

Development of Low Carbon Cities: Assessment of Carbon Dioxide Emissions from Energy Facilities in Irkutsk City

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Abstract — Decrease in greenhouse gas emissions is a current trend in solving the climate change problems. The concept of low-carbon cities is extensively discussed nowadays. It aims to reduce greenhouse gas emissions through integrated mechanisms and measures, which comply with socio-economic development and city management. Since a considerable part of the population lives in cities, the utmost goal of the study is to analyze the situation with emissions of the main greenhouse gas, i.e., carbon dioxide, in the urban environment. The major sources of carbon dioxide emissions are stationary energy facilities of different capacities burning fuel. The paper considers the city of Irkutsk as an example of the populated area included in the study on low carbon cities under the auspices of the Social and Economic Commission for Asia and the Pacific of the UN - UNESCAP. The first stage of the studies involved assessing the current carbon dioxide emissions from energy facilities of the city through the calculation of carbon dioxide emissions from boiler houses and the city cogeneration plant for 1990. The findings revealed the potential of reducing carbon dioxide emissions from energy facilities in Irkutsk. The paper suggests the basic directions and measures to mitigate greenhouse gas emissions from the urban energy facilities.

Index Terms: Climate change, International agreements, greenhouse gas emissions, the city of Irkutsk, boiler houses, the Novo-Irkutsk cogeneration plant.

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I. INTRODUCTION

At present, the world community raises an issue on the role of cities as the major sources of greenhouse gas emissions increasingly more often. In 2011, the UN Economic Commission published the report “Climatically neutral cities” [1], which analyzed the role of cities and their effect on climate change. The bulk of the population resides in cities concentrating on business activity, social and intellectual life. Therefore, the urban environment possesses the greatest resources to decrease energy intensity and energy consumption and thus mitigate greenhouse gas emissions. The concept of low carbon cities suggests not only a direct cutdown in emissions but also the design of mechanisms and complex measures that are integrated within the city and aimed at making coordinated decisions on the reduction of carbon dioxide emissions.

The idea of low carbon cities was supported by the Social and Economic Commission for Asia and the Pacific of the UN (UNESCAP). The Commission is developing some programs on environmental cooperation in Northeast Asia. The platform on the low carbon cities in Northeast Asia - NEALCCP (Northeast Asia Low Carbon City Platform) operates under the auspices of UNESCAP. The platform aims to involve different stakeholders in climate protection and the development of low carbon cities, i.e., cities with a low level of carbon dioxide emissions. The twenty-third panel of UNESCAP in October 2019 supported the proposal put forward by Mongolia and the Russian Federation to expand the activities and incorporate the Mongolian (Chingis, Tsetserleg) and the Russian (Ulan-Ude and Irkutsk) cities in the study on the development of low carbon cities.

The development of comprehensive measures on the mitigation of carbon dioxide emissions in the cities requires, first of all, an analysis of the current general state of the settlement (population, economy, climate, transport, and energy infrastructure), and also the ecological state.

This study considers the energy sector as one of the chief sectors of the economy in Irkutsk. The paper

presents an assessment of carbon dioxide emissions caused by the operation of energy facilities.

II. LITERATURE REVIEW

The world community has been discussing the issues of greenhouse gas emissions for long. The first reliable information on changes in climate and possible causes of its fluctuations appeared as far back as the 19th century [2], and the relation between these changes and the higher carbon dioxide concentration is validated by numerous studies [3-5].

However, the debates concerning the effect of greenhouse gases on climate both locally and globally are still going on. Of special concern is the human contribution to the accelerated warming in the last decades. The opinions of scientists on this issue vary. Some of them discuss the theories of natural cyclical changes caused by the release of space and solar plasma [6, 7], while others lay the stress on the anthropogenic effects due to human activity and increase in carbon dioxide emissions as a result of growing business activity [8, 9].

