LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY
School of Energy Systems
Department of Environmental Technology
Sustainability Science and Solutions
Master's thesis

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POSSIBILITIES OF CO_2 EMISSIONS REDUCTION BY IMPLEMENTATION OF TOOLS FOR DECREASING ENERGY OVERCONSUMPTION IN RUSSIAN HOUSING SECTOR

Examiners: Assistant Professor Ville Uusitalo

Postdoctoral Researcher Anna Kuokkanen

ABSTRACT

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Possibilities of CO_2 emissions reduction by implementation of tools for decreasing energy overconsumption in Russian housing sector

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2019

91 pages, 46 figures, 20 tables, 11 equations, 3 appendices

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Keywords: Residential heating, Russia, energy efficiency, district heating, CO_2 emissions reduction, economic benefits.

This paper provides investigation of the reasons of energy overconsumption in the residential sector of Russia and its environmental impact. The solutions which are able to fight the low energy efficiency of the residential heating sector and to curb CO_2 emissions are the key subject of the study. The current district heating system is assessed step by step covering supply, distribution and demand sides. On the supply side the possibility of renewable energy sources utilization for residential heating is studied based on their availability in different regions of the country. On the demand side the special attention is paid to the energy consumption behavior of Russian people. To analyze current energy consumption behavior of Russians the public survey was conducted. The results of the survey are discussed and used for development of measures which aim shifting to more sustainable energy use on the demand side. The possibility of CO_2 emissions reduction due to proposed improvements in the residential heating system is assessed through scenario analysis. In total four scenarios which assume implementation of proposed efficiency enhancing measures are built and compared with baseline scenario that assume no improvements. The period until 2030 is chosen as the forecast horizon. According to the scenario analysis, the highest potential to mitigate CO_2 emissions from the residential heating is on the demand side. The economic benefits of such actions may contribute to money saving of an average residential building on heating bills in the amount of 692.6 euros for ten years (from 2020 to 2030). The combination of all the discussed measures on the supply, distribution and demand sides will cause the total reduction of GHG emissions for the assessed period by 255.91 million tons of CO_2 equivalent.

ACKNOWLEDGEMENTS

I am grateful to my girlfriend and to my parents whom supported me on all the way of my Master's degree. This work would not have been possible without your help and moral support. Thank you!

In Lappeenranta 1 June 2019

Andrei Terleev

LIST OF SYMBOLS AND ABBREVIATIONS

Capex Capital Expenditures

CFD Central Federal District of Russia

CHP Combined Heat and Power

CO_2. Carbon dioxide

FEFD Far East Federal District of Russia

GDP PPP Gross Domestic Product at Purchasing Power Parity

GPRS General Packet Radio Services

INDC Intended Nationally Determined Contributions

M2M Machine-to-Machine

MSW Municipal Solid Waste

NCFD Northen-Caucas Federal District of Russia

NWFD Northern-West Federal District of Russia

Opex Operational Expenditures

PUR Polyurethane

PV Photovoltaic

RFT Russia Federation Total

SbFD Siberian Federal District of Russia

SFD South Federal District of Russia

TOE Tons of Oil Equivalent

UFD Ural Federal District of Russia

VFD Volga Federal District of Russia

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1 INTRODUCTION

Russia is the 4th largest greenhouse gas emitter in the world after China, United States and India. It has 4.68% share of world's total CO_2 emissions (figure 1). Hence, the climate change is a problem of increasing concern in Russian society. The average warming rate for the period from 1976 to 2014 was 0.42 °C per 10 years. In Arctic region of Russia, the rate is even higher – 0.42°C per 10 years. Considering that 67% of country's territory is located in the permafrost zone, the warming process may destroy the fragile ecosystem of most Russian territory.

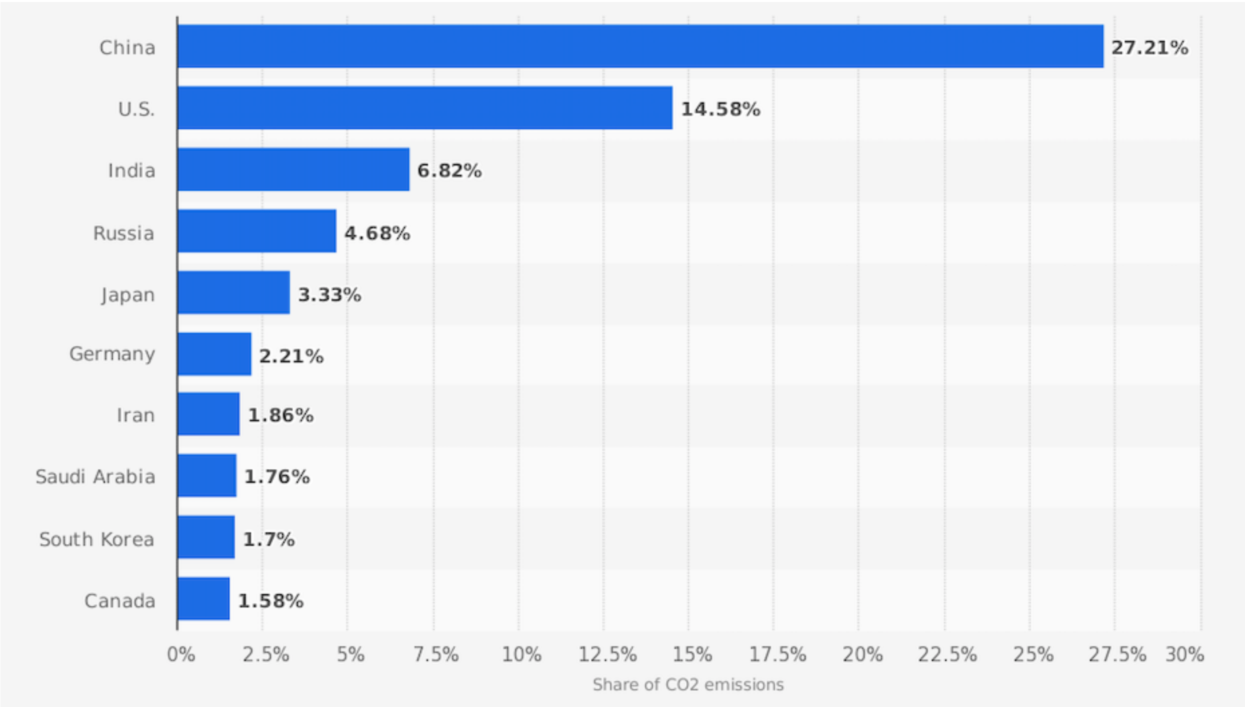

Figure 1. Largest producers of territorial fossil fuel CO2 emissions worldwide in 2017 (Statista, 2018).

Energy consumption in Russian housing sector play a significant role in the process of climate change accounts for 36% of total country's energy consumption (figure 2) and for 30% of total country's CO_2 emissions. To reduce amount of CO_2 emissions and meet the goals of country's Intended Nationally Determined Contributions (INDC) in frame of the Paris Agreement, energy efficiency improvements in Russian housing sector are necessary.

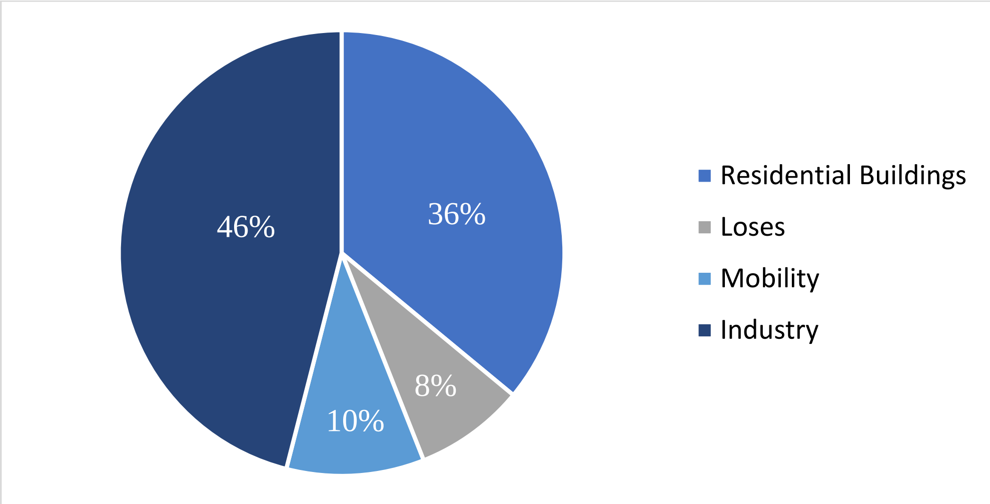

Figure 2. Structure of use of primary energy resources by end users in Russia (McKinsey & Company, 2009).

Low energy efficiency in Russian housing sector and historically established irresponsible energy consumption behavior of residents (Millhone, 2010) have received very little attention in Russian Federation until recently, but today it is one of the hottest topics at the highest level due to enormous economic and ecological benefits that can be potentially achieved by improvements in this field. Average residential building in Russia consumes up to two times more energy than those in climatically similar areas in developed Western countries (The Moscow Times, 2013). The roots of the problem, among others, are outdated construction techniques which have been used for decades according to government standards of Soviet Union era, lack of effective metering of consuming recourses and obsolete equipment.

