The Impact of Sizing and Packaging of the Dzhebariki-Khaya Coal on Carbon Emissions Embodied in Final Demand

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***Abstract*— The paper provides a quantitative assessment of carbon dioxide emissions from coal-fired boiler plants serving large areas of the Northeast of Russia. The assessment is exemplified by a case study of boiler plants fired by the coal sourced from the Dzhebariki-Khaya deposit. The calculations were made under the assumption that all the carbon contained in the delivered coal, including its loss in transit, through spillage and dust, and during combustion, is eventually converted into carbon dioxide through various oxidation processes. The method of calculation relies on a model of the change in the net calorific value of coal during long-term bulk storage in open stockyards and takes into account coal losses that occur throughout a complex supply chain. Two cases are analyzed: (1) the current conditions and (2) with the adoption of coal sizing and big bag packaging. The carbon dioxide emissions produced by the boiler plants running on the Dzhebariki-Khaya coal currently total about 670 thousand tons per heating season. However, coal sizing and bagging can reduce coal deliveries and, consequently, CO_2 emissions by 21%.**

***Index Terms*— Russia, carbon footprint, district heat, coal sizing, coal bagging, transportation.**

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I. Introduction

In 2021, the Russian Federation adopted the Strategy for socio-economic development with low greenhouse gas emissions to 2050. Among the basic approaches to reducing greenhouse gas emissions, it specifies “realizing the full potential of cutting greenhouse gas emissions contributed by coal-fired power generation.” Although the task of improving the efficiency of power generation has essentially remained unchanged, this introduces an additional criterion for comparing alternative options for the development of the industry. Previous studies [1–4] indicated the possibilities of improving the efficiency of coal-fired boiler plants in the Republic of Sakha (Yakutia), relying on investigation of coal supply chain and changes in coal quality during its transportation and storage. The main conclusion from those studies is the necessity to supply boiler plants with sized coal and to deliver and store it in a packaged form.

Most researchers suggest reducing greenhouse gas emissions from coal-fired power generation by introducing renewable energy sources or switching to natural gas. In the case of northeastern Russia, however, such an approach is currently feasible only near deepwater ports with LNG shipping infrastructure or in a narrow strip of the coastal area where there is some wind potential. In the distributed power sector, photovoltaic inverters can effectively replace 10–15% of the annual output of diesel power plants. In general, the battle to reduce carbon dioxide emissions from small consumers spread over a large area comes down to curtailing the overall consumption of

Fig. 1. The geography of the use of the Dzhebariki-Khaya coal and routes of its delivery by water.

conventional fuels. Other solutions, such as CO_2 capture and disposal for small consumers, are still far from being economically viable.

In the heating sector, the potential for efficiency improvements is huge and covers many areas: from primary fuel extraction and treatment technologies to heat use conditions [5]. Study [6] provides quantitative assessment of carbon dioxide and methane "non-emissions" after the implementation of energy efficiency measures at some boiler plants in the Republic of Sakha. Paper [7] compares district heating and an individual heating system in terms of CO_2 emissions. Emissions from transportation can start to affect the carbon footprint when long distances and complex haul routes are involved [8].

II. Background Information

Coal accounts for 50% of the energy balance of the Arctic zone of Sakha and 70% of energy demand for heating [9]. Such a balance was formed due to the relatively low cost of coal and a number of other factors, such as: 1) the need to operate a large fleet of oil storage facilities for liquid hydrocarbons, 2) a limited number of oil tankers capable of navigating the waters of small rivers, especially low tonnage vessels, etc. Although these issues have been addressed, coal is still expected to retain its dominant role in Yakutia's heating sector for a long time to come.