Recent decades have seen new records of the climatic changes, the mean temperatures rise, and the distribution of atmospheric precipitation changes. The area of glaciers, ice sheets, and arctic seawater ices shrinks faster than it was forecasted. The most significant climate change consequences both observed and forecasted were revealed in all European regions. Accordingly, the climate change consequences for seas are related to the rise in water temperature and acidity. In the coastal zones, the sea level rose, the shorelines eroded, the storms became more frequent and severe [10]. It is expected that in the future, there will be more intensive and numerous climate changes. Even if the greenhouse gas emissions were completely stopped now, the climate would continue to change for many decades because of earlier releases and inertia of the climatic system [10].

At present, the planet climate conservation issue is the focus of attention of practically all world's countries. The UN Framework Convention on Climate Change (UN FCCC) reflected the interest of the international community in decreasing greenhouse gas emissions in 1992. The goal of the Convention was to stabilize the greenhouse gas concentrations in the atmosphere at a level, which would prevent dangerous man-induced impact on the climatic system [11]. This Convention was signed by 197 countries, including those of the former USSR and all industrially developed countries. Later, in 1997, the Framework Convention was supplemented by the Kyoto Protocol that fostered the development of the provisions of the UN FCCC, calling for the developed countries to limit and cut down greenhouse gas emissions under the agreed national commitments. The Protocol was adopted since the Convention of 1992 contained only the calls to these countries to pursue a policy and take measures to prevent climate change. The Kyoto Protocol establishes

specific emission reduction commitments for industrially developed countries, including the European countries. Generally, these commitments correspond to approximately a five-percent decrease in emissions against the 2012 levels [12]. With the complex process of the Kyoto Protocol ratification and the need to solve the problems of climate change, in 2015, the world community once again adopted the worldwide document, the so-called Paris Climate Agreement [13]. It formulates the issues of greenhouse gas emission mitigation somewhat differently. The Agreement suggested limiting global warming, providing temperature change by no more than 2°C by 2050, and preferably 1.5°C by 2040 with further zero (zeroing) growth of the global temperature on the planet. Essentially, it declared a transition to carbon-free technologies.

It is worth noting that many world's countries are affiliated with this process. The Paris Agreement was signed by 196 countries of the world, including Russia, China, Mongolia, Japan, European countries, and others. At the beginning of 2021, the USA also signed this Agreement.

The Russian Federation confirmed its commitment to the Paris Agreement (as of 2015) by the Russian Government Decree of September 21, 2019, and became an authorized participant in this international-legal instrument. In 2014, before signing the Agreement, Russia developed an Action Plan to ensure a reduction in greenhouse gas emissions by 2020 to a level of no more than 75% of the 1990 level (approved by the Decree of the Government of the Russian Federation of April 2, 2014, No. 504-r). And every five years, the Russian Federation undertakes to submit a report on Russia's contribution to the reduction of anthropogenic greenhouse gas emissions to the Secretariat of the UN Framework Convention on Climate Change. The Russian Federation adopted the Orders and Decrees (2014, 2015) on the inventory of greenhouse gas emissions, developed the guidelines for assessing emissions for various types of economic activities. In 2020, the Ministry of Economic Development of Russia prepared a draft long-term strategy for the development of the Russian Federation with a low level of greenhouse gas emissions until 2050 (March 2020).

The Asia-Pacific region countries also seek to transition to carbon-free technologies in their energy development [14]. The primary technologies aimed at achieving a climate-neutral world (zeroing emissions by 2050) include the use of renewable energy sources instead of coal for energy purposes; the involvement of electric transport (electric vehicles) with additional preferences in its operation; promotion of studies on the development of hydrogen technologies; bans on deforestation, and others.

The main focus is, of course, on the transformation of the energy sector, i.e., a change in the fuel and energy balance structure; energy conservation; an introduction of innovative technologies and intelligent systems for energy consumption and production; use of renewable energy resources, including hydro resources; industrial energy disposal, and others.

Table 1. The values of potentials of global warming caused by greenhouse gases.