INDC of Russia in frame of the Paris agreement intend for 25 – 30% emission reduction compare to 1990. To meet the goal, implementation of innovative tools for energy efficiency improving and introducing new energy metering practices that can fight energy loses and overconsumption in housing are needed. Historically, innovations in Russia were driving not only by market mechanisms but also with significant help of legislation. First step towards scaling down energy wasting in housing sector has already been made by adoption of the Federal Law №261 from 23.11.2009 “About energy saving and enhancing energy efficiency”. This law is considered as a tipping point that leads to more sustainable way of energy consumption including housing sector. Ten years gone since that mechanism went to its power and today we are able to summarize the results, identify barriers and develop a further action plan to reach intended goals.

The goal of the research is to assess innovative technological and policy tools that could accelerate the transition to more sustainable energy use in residential buildings sector, discuss further steps and assess how the efficiency improving can reduce the amount of CO_2 emissions.

The research questions are:

- What are the reasons of energy overconsumption in Russian housing sector?
- What are solutions and barriers to energy efficiency improving in Russian housing?
- By how much can Russia reduce CO_2 emissions via improving efficiency of residential energy use?
- What are economic benefits of residential energy consumption reduction?

In order to better understand current residential energy consumption behavior of Russian people, the public survey of 50 citizens of Saint Petersburg was conducted. The results of the survey help to elaborate innovative measures that are needed on the demand side to enable changes in energy consumption psychology and promote energy saving practices at homes.

The work has the following structure:

- Assessment of the structure of primary energy resources use by end users in Russia;
- Comparison of energy consumption in residential sector between Russia and other Northern countries;
- Investigation of reasons of high energy consumption in Russian housing;
- Analysis of current heating system in Russia. Benefits and drawbacks;
- Assessment of improvements needed on the supply side;
- Assessment of improvements needed in the heat transmission network;
- Assessment of improvements needed on the demand side;
- Development of CO_2 reduction scenarios due to implementation of the proposed improvements;
- Assessment of the economic benefits.

2 ENERGY CONSUMPTION IN RUSSIAN RESIDENTIAL SECTOR

2.1 Comparison with other Northern countries

After industry, the housing sector is the second biggest energy consumer in Russia. It uses $11.96 \cdot 10^9$ GJ of primary energy per year (Knoema, 2016). Such a high share of residential energy use might be obviously explained by cold climate of the country and, as a sequence, enlarged requirements for residential space heating. Russian Federation is one of the coldest countries on the planet and much of its population lives in very harsh weather conditions.

The climate of Russia has a special differentiation that is incomparable with any other country in the world. This is due to the wide extent of the country in Eurasia, the heterogeneity of the location of water bodies and a large variety of topography: from high mountain peaks to plains lying below sea level. Russia is predominantly located in middle and high latitudes. Due to this, the weather conditions are severe in most parts of the country, the seasons change clearly, and the winters are long and frosty. The Atlantic Ocean has a significant impact on the climate of Russia. Despite the fact that its waters are not in contact with the territory of the country, it manages the transfer of air masses in temperate latitudes, where most of the country is located. Since there are no high mountains in the western part, the air masses pass freely up to the Verkhoyansk Range. In winter, they contribute to mitigating frost, and in summer they provoke a cooling and precipitation.

There are 5 major climatic zones in Russia:

1) Tropical (southern parts of Russia);
2) Subtropical (Primorsky, Western and North-Western regions);
3) Moderate (Southern Siberia, Far East);
4) Polar (Yakutia, Northern Siberia, the Urals and the Far East);
5) Areas beyond the Arctic Circle and Chukotka.

Despite the differentiation, the major part of the land refers to fourth and fifth zones where yearly average temperatures are well below zero degrees Celsius (figure 3). Moreover, in the Areas beyond the Arctic Circle, where the mean annual average temperature is below –

15ºC, permanently lives more than 2 million people (Lukin, 2010) or approximately 1.4 % of the total population of the country (144.5 million people in 2017).

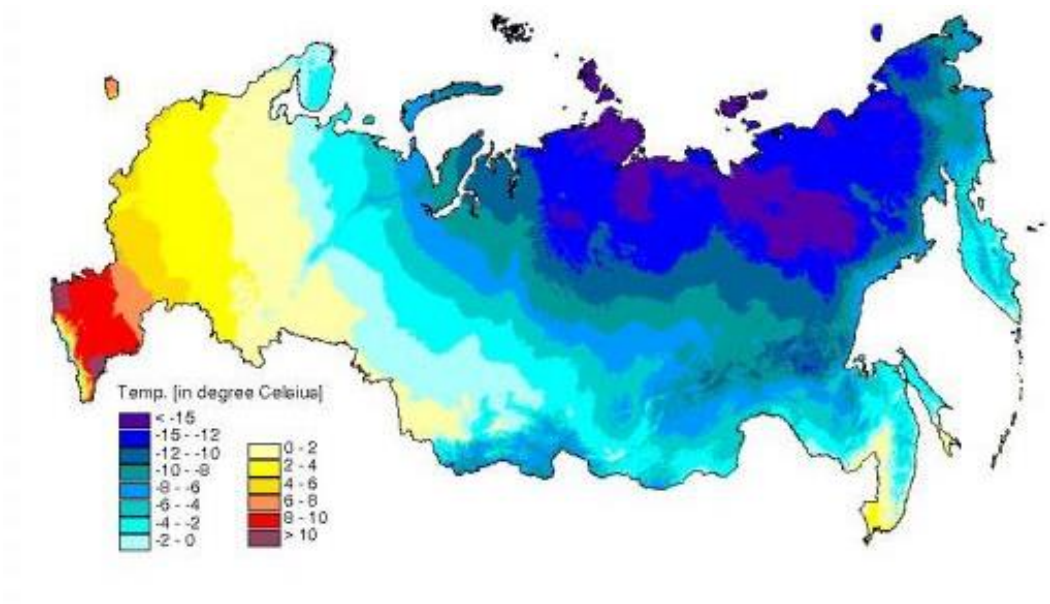

Figure 3. Mean annual temperature in Russia (Etty, 2015).

However, the high energy consumption in Russian housing cannot be explained only by cold climate. To proof this assumption, countries with similar annual temperatures were determined and investigated. These are Finland, Norway, Sweden, Iceland and Canada. The annual average temperatures of the countries under the study is presented in figure 4. The mean annual temperature in Canada is almost equal to Russia (-4.6˚C and -4.5˚C respectively). Canada has the same climatic zones as Russia and a high share of its population lives in very cold environment as well. Hence the comparison of residential energy use between these two countries is the most relevant. Finland, Norway, Sweden and Iceland show warmer average annual temperatures – 1.5-2.0˚C above zero.

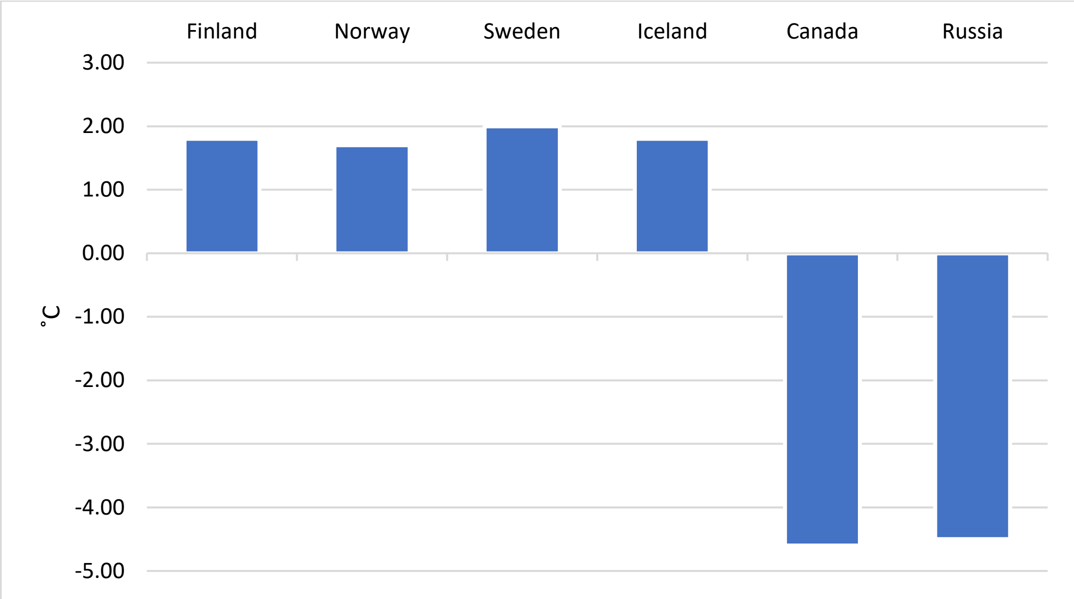

Figure 4. Average annual temperatures in the northern countries (Timothy D. Mitchell, 2004).

There are many practices exist to assess the energy performance of a building (BREEAM, LEED, etc.). In frame of our analysis the methodology of analyzing energy performance indicators for buildings, including residential, developed by Center for Energy Efficiency (CENEf) (Bashmakov, 2014) is used due to the fact it was created by Russian organization that historically has some weight in Russia:

- at the first level, integrated energy efficiency indicators for buildings are estimated. Usually they are determined by dividing the total energy consumption by GDP or by 1 m^2 of floor space area, less often by one resident, even less often by one person employed (in the service sector);
- at the next level, the integrated indicators of energy efficiency are estimated for similar types of buildings (apartment houses, individual residential buildings, etc.);
- the third level is determination of energy efficiency for different processes (heating, hot water supply, lighting, etc.) per GDP, 1 m^2 of floor space area, per resident or employed;
- on the fourth level, numerous indicators of energy efficiency of individual installations, technologies, materials and types of equipment are determined: efficiency of heating boilers, thermal protection parameters of enclosing structures, insulation thickness, daily power consumption of a refrigerator or the ratio of the power of a lighting device to its light flux.