Despite a long history of coal use, it is a rather complex fuel in terms of its structure. Almost every deposit produces coal of different specifications that depend on metamorphism, oxidation, chemical composition, etc. In 2010–2011, we attempted to study the changes in ash and moisture content of Dzhebariki-Khaya coal, which is widely used in the heating sector of the Republic. On the basis of experimental data, we proposed a model of change in the net calorific value of Dzhebariki-Khaya coal as a function of the duration of storage. Model calculations showed that packaging coal in soft containers (big-bags) is a feasible option. Coal bagging also facilitates accurate coal measurements, significantly reduces oxidation rate, and nearly eliminates spontaneous combustion of coal. Bagged coal also has such advantages as quick suppression

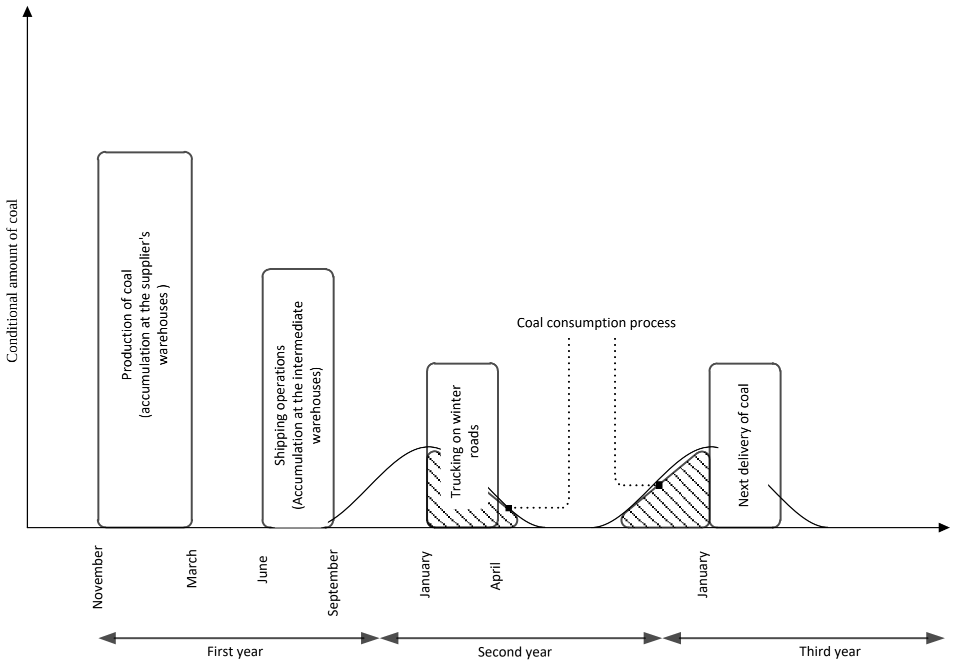

Fig.2. A representative coal delivery schedule in the Republic of Sakha (Yakutia)

of self-heating spots, no coal losses when building up pile beds in stockyards, significant reduction in requirements for coal storage areas, etc. Thus, coal bagging is a way to save coal as it significantly decreases coal loss in transit and besides makes coal theft more difficult.

The low efficiency of boiler plants results, among other things, from the use of run-of-mine (ROM) coal containing a large number of fines, and it is difficult to automate the combustion of ROM coal [4, 10, 11].

Thus, the reduction of carbon dioxide emissions in district heating of the Republic depends on the efficiency of fuel use, especially that of coal. The most effective measures to that end are coal sizing and bagging. This paper assesses the effect of such measures on the reduction of CO_2 emissions for the area supplied with the coal from the Dzhebariki-Khaya deposit.

The Dzhebariki-Khaya deposit is located in the middle course of the Aldan River. Figure 1 shows the municipal districts and local areas that consume the coal of the deposit. The main transport corridors are the navigable sections of the Aldan, Amga, Lena, Vilyui, and Yana rivers, along with an extensive network of winter roads. Year-round roads are used to serve only part of the consumers in the Amga, Tomponsky, and Oymyakonsky districts. Consumers in the Verkhoyansk district have the most involved haul route [1, 2]: it normally takes up to 2.5 years from production to consumption of coal there (Fig. 2) and in the case of using reserve stockpiles, this period can extend to 3.5 years. To put things into perspective, the typical timeframe for other consumers is 1.5–2 years.