Greenhouse gas	Chemical formula	Potential of global warming, t CO ₂ -equiv./t	Production process
Carbon dioxide	CO ₂	1	Stationary fuel combustion, flaring, fugitive emissions, oil refining. Production: coke, concrete, lime, glass, ceramic wares, ammonia, ferroalloys, primary aluminum. Petrochemistry, ferrous industry, air, railway transport, and other industrial processes.
Methane	CH ₄	25	Flaring, fugitive emissions
Nitrogen oxide	N ₂ O	298	Production of nitric acid, caprolactam, glyoxal, and glyoxalic acid.
Fluoroform	CHF ₃	14 800	Production of fluorine-containing compounds.
Perfluoromethane	CF ₄	7 390	Production of primary aluminum.
Perfluoroethane	C ₂ F ₆	12 200	Production of primary aluminum.
Sulfur hexafluoride	SF ₆	22 800	Production of fluorine-containing compounds

Since it is rather difficult to stop using fossil fuel in the near future, the world community has proposed developing commercially viable clean coal technologies with 100% of CO₂ capture as soon as possible. Carbon capture and storage technology allows capturing waste carbon dioxide from flue gases of power plants based on the methods of absorption, adsorption, membrane gas separation, and others [15]. Experts claim that technically the capture and storage of large amounts of CO₂ will not pose a big problem. Moreover, the widespread use of these technologies can significantly contribute to the achievement of the ambitious climate targets set by the Paris Agreement.

In 2019, the world had 17 carbon disposal projects aimed at capturing up to 31.5 million tons of CO₂ per year, with 3.7 million tons stored in geological structures [16].

At the initiative of the Global Energy Association for the development of international research and projects in the field of energy and with the direct participation of the world expert community representatives, breakthrough energy technologies have been developed to minimize or avoid carbon dioxide emissions [17].

The technologies for mitigation of greenhouse gas emissions also include new technologies for energy production and conversion, which involve creating closed thermodynamic cycles with zero emissions [18]. Specific features and advantages of such technologies are oxygen fuel combustion accompanied by the production of water vapor and carbon dioxide with the condensation of the latter, its capture, and transportation to the storage site.

The efficient use of resources and the creation of a low carbon society are the focus of the world's discussions on the transition to the "green" economy, which is reflected in the mid-and long-term plans of Europe's development [19]. The Action Plan for the transition to the low carbon economy suggests that the emissions of the European community must be decreased by 80% by 2050 against the 1990 level based on the internal mitigations.

Thus, to date, a global opinion has been formed, which is supported and authorized by the relevant documents aimed at reducing greenhouse gas emissions and using carbon-free or low carbon technologies for the vital activities of the planet's population.

III. THE METHODOLOGY OF INVESTIGATION

Since June 2015, the Order of the Ministry of Natural Resources of the Russian Federation No. 300 has been in effect in Russia, which approves methodological guidelines and guidance for quantifying the greenhouse gas emissions by organizations engaged in various economic activities [20]. These guidelines are based on the Action Plan to decrease greenhouse gas emissions by 2020, which was approved by Order No. 504-r of the Government of the Russian Federation dated April 2, 2014. The main goal of the Plan is to ensure that by 2020 Russia's greenhouse gas emissions do not exceed 75% of the 1990 emissions [21].

The methodological guidelines establish a procedure for quantifying greenhouse gas emissions for their monitoring, reporting, and verifying. Since 2017, all enterprises with emissions of more than 50 thousand tons of CO₂-equiv. per year must report on greenhouse gas emissions.

The developed Greenhouse Gas Inventory Methods are based on the international recommendations, are approved by the Ministry of Natural Resources of the Russian Federation, and include all categories of sources and sinks of greenhouse gases.

In general, seven gaseous compounds, which cause the so-called greenhouse effect, i.e., upset the planet's heat exchange, are classified as greenhouse gases (Table 1). The data on the global warming potential for the selected greenhouse gases were developed following Decision 24 / SR.19 of the Conference of the Parties engaged in the UN Framework Convention on Climate Change, ratified by Federal Law No. 34 of 04.11.1994 "On Ratification of the UN Framework Convention on Climate Change" [22, 23]. The gases indicated in the Table have different warming potential: carbon dioxide has the lowest potential, and sulfur hexafluoride (released during the production of fluorine-containing compounds) has the highest potential.

