarsk region by type of objects of pollution, %. Source: Compiled based on the conclusions of the summary estimates of air pollution in the cities of the Krasnoyarsk territory [11].

available coal combustion technologies, will reduce the human-induced environmental impacts.

III. Structure of Energy Generation in the Regions of Siberia

As it stands now, thermal power plants are the basis of Russia's electric power industry, accounting for 60% of all electricity generation in 2021. Nuclear and hydroelectric power plants also make up a significant share: 20% and 19%, respectively. The share of other sources, including solar, wind, and others, is less than 1%. In Siberia, the power generation mix is different: due to the presence of large rivers, hydroelectric power plants generate more than 60% of the electricity in this area. Nuclear power is not developed in Siberia. There are solar power plants in some regions, and in the Republic of Altai they generate most of the electricity – about 77% (Fig. 1).

In most regions of Siberia, thermal power plants form the basis of the sector. In regions where hydroelectric power plants prevail, their capacities are used for the needs of large industrial facilities, and the electricity and heating needs of cities are met by combined heat and power plants. As noted above, the type of fuel used is of particular importance in terms of the impact on air quality. The most environmentally friendly type of fuel for thermal power plants is natural gas, its use prevails in the European part of Russia, whereas Siberia and the Russian Far East use mainly coal (Fig. 2).

As noted above, during coal combustion, a significant amount of sulfur dioxide, nitrogen oxides and particulate matter is emitted. Therefore, the dominant use of coal as a fuel is responsible for the high percentage values of emissions of these pollutants during the generation of electricity and heat in the total emissions in the regions (Table 2).

IV. Impact of Electricity and Heat Production on Air Quality in the Cities of the Krasnoyarsk Territory

In what follows, through a case study of the Krasnoyarsk territory we consider the impact of individual major generating enterprises on air quality. The total amount of pollutant emissions contributed by the activity referred to as «Production and distribution of electricity, gas and water» in 2020 amounted to 188 thousand tons, 27% of emissions in the region. The top six enterprises (Table 3) account for 44% of all emissions into the atmosphere in the industry referred to as «Production and distribution of electricity, gas and water» and 12% of the total emissions in the region [8].

There are 14 thermal power plants in the region that supply heat and electricity to homes in most cities and industrial centers. There are also several facilities that serve industrial consumers. Heat and power plants in the Norilsk-Taimyr Region use natural gas as their fuel, while all other facilities use lignites from Krasnoyarsk territory's coal deposits, which, as has been repeatedly noted, is a negative factor.

As can be seen from Table 3, all thermal power plants have a significant impact on the air quality in the areas where they are located. With the exception of the Berezovskaya GRES and Minusinskaya CHPP, all of them are located in urban areas, which determines the greatest impact on the population of those cities. Here it should be noted that in the mix of heating production in cities, apart from major thermal power plants, an important part is played by boiler plants and individual heat sources, which are usually located directly inside residential buildings. From this point of view, cogeneration plants, even those that are coal-fired, have significant environmental and economic advantages over small boilers: they provide greater reliability of heating, have lower specific fuel consumption, lower specific emissions of pollutants, and are subject to stricter control with respect to emissions.

There are 1 255 boiler plants in Krasnoyarsk Krai that serve as auxiliary sources in heating layouts of large cities and are the main heat sources for the majority of small cities of the Krai. This situation is characteristic of other regions of Siberia as well. The main type of fuel used by boiler plants is coal, and in the case of individual heating sources it is coal and wood. For a number of Siberian cities a program of replacing inefficient boilers and connecting their consumers to CHPPs is currently underway; such measures are planned or already being implemented by the Siberian Generating Company in Krasnoyarsk, Kansk, Nazarovo, Novosibirsk, Kemerovo, Belovo, Abakan, Chernogorsk, Barnaul, Biysk, and Kyzyl. According to the Siberian Generating Company, during the 5 years of the program implementation it was possible to reduce the volume of pollutant emissions by 10 thousand tons per year and to reduce their impact on the urban environment [10].

It is worth noting that accounting for the adverse impact of boilers on air quality is difficult because of the lack of complete data on all boilers and the derelict state of statistics on air emissions at the municipal level - there is simply no usable data on small towns of the region.

Individual heat sources - boilers and stoves, which are used for heating purposes in the residential sector - are an even more challenging component to analyze. In 2021 in the Krasnoyarsk territory there were performed summary estimates of air pollution in several cities of the territory, which included the formation of data on emissions from housing facilities and non-residential premises equipped with autonomous heat sources (AHS).

Figure 3 indicates that in the cities having no major industrial pollutant facilities, autonomous heating sources make a significant contribution to air pollution.

In all surveyed cities AHS facilities contribute to exceedances of maximum permissible concentrations for such substances as nitrogen dioxide, carbon monoxide, dust, and suspended substances [11]. Since the exceedances were recorded within the boundaries of residential areas, it

can be argued that AHS emissions have an adverse impact on the health of people living in those areas.

V. Conclusion

A number of factors, including the generation mix and the type of fuel used, contribute to adverse impacts of power generation on air quality. The predominance of coal in the mix of consumed fuel at thermal power plants and boilers increases the contribution of heat generation to air pollution for all major pollutants, including particulate matter and nitrogen oxides, which are most reliably associated with negative effects on human health. For many Siberian cities, the adverse impact is exacerbated by natural and climatic features with unfavorable conditions for dispersion of pollutants.

To address the environmental issues of the Siberian regions, a gradual transition to cleaner energy sources and fuels is necessary. Due to the lack of foreseeable prospects for the development of alternative types of energy, the focus should be on expanding the use of natural gas. In addition, it seems relevant to analyze the current equipment and technologies of coal combustion at existing thermal power plants in order to choose options for their modernization so as to reduce emissions of the most hazardous pollutants.

The power generation mix within individual settlements is also important. Consequently, other key areas of greening in the field of heat production are the continuation of projects to replace small boilers and the transition of the residential sector to more environmentally friendly fuels.

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