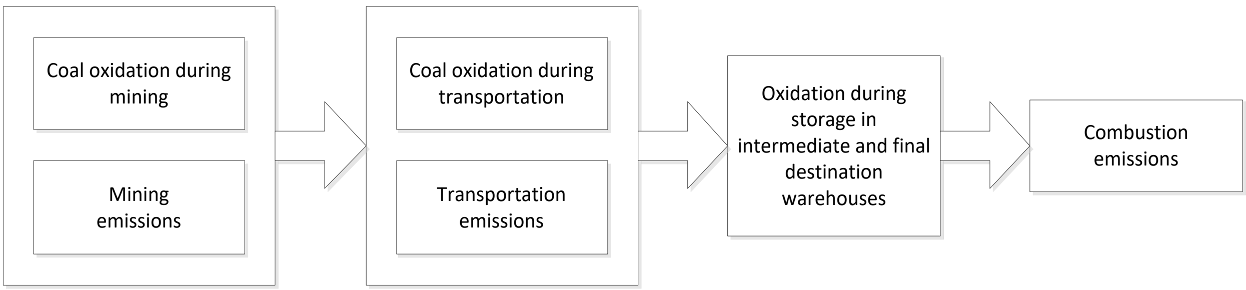

Fig.3. Key stages of carbon dioxide emissions throughout the process chain of coal use in heating systems.