In addition, indicators of the proportion of consumer provision with metering devices and various kinds of energy-efficient equipment (highly efficient light sources, energy-efficient windows, the proportion of buildings with insulated facades, etc.) are also indicators of energy efficiency in residential buildings. These indicators can be determined at each level of energy efficiency management: from household to country, or even a group of countries.

In frame of our analysis, only first level of the proposed pyramid of energy performance indicators for residential buildings is considering due to poor quality of input data about household appliances in Russia.

Energy intensity of residential energy consumption (1) was chosen as a comparison indicator.

$$Energy\ Intensity_{residential} = \frac{Energy\ consumption_{residential}}{GDP_{ppp}} \tag{1}$$

Energy intensity indicator shows how much units of primary energy required to produce a unit of product or service (in our case the service is residential energy consumption). The value is calculated by dividing the amount of energy consumed by residential buildings to country's GDP purchasing power parity (GDP PPP). The result of calculation of energy intensity of residential energy use for Russia and Canada is presented in figure 5.

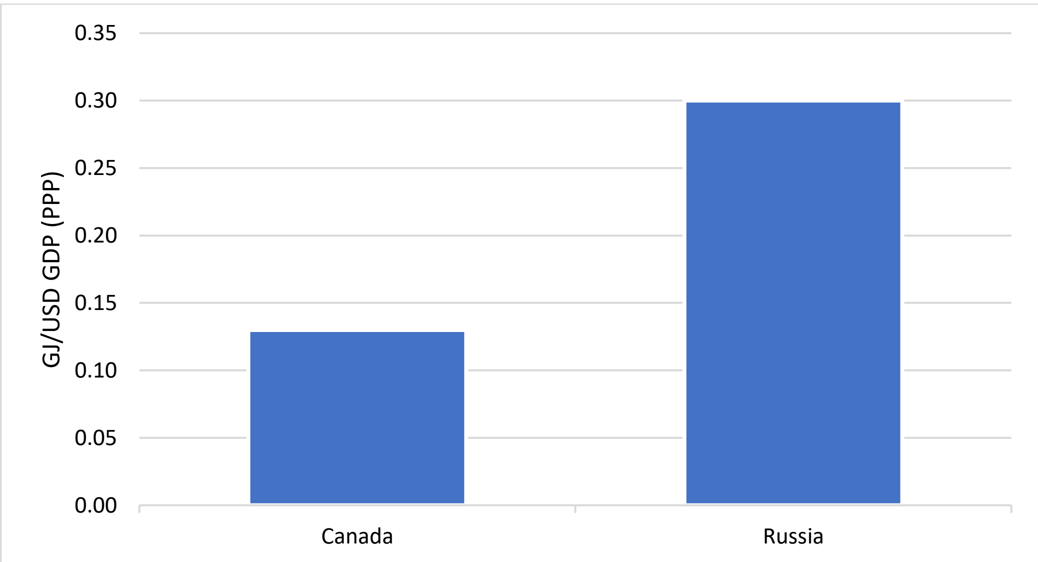

Figure 5. Energy intensity of residential energy consumption (IFC, 2013).

The energy intensity in Russian residential sector is more than twice bigger than in Canada despite similar climate and close average annual temperatures. It proves assumption that the climate cannot be the only explanation of energy overconsumption in Russian housing.

To deepen the comparison of energy consumption between Russian and Canadian housing sector, the structures of residential energy by end-use for both countries were studied (figure 6, figure 7). There are some similarities as well as differences.

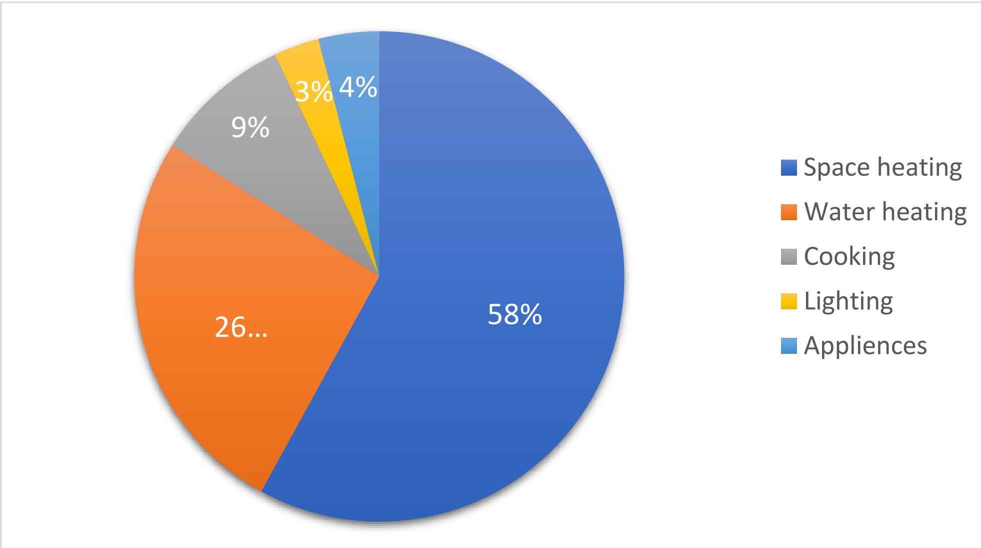

Figure 6. Residential energy use by end-use in Russia (IFC, 2013).

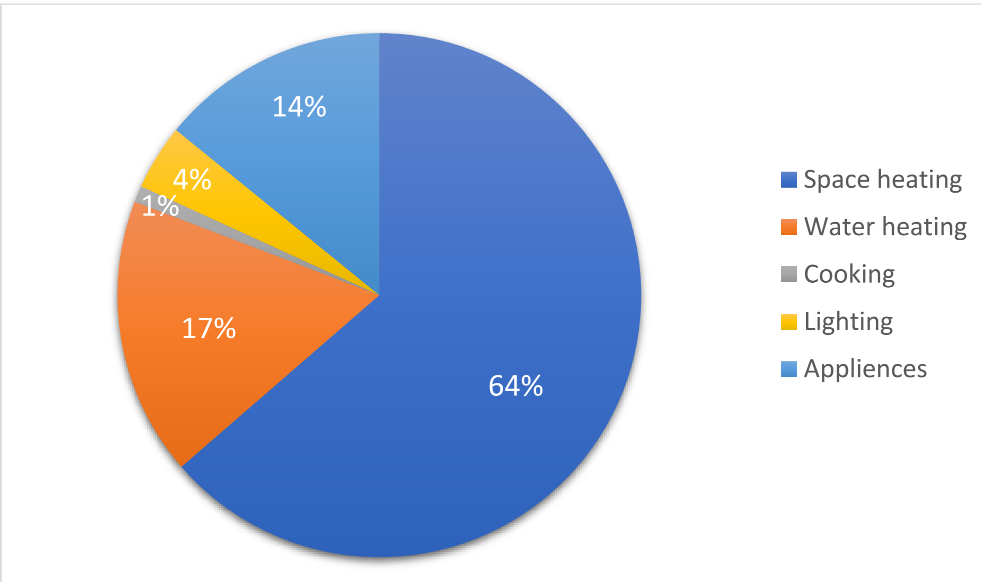

Figure 7. Residential energy use by end-use in Canada (Natural Resources Canada, 2012).

Similarities:

- The largest share of the consumption refers to space heating: 58% in Russia versus 64% in Canada.
- The second place in the total consumption picture is taken by water heating: 26% in Russia versus 17% in Canada.
- Shares of the total heating energy use (space heating and water heating) are almost equal for the countries under the investigation: 84% in Russia versus 81% in Canada. It can be explained by cold weather for most of the year with long winters which leads to increased need for heat. Moreover, the efficiency of energy conversion from primary to end-use for heating is much less than the efficiency for electric appliances, for example.
- Energy consumption of lighting shows a non-significant share in the whole picture: 3% in Russia versus 4% in Canada. High level of energy-saving bulbs penetration and phase-out of incandescent bulbs is a major explanation.

Differences:

- Analysis of energy consumption for cooking purposes illuminates differences in habits and lifestyle choices of local people. Cooking consumes 9 times more energy in Russian homes than in Canadian (9% in Russia against just 1% in Canada). There are two possible reasons:
  1) Natural gas is vastly used for cooking in Russia while electricity stoves are only gaining popularity (Businesstat, 2015). Energy efficiency of gas stoves is just 32% versus almost 75% of electric one (Alter, 2016). Canadian homes are more often equipped with electric or induction stoves.
  2) The second reason is less obvious but also has a place to be – Russians cooking at home more often than Canadians. To prove this assumption a deeper analysis of people's behavior in these countries is needed. This is beyond the scope of our study.
- Appliances take 4% of total residential energy use in Russia versus 14% in Canada. Canadian homes are better equipped with appliances than Russian. For instance, the share of homes with 2 refrigerators in Canada is 27% while in Russia just 5% (Statista, 2019).

The comparison of energy use in residential buildings between Russia and the country with similar climate (Canada) revealed high energy intensity of Russian housing. It proves the assumption that severe climate conditions cannot be the only reason of residential energy overconsumption. Analysis of structure of residential energy use by end-use shows the dominant position of space and water heating in the whole picture for both countries. The fact leads to a conclusion that energy efficiency improving in heating segment would significantly reduce the amount of primary energy consumed by housing in Russia and decrease the volume of total country's CO_2 emissions.