Among different production processes, energy facilities and especially fossil fuel combustion cause the greatest emissions of greenhouse gases and primarily CO₂.

The greenhouse gas emissions are determined quantitatively by different methods designed for corresponding categories of their sources:

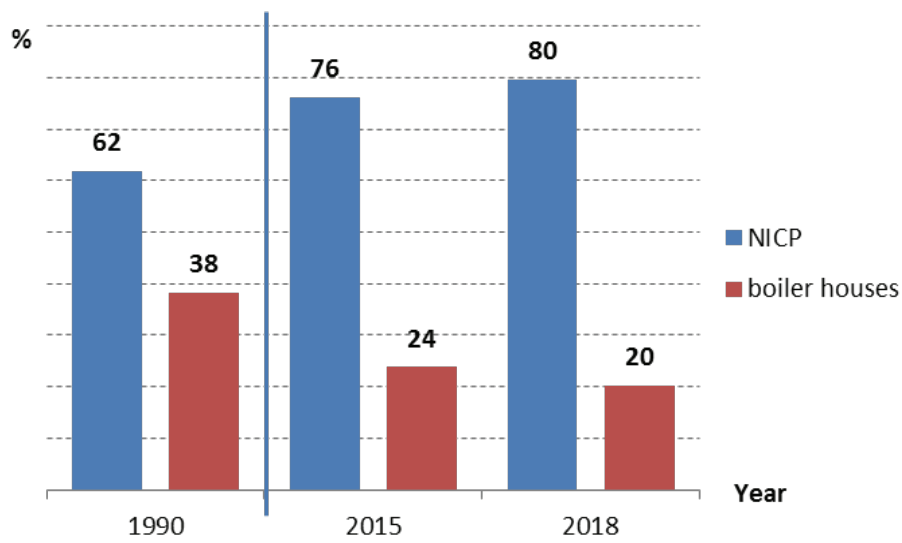


Fig. 1. Dynamics of fuel consumption structure by energy facilities in the city of Irkutsk.

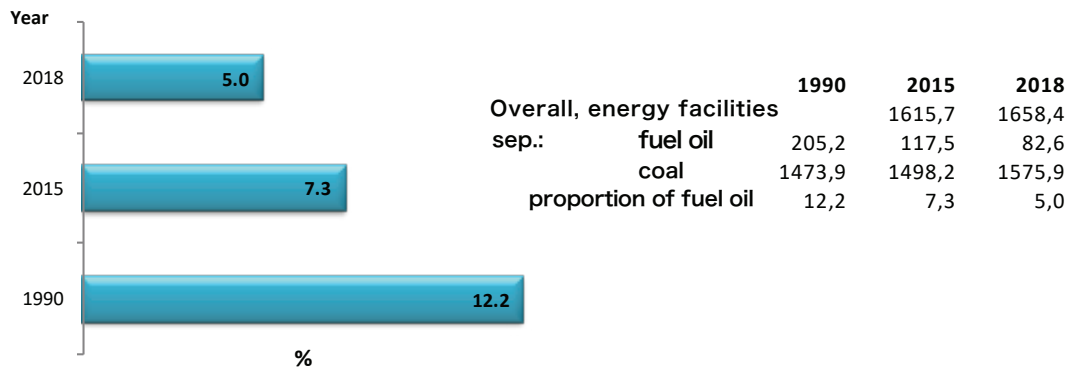


Fig. 2. Dynamics and share of fuel oil in fuel consumption structure for energy facilities in the city of Irkutsk.