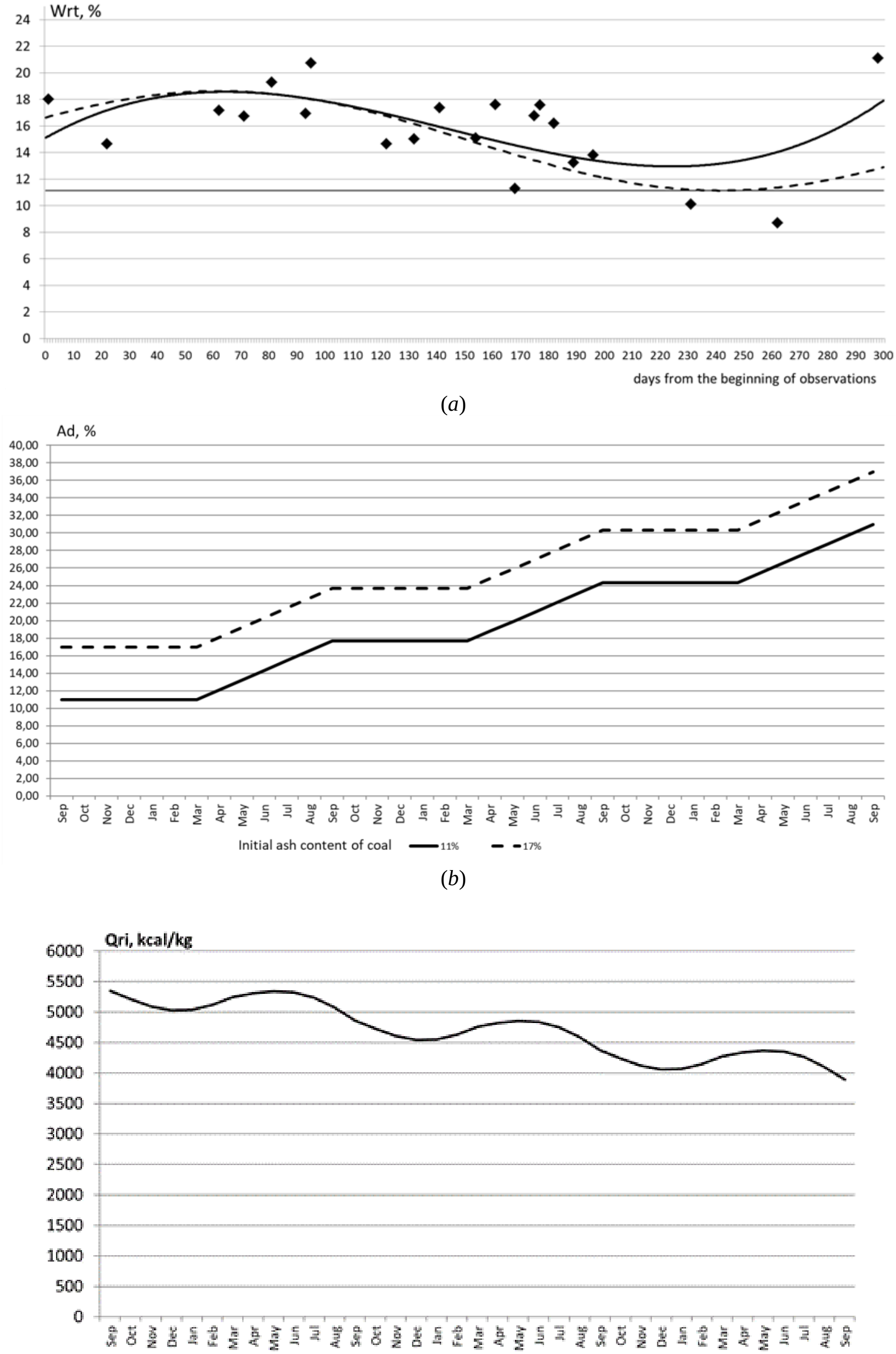

Fig.4. (a) The pattern of moisture change, (b) the pattern of ash content change, and (c) the pattern of net calorific value change for ROM coal of the Dzhebariki-Khaya deposit during outdoor storage.

TABLE 1. Coal Losses During Transportation

Stage	Normal loss %
Transportation of coal from mining sites to truck loading points	0.15
Transportation by river and sea	1.5
Transportation by road:	
up to 100 km	1
up to 350 km	1.5
up to 750 km	1.8
Ship-to-ship transshipment	0.8
Transshipment	1
Unloading and transshipment in stockyards	0.5
Storage for over 6 months	1
Transportation from stockyards to boiler plants	0.2

Similar supply schedules are common for the majority of coal consumers in the Northeast of Russia.

III. MODELS

Emissions of greenhouse gases, including carbon dioxide, are generated throughout the entire coal supply chain: beginning with coal extraction and culminating in its combustion (Fig. 3). Low-temperature oxidation takes place during the storage and delivery phases. Coal transportation also leads to indirect emissions from the combustion engines of river and sea vessels, crane ships, motor vehicles, and tractors. In the case of coal deliveries to the northern regions of the Republic of Sakha (Yakutia), this is more pronounced due to the intricate and long haul route and the reliance on shallow river routes.

Long-term storage of coal in numerous open stockyards, as well as continuous transportation by river and road, significantly accelerate its oxidation process. Storing coal outdoors alters its humidity. Humidity is at its highest in winter when coal is consumed. These factors reduce the heat of combustion of coal and lead to its overconsumption. Study [8] proposes a model of the decline in the net calorific value of ROM coal as a function of the storage duration. This model is based on the data of periodic testing of Dzhebariki-Khaya coal for the consumer in the Ust-Yansky district (Fig. 4). The model

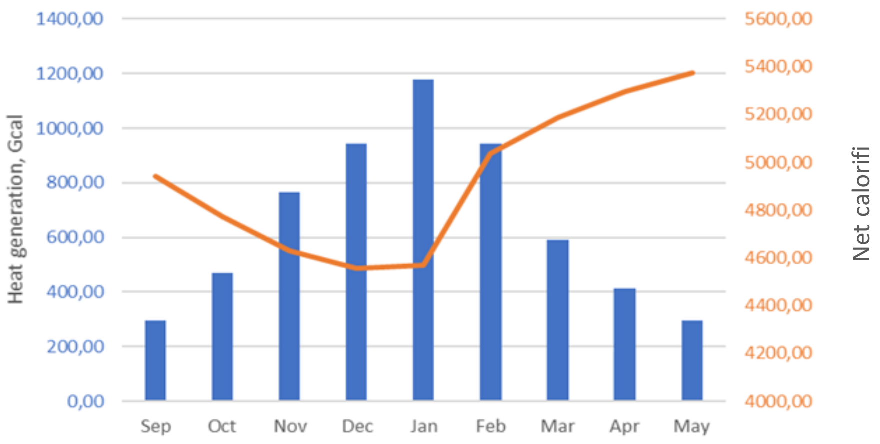

Fig.5.Correlation between the amount of coal consumed and the net calorific value during the heating season (the case of the boiler plant in Amga).

TABLE 2. Results of the Assessment of CO_2 Emission Reduction Due to Coal Sizing and Bagging at the Dzhebariki-Khaya Deposit.