2.2 Types and structure of district heating system

Improvements in residential space and water heating segment is a key on the way to more sustainable energy use in Russian housing and reducing CO_2 emissions. This chapter implies that the improvement of the heat consumption in the housing sector leads to the reduction of the environmental impact and therefore these impacts were not discussed separately in this chapter.

The heating period in Russia lasts on average from October 1 to March 31. It is longer in Siberia, the northern regions and the Far East than in the central regions and in the south. To understand the reasons of low energy efficiency of heating systems in Russian residential buildings, the detailed analysis of its working principle is needed.

District heating system is a prevalent technology that provides millions of Russian homes with heat and hot water. The main distinctive feature of the system is heat generation outside heated buildings, the delivery of which from a heat source is carried out through pipelines. In other words, district heating is a complex engineering system, distributed over a large area, providing heat simultaneously to a large number of objects.

The existing variety of schemes for the organization of district heating allows them to be ranked by some classification criteria (table 1).

Table 1. Classification of district heating systems (Behnaz Rezaie, 2000).

Type	Comment
1. By heat energy consumption mode	
Seasonal	When heat is only required during the cold season.
Year-round	If constant heat supply is needed.
2. By use of heat carrier	
Water-type	It is the most common heating type that is used in apartment buildings. Such systems are easy to operate and maintain, allow the fluid to be transported over long distances without reduction of quality indicators and adjust the temperature at the centralized level. Moreover, water-type heating systems are characterized by good hygienic and sanitary qualities.
Air-type	These systems allow not only heating but ventilation of buildings as well However, due to high capital and operational costs of this heating scheme it does not have a wide application in Russia.
Steam-type	This scheme is recommended for those facilities that require water vapor in addition to heat (mainly industrial enterprises). Due to small diameter of pipes that are used to heat the house and low hydrostatic pressure in the system, steam-type district heating systems are considered as the most economical.
3. By the method of connecting to the heat supply system	
Independent	The coolant circulating via the heating network heats the coolant fed into the heating system in the heat exchanger.
Dependent	The heat carrier heated in the heat generator is supplied directly to the heat consumers through networks.
4. By the method of connecting to the hot water supply system	
Open	Hot water is taken directly from the distribution network
Closed	Hot water is taken from the general water supply network. The water heating is carried out in the network heat exchanger of the main line.

All the mentioned types of district heating schemes are, more or less, represented in Russia but the most common is seasonal water-type dependent system, the main structural elements of which are presented in figure 8.

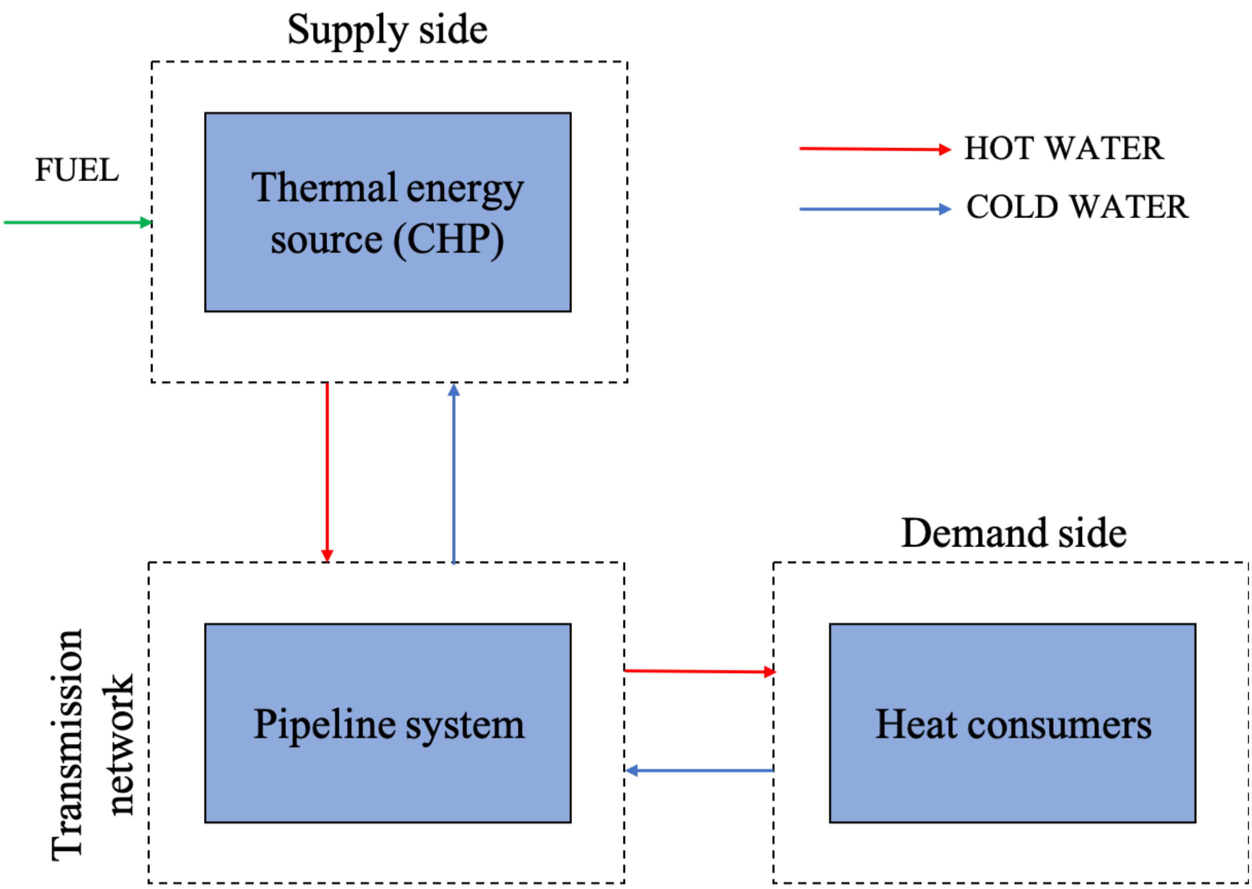

Figure 8. Structure of a district heating system.

- **The source of thermal energy.** It can be large boiler houses or combined heat and power plants (CHP). CHP are used to heat the coolant through the use of any type of energy source. Boiler houses use water to transfer thermal energy to consumers, whereas in CHP plants it first heats up to a state of steam, which has higher energy indicators and goes to steam turbines to generate electricity. The exhaust steam then is used to heat the water that enters the heating system of a residential building. One combined heat and power plant is able to replace several boiler houses, as a result of which not only construction costs are reduced, and significant areas are released, but the overall environmental situation is significantly improved.

- **Pipeline system** is a complex, extensive pipeline system designed to transport heat to facilities. It represents two pipelines – supply (hot) and return (with exhaust coolant). The system is usually made of steel pipes with a diameter of 1000 – 1400 mm. Laying of heating systems can be carried out both by land and underground methods with mandatory thermal insulation in both cases. It should be noted that large district heat supply systems, as a rule, have several sources of heat, connected by backup highways and ensuring the reliability and maneuverability of their operation.
- **Heat consumers** are heating equipment installed directly in an apartment building or other facility. Moreover, residents itself are also called heat consumers.

To define measures required to improve the district heating performance and reduce environmental impact, the detailed analysis of each component of the system is carried out in the next chapters. Additionally, availability of renewable energy sources for heat generation on a supply side instead of fossils in Russia is estimated.

2.3 Opportunities for improvement on a supply side

District heating system of Russia is among the oldest and the largest in the world. Use of the obsolete equipment of Soviet Union era is one of the main reasons of low energy efficiency and environmental impact. Modernizing the supply side of the chain is essential to combat the climate change and reorient Russia to more sustainable energy use pattern.

2.3.1 Renovation of combined heat and power plants

Russia extensively utilizes CHP generation in frame of district heating system. For example, in Moscow region, CHP accounts for 77% of total heat production (table 2). CHP is an integral part of district heating system of Russia providing space heating and hot water to the majority of its population. Despite the fact that the country has the greatest CHP installed capacity in the world, almost no reliable data about its energy efficiency are available. Moreover, while there is EU Cogeneration Directive (2004/8/EU) in Europe exist to evaluate energy efficiency of a CHP, there is a lack of such a legal framework in Russia. Another obstacle on the way to more sustainable domestic heat use in Russia is the absences of an overall strategy and vision for the heating sector.

Table 2. Heat-supply system of Moscow (Kerr, 2012).

Designation	**Heat capacity**	**Heat production**	
	MW	GWh	Percentage
CHP plants	37 481	92 861	77%
District and local heat plants	15 922	26 382	22%
Local boilers	290	$4.6 \cdot 10^{-4}$	<1%
Total	53 693	119 243	100%

Theoretically, combination of high share of CHP plants and centralized heating system can be one of the most efficient way of providing heat to apartment houses which are dominating in modern Russian housing market. CHP plants recover the thermal energy which is a by-product of electricity generation and largely wasted with conventional way of electricity production. This reuse of waste-energy and further directing it to residential buildings is a key factor of effectiveness of CHP compare to individual heat boilers.

To reach the goal of high efficiency of existing heat production system, it should be well managed and maintained. However, in Russia heat production installations are utilized at a level of energy efficiency well below international averages due to its poor state (Boute, 2012).

The urban heat supply system was introduced in Russia in the late 1930s. For those times, given that most of the buildings were supplied with heat from individual boiler houses heated by oil, the transition to the district heating system was a significant increase in comfort for citizens. As a result of the centralization of the heat supply, the houses were provided with hot water all the year round. For fifty years, the costs of the system maintenance were covered by the state budget. Today in some regions the wear rate of the equipment reached 70%, and the state has no money for their repairs and renovation. Nowadays, it is not clear who is responsible for the quality of repair of heating networks and management of CHP, who supplies fuel at what prices, who provides water treatment and distribution of thermal energy.