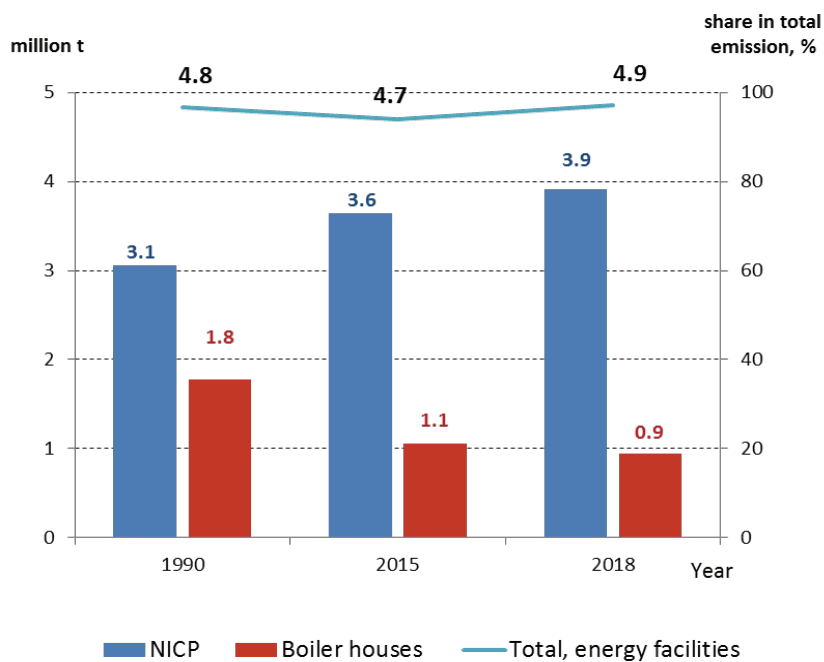


Fig. 3. Dynamics of emissions and assessment of the contribution of energy facilities to the total CO₂ emission in Irkutsk city in 1990, 2015 and 2018.

Table 2. Dynamics of fuel consumption by type in Irkutsk, thousand tce.

Energy facilities	Fuel	Year			
		1990	2015	2018	
NICP	fuel oil	17.9	2.4	2.1	
	brown coal	1 019.5	1 228.5	1 319.6	
	<i>total</i>	<i>1 037.4</i>	<i>1 230.9</i>	<i>1 321.7</i>	
Boiler houses	fuel oil	187.3	115.1	80.4	
	coal	brown	454.4	253.6	246.4
			hard	16.1	9.9
	<i>total</i>	<i>641.7</i>	<i>384.8</i>	<i>336.7</i>	
Total		1 679.1	1 615.7	1 658.4	

- the calculation method based on the periodic measurements of emissions;
- the method of the continuous monitoring of greenhouse gas emissions;
- the calculation method based on material balance;
- the calculation method based on the data on the enterprise performance and the emission factors.

The calculation methods relying on periodic measurements and continuous monitoring of greenhouse gas emissions employ the results of instrumental measurements at the enterprises for a period (year) at issue. These results are given in the protocols of measurements, technical specifications, reports of inventory checks of emission sources, data on in-process control of emissions and production of waste, and others. The rate of data logging and the methods of their averaging are chosen by the organization individually so as to provide their objectivity for the considered period.

Calculation based on the material balance assumes the use of data from the accounting documents on the consumption of raw materials, fuel, and materials; production of products (for example, technical reports, balances, statistical reporting forms, and others); quality certificates, and other sources of information. The calculation takes into account changes in the reserves of resources at the enterprise [20].

The input data for the greenhouse gas emission calculation by the method based on the data on enterprise performance and emission factors are the actual data, which characterize the enterprise activity for the sample period (for example, fuel consumption by type, consumption of carbon-containing materials), greenhouse gas emission factors, calculated factors of carbon content in fuel, and component composition for gaseous fuel.

This study relies on the methodological guidelines [20] for the category of stationary fuel combustion to estimate the greenhouse gas emissions from energy enterprises generating electric and thermal energy. At the same time, only carbon dioxide (CO₂) emissions are classified as greenhouse gas emissions subject to mandatory accounting (in this category of emission sources).