	Boiler consumption, thous. tons	Loss in transit, thous. tons	Coal demand, thous. tons	Same, in %	CO_2 emissions, thous. tons	Same, in %
Current state	331.7	20.6	352.3	100.0	669.7	100.0
Coal bagging + installation of Class 1 boilers	246.7	0.0	246.7	70.0	525.4	78.4

assumes a sinusoidal seasonal moisture fluctuation and a piecewise linear pattern of changes in ash content of the coal during bulk storage in an open stockyard.

Numerous handling operations in intermediate stockyards and rehandling, which involves various means of transportation, result in major coal losses through spillage and dust during bulk transportation. Accurately assessing such losses experimentally is extremely challenging, as there are multiple influencing factors that are not tractable. Expected loss of coal during transit is determined by standardized values outlined in [13]. Table 1 shows normal loss percentages for coal at each stage of transportation, derived from these established standards.

IV. METHOD FOR ESTIMATING CO_2 EMISSIONS

We assume that all the carbon contained in coal delivered for heating, including loss in transit, through spillage and dust, and during combustion, is finally converted into carbon dioxide through various oxidation processes. Thus, carbon dioxide emissions E_{CO_2} are estimated from the total coal demand according to the procedure detailed in [10]:

$$E_{CO_2} = FC \cdot EF_{CO_2} \cdot OF_{CO_2}, \tag{1}$$

where $EF_{CO_2} = 2.76$ t CO_2/tce is the coefficient of carbon dioxide emissions during combustion for the coal produced in Sakha;

$OF_{CO_2} = 1$ is the coal oxidation factor;

FC is total mass of coal.

The total mass of coal, given loss in transit, is calculated as per the following equation:

$$FC = t \sum_n k_n \cdot \sum_i \frac{1000 Q_{in}}{q_i \eta_n}, \tag{2}$$

where t is the coal equivalent (tce) conversion factor;

k_n is the transportation loss coefficient for the boiler plant n;

Q_{in} is the heat output by boiler plant n in month i of the heating season, Gcal;

q_i is the average net calorific value of coal under the operating conditions assumed for month i of the heating season (calculated by the model given in [12]), kcal/kg;

η_n is the efficiency of boiler plant n.

V. RESULTS

The calculations were based on the data from the proprietary database of 169 boiler plants in the Republic of Sakha (Yakutia) that run on the coal from the Dzhebariki-Khaya deposit, as of the end of 2021. The demand for coal was calculated for the current combustion efficiency and existing supply chain. The obtained results were compared with the calculations made for the case of sized coal, the coal combustion efficiency compliant with Class 1 as per [15] (gross efficiency of 82%), and coal shipment in special closed soft containers that prevent losses and deterioration of coal quality. Depending on the location of the boiler plant, parameters of the haul route and the delivery time were input into the calculation model to determine the heat of coal combustion at the time of consumption and the coal loss in transit. For example, Fig. 5 shows the correlation between coal consumption and net calorific value during the heating season at the boiler plant in the village of Amga. Table 2 summarizes the final results of the assessment of the reduction in carbon dioxide emissions achieved through the implementation of coal sizing and bagging at the Dzhebariki-Khaya coal deposit.

VI. CONCLUSION

Quantitative assessment of greenhouse gas emissions is becoming a mandatory parameter for strategic planning of energy sector development, regardless of the scale of production. The key strategy for reducing emissions in the northern areas of Russia lies in enhancing the efficiency of hydrocarbon use throughout the entire supply chain, from extraction to end use.

The introduction of coal sizing and bagging in soft containers at the Dzhebariki-Khaya deposit can lower CO_2 emissions from the municipal sector by 21.6%.

Energy conservation efforts, both by consumers and within the district heating sector, can significantly reduce demand for coal and decrease CO_2 emissions.

This study has not considered carbon dioxide emissions produced by the machinery needed for coal mining and transportation. Therefore, the next stage of the research project will focus on developing a model to quantify carbon dioxide emissions associated with this machinery.

Preliminary estimates indicate that the municipal energy sector of the Republic of Sakha (Yakutia) can achieve a twofold reduction in CO_2 emissions by fully leveraging all available strategies to enhance the efficiency of fuel and energy supply.