The outdated legislation was the main obstacle for long-term funding in renovation of existing district heating infrastructure including replacement of CHP plants. The low level of reliability, as well as the fact that the heat supply system of Russian cities is not customer-oriented, led to a mass exodus of consumers, who began to build local boiler rooms that were worse than CHP in terms of efficiency. Due to the decentralization of heat supply, the capacity of heat sources exceeded even potential demand, and the cost of maintaining an inefficient and bulky equipment fleet does not fit into a reasonable tariff rate (Anatole, 2012).

The amendments to the law on heat supply, adopted in July 2017, open the way for systemic changes. The rules established by the new legislation provide for the rejection of state regulation of tariffs in the field of heat supply in favor of price limits for consumers with use of the alternative boiler house method. This means that the price of thermal energy will be calculated on the basis of how much it would cost 1 GCal of heat for consumers if they built their own boiler room. Thus, it is possible to redistribute the load of heat sources more efficiently. For example, according to calculations by specialists of the Siberian Generating Company, that operates in one of the most "heat-intensive" regions of the country, today only in Novokuznetsk the reserve of heat capacity relative to the current load is 142%, in Kemerovo - 120%. Replacing inefficient heat sources will significantly reduce existing costs (Sergeev, 2017).

The lack of unified rules for calculation of tariffs for heat energy led to a high level of corruption in the heat supply segment. With the adoption of amendments to the Federal Law №190-FZ "On Heat Supply", equal principles for the calculation of prices for thermal energy appear for all, thus preconditions are created for the inflow of investments into the segment and subsequent modernization.

The more adequate redistribution of the load of heat sources will benefit the overall efficiency of CHP. The highest efficiency is achieved close to 100% capacity of the plant. Existing in Russia district heating solution where cities are supplied with the thermal energy by independent local CHP plant via not connected distribution network, in many cases, cannot provide 100% load and, therefore, cannot ensure a high level of efficiency. Combining the separate plants to a uniform district heating network (figure 9) in frame of renovation would help to achieve impressive improvements in regional level of energy efficiency (Oulu University of Applied Sciences, 2016).

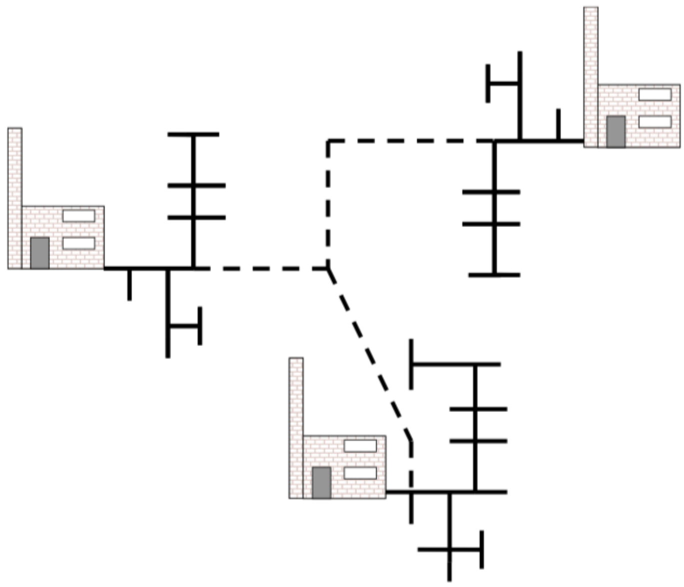

Figure 9. Combining separate local CHP to the shared network to ensure high load (Mäkelä, 2016).

Summing up, CHP plants in Russia, in addition to the equipment upgrading, requires more wise management approach. Current underuse of generating equipment is a major problem of low energy efficiency as well as high degree of equipment wear. The renovation of existing infrastructure was not possible due to unclear tariffs regulation and, consequently, lack of investments. The new legislation (amendments to the Federal Law №190-FZ “On Heat Supply”) adopted in July 2017 aims to trigger investments into Russian district heating sector and change the current situation.

2.3.2 Use of renewable energy sources

Potential of renewable energy sources for heat generation is gaining more and more recognition in many northern countries worldwide. For instance, Denmark is actively utilizing bioenergy for heat production, shifting large CHP plants from fossils to solid biomass (Danish energy agency, 2019), while Iceland is a pioneer of direct utilizing of geothermal energy. Today 9 out from 10 houses in Iceland are heated with geothermal energy (Orkustofnun, 2019).

There are three main options of converting renewable energy to useful heat: direct use, utilization of heat from CHP or converting to another type of energy carrier (figure 10).

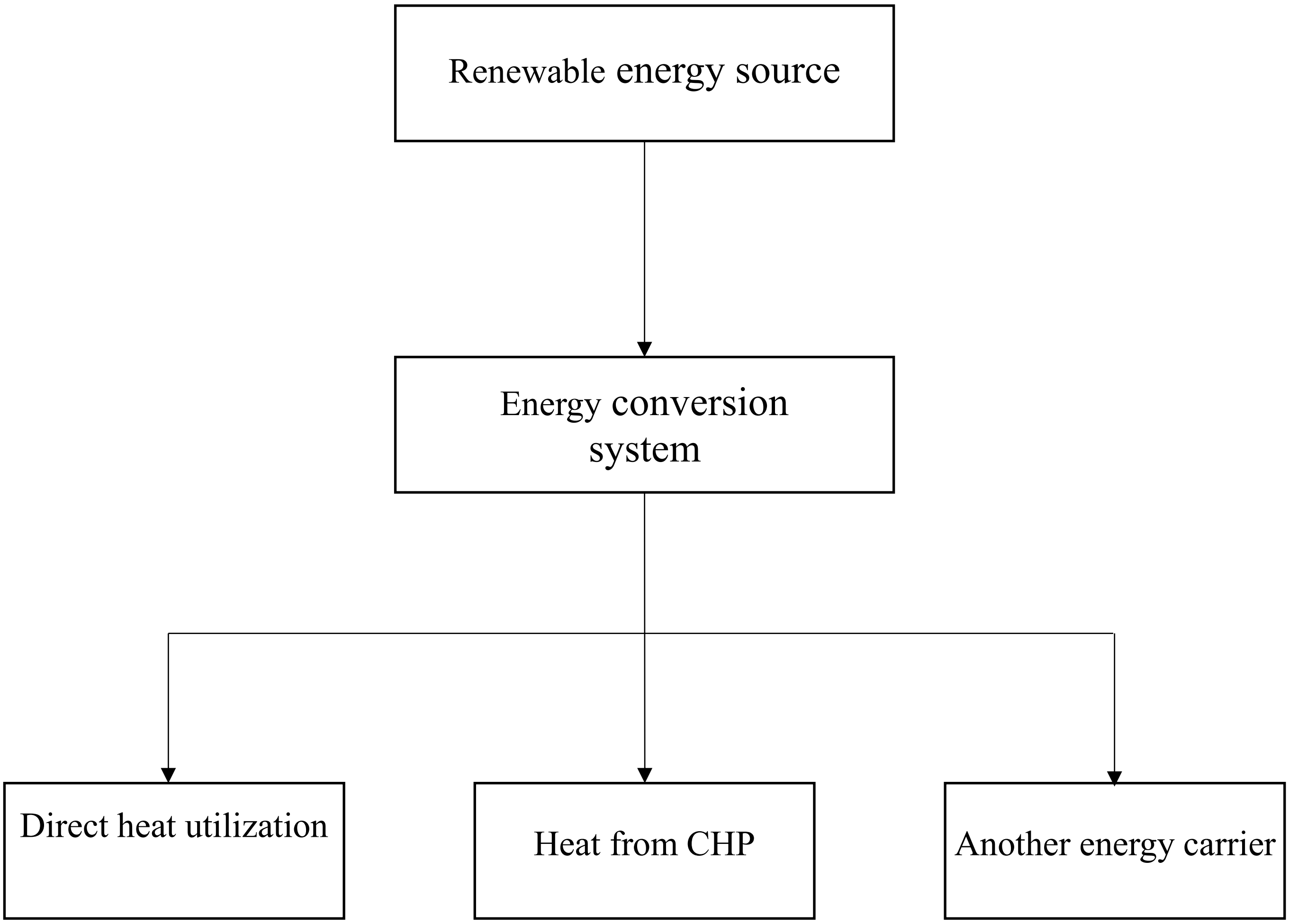

Figure 10. Options of renewable energy heat production (IEA, 2017).

In addition to significant reduction of CO_2 emission, utilization of renewables for thermal energy production with help of modern technologies increasing overall efficiency (Kemna, 2002). Although, there is a variety of conversion chains with different level of energy efficiency (figure 11). For instance, traditional use of woody biomass has less efficiency than solar thermal systems (50-70% versus 70-90%).