IV. RESULTS

The primary energy facilities for electricity and heat supply to the population and industrial enterprises of Irkutsk are boiler houses of different capacities, the Irkutsk HPP, and one large thermal power plant, i.e., the Novo-Irkutsk cogeneration plant (NICP). The installed capacity of the Irkutsk HPP is 662.4 MW, NICP – 708 MW, which characterizes Irkutsk as the city with a high share of renewable energy sources. The electric power generated at the Irkutsk HPP covers the city's demands and ensures the functioning of large enterprises in the nearest populated areas: the Irkutsk aluminum smelter (Shelekhov town) and Irkutsk aircraft plant, which is currently increasing its production capacities. On the whole, the industry share in energy consumption of the city reaches 66%. The rest of the electric power covers population needs. The main consumers of thermal energy produced by the NICP and municipal and departmental boiler houses are the population and social infrastructure.

In 2018 there were 89 boiler houses in the city, of which 57 used coal, 17 used liquid fuel (primarily fuel oil), and 15 were electric boiler houses. One boiler house burns fuelwood, i.e., sawdust. The city has no renewable energy sources for large-scale thermal energy production. Electric boiler houses and a boiler house running on fuelwood are not considered in assessing the CO₂ emissions from boiler houses, and only coal and fuel oil-fired boiler plants will be analyzed further.

To calculate the CO₂ emissions from energy facilities (boiler houses on fossil fuel and the NICP) in Irkutsk, fuel consumption was analyzed for 1990, 2015, and 2018.

A. Fuel consumption by energy facilities in the city of Irkutsk

The consumption of fuel in 2015 and 2018, given its types, was determined using the data of heat supply schemes of Irkutsk for different years of their updating [24, 25], the State report on the protection of Lake Baikal [26], and the data of technical specifications of heat sources of the municipality of Irkutsk [27]. Brown coal is the primary fuel for thermal energy facilities of the city, Table 2.

Table 3. Calculated CO₂ emission from energy facilities in Irkutsk city, thousand tons/year.

Energy facility	Year		
	1990	2015	2018
NICP	3 058.4	3 641.7	3 910.9
Boiler houses	1 770.2	1 056.6	939.3
Total	4 828.5	4 698.4	4 850.1

The data on the amount of fuel burnt by the Irkutsk boiler plants and the NICP in 1990 are taken from the 1995 and 1999 official letters of the JSC "Irkutskenergo".

At present, the NICP burns primarily brown coal imported from the Kansk-Achinsk basin. Boiler houses use coal from local deposits of the Irkutsk region: brown coals and, in small amounts, hard coal.

For the considered period, the total fuel consumption (coal and fuel oil) by all energy facilities of the city is estimated at 1.6-1.7 million tce per year.

The major fuel consumer among the energy facilities is the NICP, with its share in the fuel consumption structure ranging from 62 to 80% in different years, Figure 1.

As seen from Figure 1, the share of boiler houses in the total fuel consumption declined almost twice (from 38% in 1990 to 20% in 2018) with a significant increase in the share of NICP.

In the total fuel consumption structure, the fuel oil share gradually decreases from 12.2% in 1990 to 5% in 2018, i.e., by 2.5 times, Figure 2.

B. Assessment of carbon dioxide emissions from energy facilities in the city of Irkutsk

The calculations of carbon dioxide emissions from energy facilities with stationary fuel combustion are based on Order No. 300 of June 15, 2015 [28]. It is worth noting that greenhouse gases emitted by this category of sources includes only CO₂ emissions due to the combustion of all liquid and hard fuel types used at boiler units to produce heat and/or electricity. Methane (CH₄) and nitrogen oxide (N₂O) emissions, which are potentially likely during stationary fuel combustion, are not considered.

The calculation results for carbon dioxide emissions from energy facilities of Irkutsk city are presented in Table 3.

The calculations show that the amount of CO₂ from the city's energy facilities in different periods is 4.7 (2015) to 4.9 million tons (2018). The emissions of 2018 exceed those of the so-called reference year of 1990 by 21.6 thousand tons. Whereas according to the plans of the Russian Government, the emissions in 2020 must be equal to 75% of the 1990 level, i.e., no more than 3.6 million tons for Irkutsk city.

The thermal power plant (Novo-Irkutsk cogeneration plant) is the main contributor to CO₂ emissions, with its share in the total carbon dioxide emissions increased from 63% to 80% in 2018, compared to 1990 (Fig. 3).