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References

[1] V. E. Zakharov, D. V. Prokhorov, V. L. Gavrilov, "Loss of energy value of raw coal in transit to Arctic consumers of the Republic of Sakha (Yakutia)," Power Engineering: research, equipment, technology, no. 5–6, pp. 13–22, 2013. (In Russian)

[2] V. E. Zakharov, "Features of the transport system of the Republic of Sakha (Yakutia) and the substantiation of the need for searching of ways to increase the reliability of coal supply," E3S Web of Conferences, vol. 77, Art. no. 04001, 2019. DOI: 10.1051/e3sconf/20197704001.

[3] V. E. Zakharov, "Improved metering of stored coal supplied to remote consumers," in Proc. the Eurasian symposium on the issues of reliability of materials and machines in cold climate regions (EURASTRENCOLD-2018), Yakutsk, Russia, Sep. 3–5, 2018, vol. 2, pp. 260–269. (In Russian)

[4] A. E. Ivanova, V. E. Zakharov, T. N. Petrova, "The current state, problems and perspective of development on the North region's Housing and Utilities: After the example of the Republic of Sakha (Yakutia)," in International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2020, Vladivostok, Russia, Oct. 06–09, 2020, pp. 1–4. DOI: 10.1109/FarEastCon50210.2020.9271489.

[5] I. V. Petrov, "Economic valuation of energy efficiency of coal power technologies," Mining Informational and Analytical Bulletin (scientific and technical journal), no. 1, pp. 180–189, 2014. (In Russian)

[6] T. N. Gavril'yeva, A. V. Nogovitsyn, "Impact of energy and resource conservation programs on carbon emission dynamics in the Republic of Sakha (Yakutia)," The Arctic. The XXI century. Natural Sciences, no. 1(4), pp. 29–42, 2016. (In Russian)

[7] E. G. Gasho, A. I. Kiseleva, A. M. Fokina, "Carbon footprint of heating systems in relation to the type of a heat source," Energy Systems, no. 1, pp. 55–60, 2022. DOI: 10.34031/es.2022.2.007. (In Russian)

[8] R. W. Howarth, "The greenhouse gas footprint of liquefied natural gas (LNG) exported from the United States," Energy Sci & Eng., vol. 12, no. 11, pp. 4843–4859, 2024. DOI: 10.1002/ese3.1934.

[9] A. E. Ivanova, V. E. Zakharov, T. N. Petrova, "The Issue of Electricity Subsidizing in the Arctic zone of Sakha Republic (Yakutia)," in International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019, Vladivostok, Russia, Oct. 01–04, 2019, pp. 1–4. DOI: 10.1109/FarEastCon.2019.8934234.

[10] V. E. Zakharov, D. V. Prokhorov, N. V. Pavlov, "Russian Arctic region balance (Republic of Sakha (Yakutia))," E3S Web of Conferences, vol. 114, Art. no. 02005, 2019. DOI: 10.1051/e3sconf/201911402005.

[11] V. E. Zakharov, A. E. Ivanova, T. N. Petrova, "Energy of the Arctic zone of the Republic of Sakha (Yakutia): current state and development prospects," Economics of Russian East, no. 1, pp. 81–86, 2019. (In Russian)

[12] V. E. Zakharov, A. N. Kozlov, I. G. Donskoy, "Modeling the change in the heat of combustion of coal during its transit to the regions of the Far North: a case study of the Republic of Sakha (Yakutia)," Izvestiya RAN. Energetika, no. 6, pp. 132–141, 2018. DOI: 10.31857/S000233100003526-2. (In Russian)

[13] Resolution of the Government of the Republic of Sakha (Yakutia) (2005, Jul. 14). No. 433, On approval of fuel and energy resource consumption rates for heat generation by heating and industrial boiler plants of the Republic of Sakha (Yakutia). (In Russian)

[14] Order of the Ministry of Natural Resources of Russia (2022, May 27). No. 371, On approval of methods for quantitative assessment of greenhouse gas emissions and greenhouse gas absorption. (In Russian)

[15] State Standard (GOST) 30735-2001 "Hot water heating boilers with heat output up to 4.0 MW." (In Russian)

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