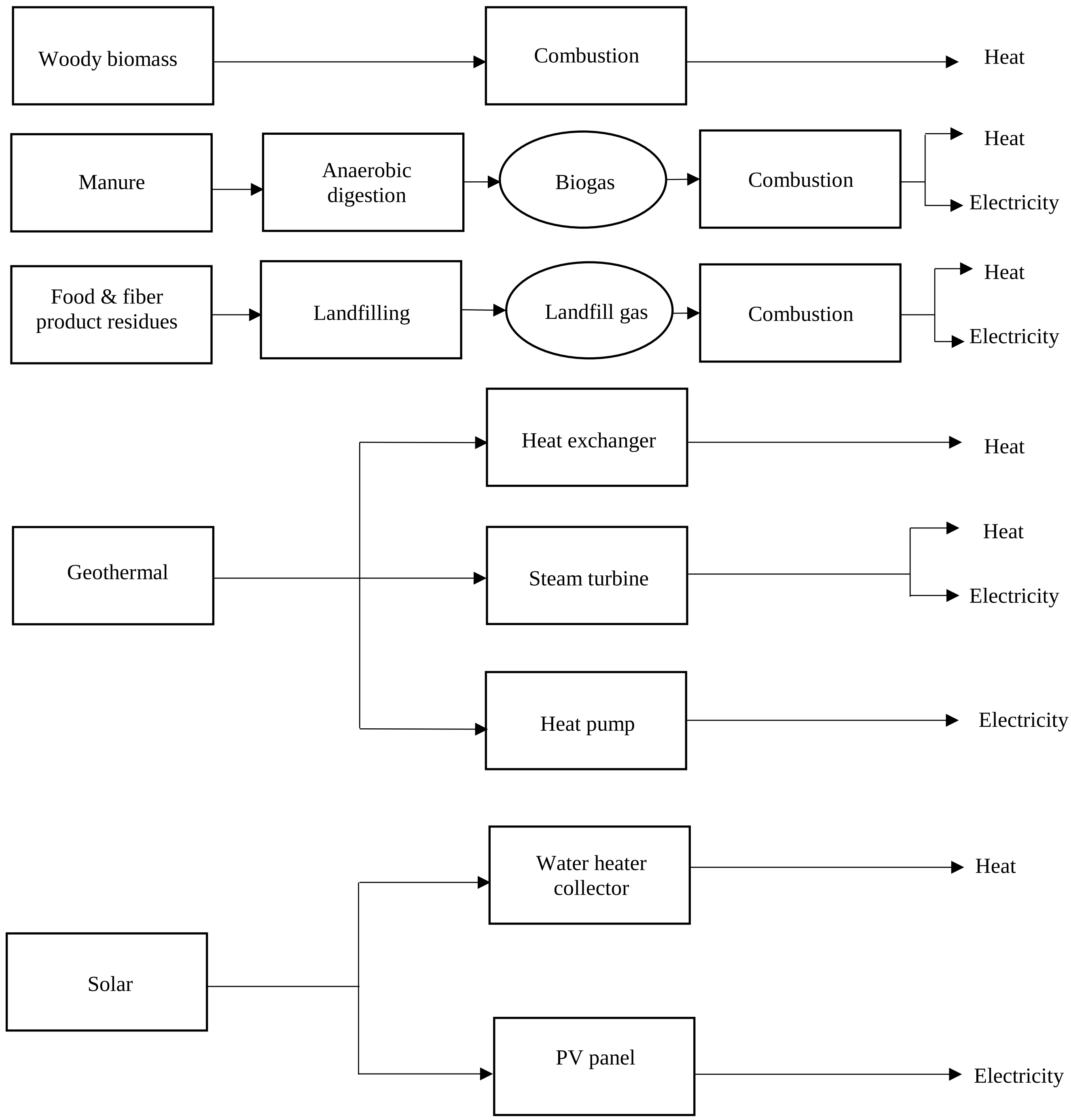

Figure 11. Examples of renewable heat conversion technologies.

In Russia, due to large share of CHP, heating sector is closely connected with electricity generation. However, the renewable heating support measures are less developed than the policies to support use of renewables in frame of electricity production. There are big differences between these two sectors in Russia and, therefore, the experience gained in policy related to electricity generation cannot be simply transported to heating. Russian electricity sector is much more centralized and monopolized while heating sector is rather heterogeneous with great number of players operating on local heat markets.

District heating system of Russia shows a great potential for the renewable energy use due to high availability of biomass and even geothermal energy in some regions. However, today renewable energy sources have a non-significant share in the total fuel mix which is used for heat production. The dominant input fuel for heating in Russia is natural gas. It accounts for 83% in country's most populated area (European part of Russia). In more isolated regions of Far East and Siberia the majority of CHP plants are fed by coal (up to 86% in the fuel mix). While natural gas is relatively sustainable source for energy generation compare to other fossils, coal is one of the most environmentally harmfull. Coal burning causes respiratory and pulmonary chronic illnesses like asthma and high level of mortality among local people (Paramonova, 2015).

According to statistics (IFC Advisory Services in Europe and Central Asia, 2011), renewable energy sources accounts for just 3-5% of the total district heat supply (CHP) in Russian Federation. In 2007 there were 66 000 sources of thermal energy generation. From which 33 400 were fueled by natural gas, 27 000 by coal, peat and solid petroleum products and 1 600 by renewables. The mix of fuel used to produce heat in Russia for the period from 1990 to 2007 is presented in figure 12.

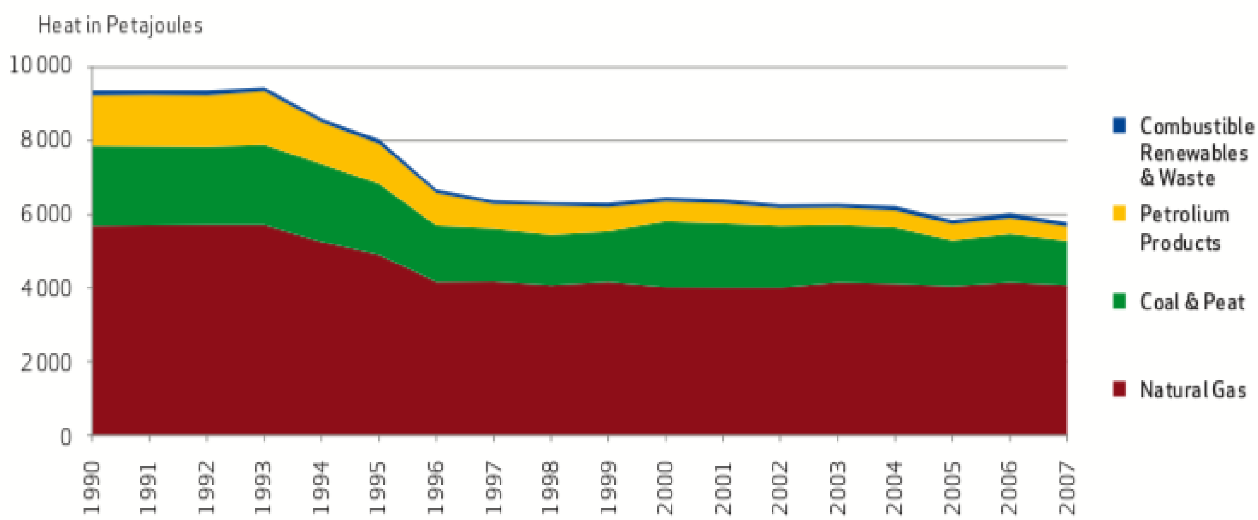

Figure 12. Fuel used to produce heat in Russia (Kerr, 2012).

Nowadays, utilization of renewables as a source for thermal energy in Russia mainly refers to the use of traditional biomass (wood) for space heating. This approach is not considered sustainable due to a big volume of pollutants from the burning process and low efficiency. However, wood pellets production sector is growing rapidly, and some experts claim that Russia may not only cover its own demand but may become the main exporter of this kind of fuel to the European market by the middle of the century (Gidmarket, 2012).

Forest industry and waste have significant potential for biofuel production that can be further used for thermal energy generation. The potential of the wood industry of the Russian Federation, according to the Society of Biotechnologists of Russia, is about 200 million m^3 per year. The annual volume of industrial and household waste to be used for energy production is about 165 million tons, and which can be produced annually up to 73 billion m^3 of biogas, up to 90 million tons of pellets or 75 million tons of syngas, which can be converted into 160 billion m^3 of hydrogen, and get up to 330 thousand tons of ethanol or up to 165 thousand tons of solvents (butanol and acetone). The maps of resource potential of biomass production from MSW and agro-industrial waste by regions of Russia are presented in Appendix 1 and Appendix 2. Co-burning option to replace a part of coal by biomass in the fuel mix of CHP in isolated regions of Siberia and Far East is a promising way to reduce CO_2 emissions and overall environmental cost of district heating.

There are two main co-firing technologies: direct and parallel. The first one implies simultaneously feeding the mix of biomass and coal in the same boiler. The first step of the process is blending coal and biomass together and processing the mixture via a coal mill. Then the substance is going to pulveriser and crusher. The final stage is a burning process. Thanks to its technical features, this technique can be used only for biomass with low moisture content, for instance wood pellets and chips.

When the biomass has higher humidity, the parallel co-firing methodology is used. This method requires separate pretreatment, feeding and combustion systems for incoming biomass. The main disadvantage of parallel co-firing is need of upgrading an existing coal-fired CHP plant to allow separate threating of biomass.

Geothermal energy also shows a high potential in Russia. Geothermal heating systems are operated in Kamchatka, Kuriles, Dagestan, Stavropol and Krasnodar Territories (Butuzov, 2008). There is experience in the development and construction of geothermal heat supply systems. For many years, five geothermal power plants have been successfully operated in Kamchatka and the Kuril Islands, with the highest capacity of which (Mutnovskaya –- 50 MW) provides up to 30% of the total electric energy consumed by Kamchatka. The map of geothermal energy resource potential by regions of Russia is presented in Appendix 3.

Another promising region in frame of geothermal source utilization is the Krasnodar region. There are 12 geothermal fields in operation nowadays, where 79 wells with a thermal capacity of up to 5 MW were drilled. The coolant temperature at the wellhead is 75–110 °C. The values of annual heat production of the main geothermal deposits of the Krasnodar region is showed in figure 13.