Correspondingly, the contribution of boiler houses to the total CO₂ emissions from energy facilities in Irkutsk city reduced from 37% in 1990 to 19% in 2018.

A decrease in coal consumption by boiler houses and the replacement of some of them with one large-scale energy source, i.e., the Novo-Irkutsk cogeneration plant, led to an increase in the plant fuel consumption. In turn, carbon dioxide emission from the NICP increased by 26% against the 1990 level.

The lowest-carbon energy facilities are electric boiler houses. However, their number has not changed over the period under review (15 electric boiler houses in 2018 [25]). Moreover, future measures to improve heat supply to consumers in Irkutsk city do not include any plans for increasing the number of electric boiler houses and sources using renewable energy.

Although the regional energy companies make their efforts to implement the program to close economically and environmentally ineffective small-capacity boiler houses and connect heat consumers to the main source in the city, i.e., the NICP, the issue of reducing carbon dioxide emissions is unlikely to be resolved. In this regard, measures are necessary to reduce (save) fuel consumption at all energy facilities of the city, including the NICP.

V. CONCLUSION

The study provides a comparative analysis of the estimated carbon dioxide emissions from energy facilities in Irkutsk in 1990 and 2018. It is a starting stage in creating a city with a low carbon status, i.e., a city with low carbon dioxide emissions. Currently, emissions from energy facilities being the primary sources of CO₂ in the city, are estimated at 4.9 million tons per year. These emissions have already exceeded the level of 1990 by 26 thousand tons. The set goals (75% of the 1990 level) can be achieved by reducing carbon dioxide emissions by at least 1.3 million tons.

With the existing energy infrastructure, Irkutsk has the potential to reduce carbon dioxide emissions. It can be implemented by cutting down fuel consumption through the adoption of innovative combustion technologies, the use of available coal-grading technology, and the increase in the number of electric boiler houses.

Modernization of the Irkutsk hydropower plant through the replacement of hydraulic units with expired service life by new ones will contribute to the energy efficiency enhancement in the near future, which will increase the plant's capacity by 20%. Thus, it will be possible to additionally generate up to 200 million kWh of electricity per year, using the same amount of water as before the reconstruction.

The low carbon development of the city will largely depend on the development plans of Irkutsk city in the future. The question of whether Irkutsk will be a low carbon city is complicated as it requires answers to many

sub-questions related to the development of a healthy urban environment. It is necessary to organize constant and continuous metering of energy consumption, to establish an energy conservation service, which will enable both individual enterprises and the entire city to significantly save energy resources.

Conversion of the city's energy facilities to gas can be one of the essential and realistically achievable measures. The use of natural gas as a fuel in the boiler houses and the cogeneration plant of the city will reduce carbon dioxide emissions more than twice against the 2018 level. Moreover, there is the Kovykta gas condensate field prepared for large-scale production in the Irkutsk region. Coordinated actions of the city and regional authorities will make it possible to convert consumers to gas not only in the cities and towns of the Irkutsk region but also in the neighboring regions.

Special attention should be paid to the transport segment, both public and personal means of transportation. Given that the city has the lowest electricity tariff in Russia, this fact should become the main stimulus for the development of electric transport.

With such a tariff policy pursued, it is also possible to carry out a gradual transition of private households to electric heating instead of the stove and often coal heating.

Wind generators and solar panels are represented by single instances (in the private sector) in Irkutsk city. The prospects for the development of renewable energy sources are limited, first of all, by the low cost of electricity. The successful use of renewable energy sources in the city in general seems unlikely without a policy focused on their support at the municipal, regional and federal levels.

Thus, to reduce carbon dioxide emissions in Irkutsk city, it is necessary to formulate a comprehensive program of carbon-free development, which should reflect not only the stages of a gradual transition to low carbon technologies but also a list of dedicated measures for specific types of economic activity. This issue must be addressed comprehensively in both the city energy sector and the entire infrastructure, from urban development to enterprises related to life support and fulfillment of various needs of citizens.

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