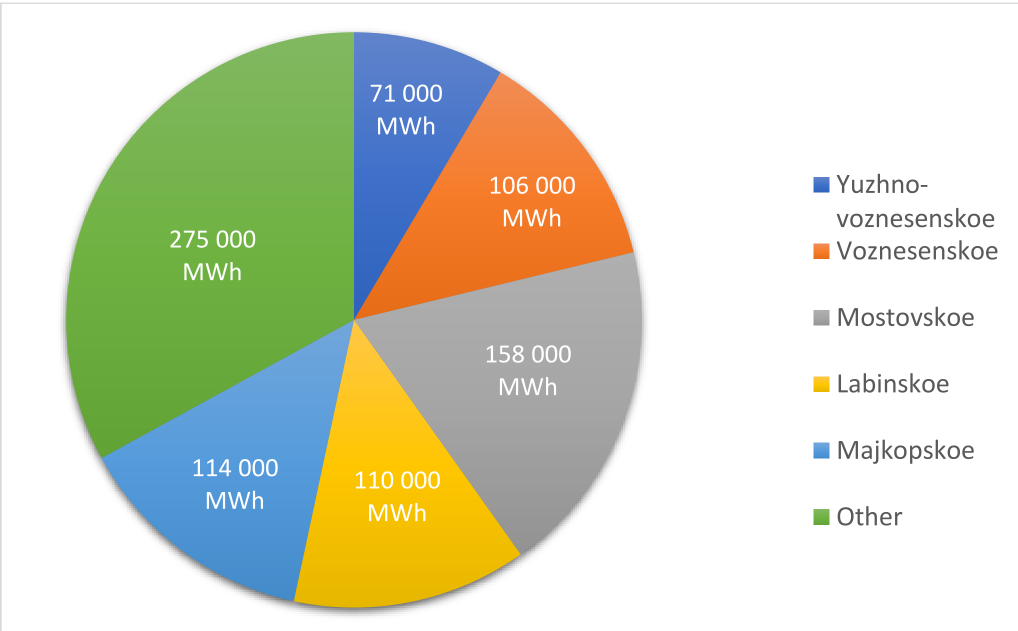

Figure 13. Annual heat production of the Krasnodar Territory geothermal deposits (Butuzov, 2008).

In accordance with the program approved by the Legislative Assembly of the Krasnodar Territory, wide integration of geothermal resources into the economy of the region is announced. The concept of development of geothermal heat supply of Labinsk, Ust-Labinsk, Goryachiy Klyuch, Apsheronsk, Anapa and Mostovsky cities is developed. It is based on the principle of highly efficient integrated use of geothermal resources in the thermal energy supply of housing, industrial enterprises and social, medical and health facilities. The

Voznesenskoye and Yuzhno-Voznesenskoye fields (capacity 50 MW) have the greatest potential.

Krasnodar region is a pioneer in developing local legislation that supports utilization geothermal energy for residential heating purposes. Although, modern federal legislation does not provide essential priorities and objective incentives for the development of this technology. Further scaling of the experience of the Krasnodar Territory in the use of geothermal energy for household heat supply is possible only in the case of the development of a federal legislative framework conducive to attracting investment in the development of geothermal energy.

Undoubtedly, utilization of renewables can become a key to decarbonizing of Russian heating sector. This solution is most relevant in isolated regions of Siberia and Far East where current district heating systems are based mainly on coal. The most promising alternatives that can replace fossils are biomass and geothermal.

2.4 Opportunities for improvement of heat transmission network

Russia has an extensive municipal heat distribution network that transfers the thermal energy from CHP plants to heat consumers. Average technical life expectancy of the pipelines is 20 years. However, some parts of the network are already 40-50 years old. It is estimated that more than 50% of the 170 000 km pipelines network are outdated, about 25-30% of the network is in critical condition and requires urgent repair (Volokhina, 2019). To keep the system in an adequate condition, upgrading of 10-12% of the network is needed annually but the lack of investments allows to replace only 1% of pipes each year (Kerr, 2012). The situation leads to low reliability, frequent failures and high losses of the thermal energy at this part of the chain. According to Skolkovo Energotech (Skolkovo, 2011), energy losses along heat distribution system in Russia is several times bigger compare to other northern countries (figure 14).

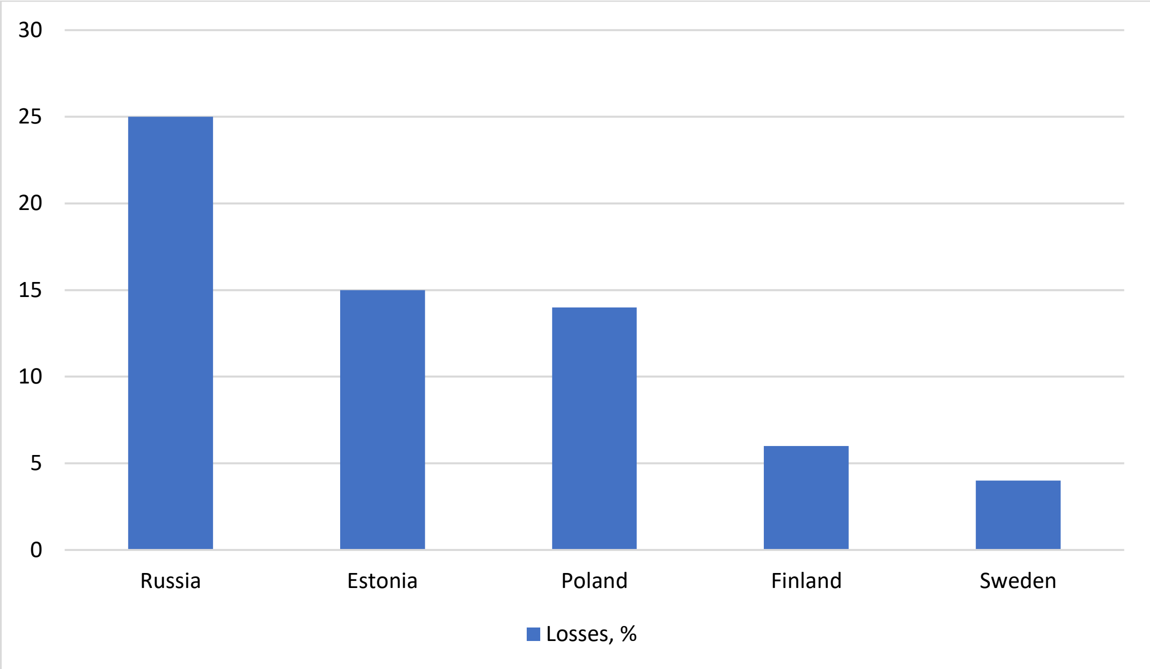

Figure 14. Heat energy losses during heat distribution (Skolkovo, 2011).

2.4.1 Losses along district heating network

The total length of heat pipelines in the Russian Federation and their structure by pipeline diameter in 2012–2016 is presented in figure 15.

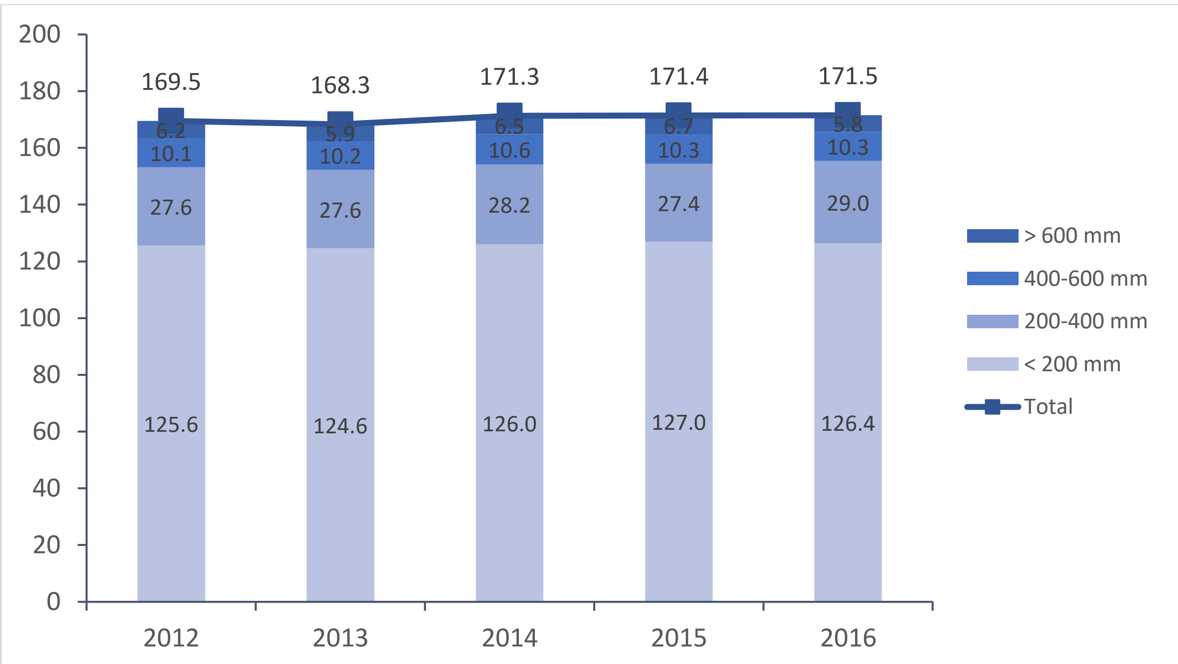

Figure 15. Length of heat networks by pipeline diameters in double-pipe terms in 2012-2016, thousand km (FGBU "REA" Ministry of Energy of Russia, 2018).

Since 2012, the length of heat pipelines in the Russian Federation has increased by 2.02 thousand km, mainly due to pipes with a diameter of 200 to 400 mm and in 2016, in two-pipe terms, amounted to 171.5 thousand km.

The most developed district heating networks in the Central Federal District. Their total length in double-tube terms is 44158 km, which is 25.7% of the total length of heating networks in the Russian Federation. Least developed heat networks in North Caucasus Federal District. In total, their length is 3421 km, or about 2.0% of the total length of heating networks in the Russian Federation (FGBU "REA" Ministry of Energy of Russia, 2018). The total length of heat pipelines by the federal districts of the Russian Federation in 2016 is presented in figure 16.

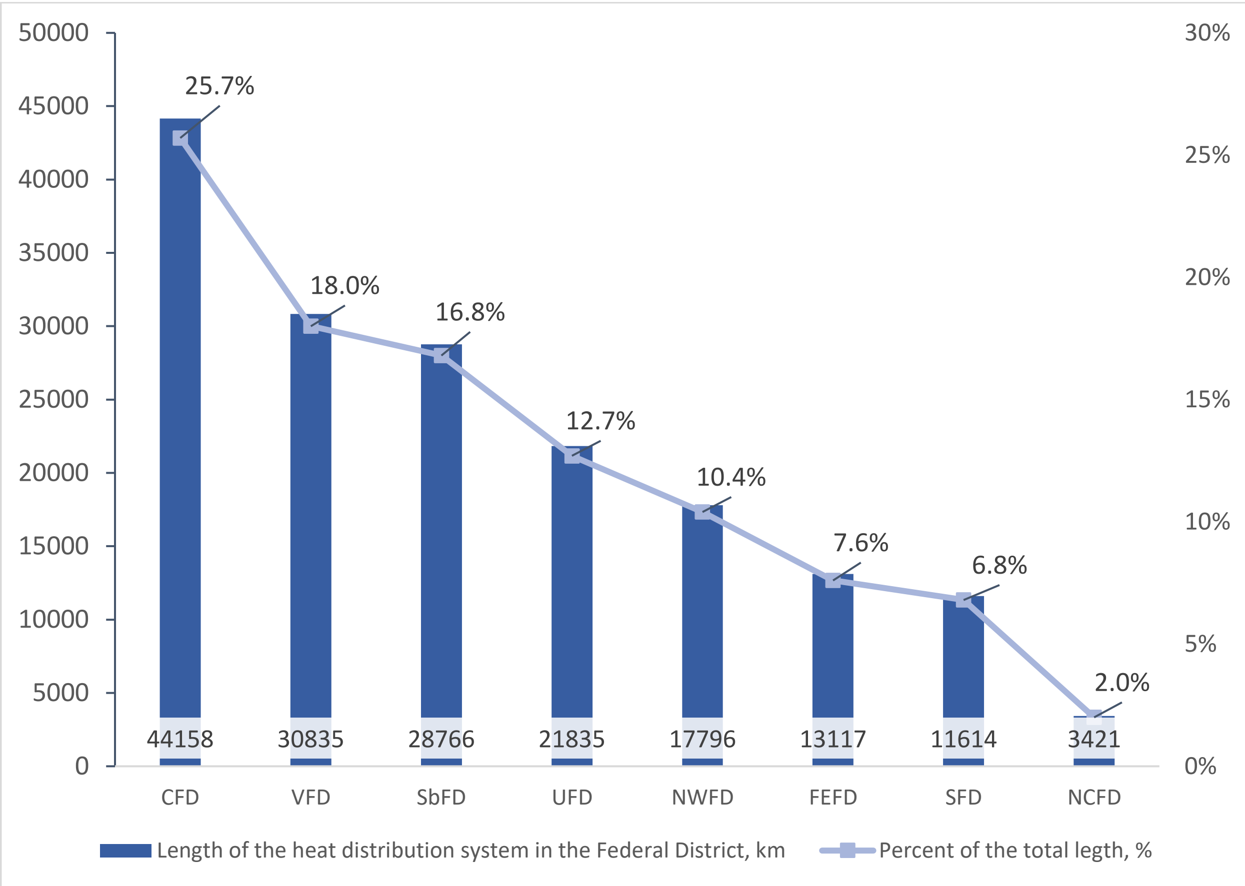

Figure 16. The total length of heat distribution network by federal districts of Russia in 2016 (FGBU "REA" Ministry of Energy of Russia, 2018).

The length of heating networks of large diameter characterizes the level of centralization of heat supply. The greatest extent of the network of large diameter (over 400 mm) is in the

Central Federal District. The length of such networks here is 4006 km from the total length of all heating networks in the district. The North Caucasus Federal District has the shortest length of heat pipelines with a diameter of over 400 mm. The share of such networks in this district is 6.0% (FGBU "REA" Ministry of Energy of Russia, 2018).

Pipelines of the heat distribution system need regular repair and restoration of both the pipes themselves and thermal insulation. According to Rosstat, in 2016 28.8% of the heat pipes of the heat supply systems of Russia need to be replaced. Including the share of dilapidated heat pipelines, that is, those that pose a real threat of destruction during the heating period, is 21.5%. However, the existing official statistics observe the condition of the pipelines of heat networks only in terms of their service life do not considering their real condition. In this regard, the statistics do not fully reflect the real situation. The share of heat pipes that require replacement by regions of Russia is presented in figure 17.

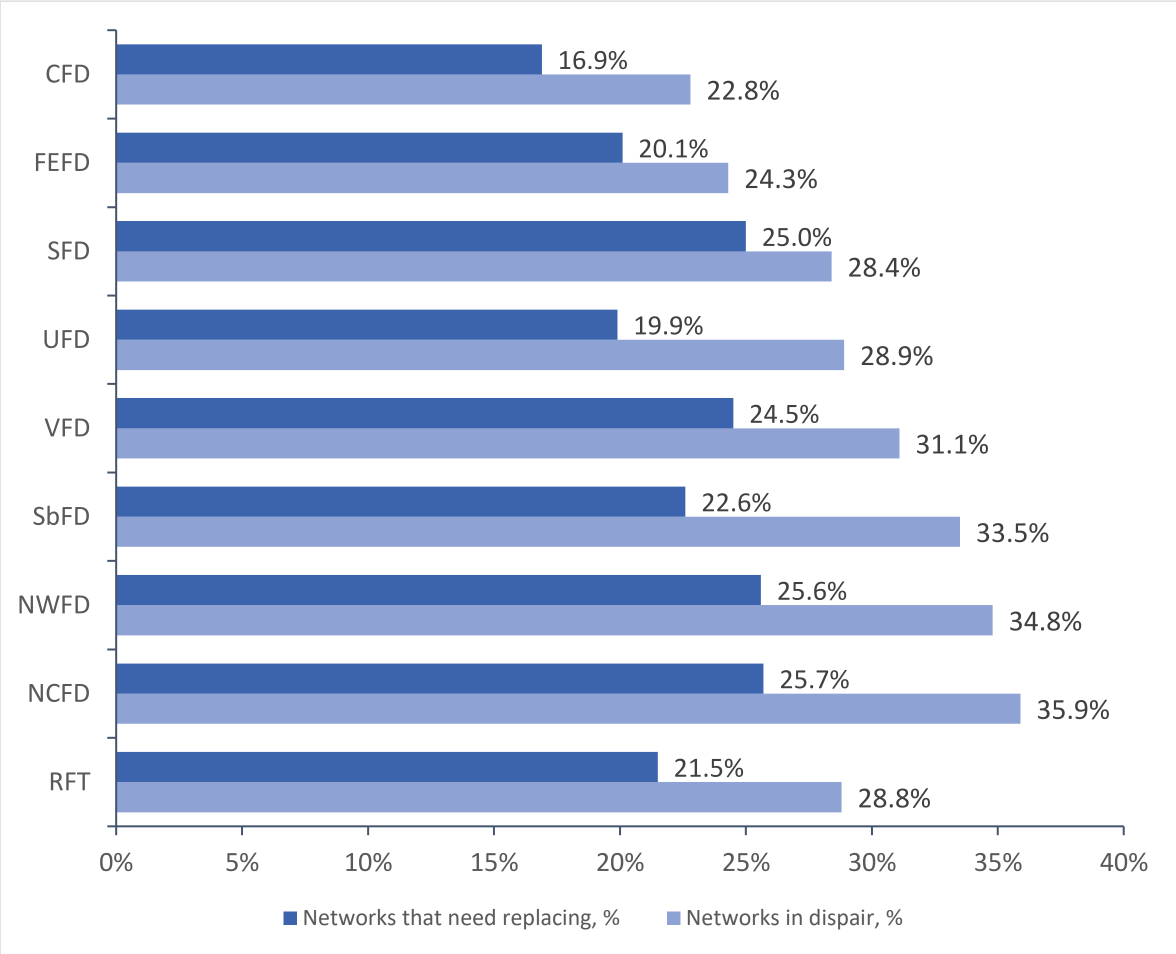

Figure 17. The share of heat pipes that require replacement by regions of Russia in 2016 (FGBU "REA" Ministry of Energy of Russia, 2018).

The largest share of heat pipelines that need to be replaced is in the North Caucasus Federal District (35.9%). This indicator is higher than the national average in the North-Higher Western (34.8%), Siberian (33.5%), Volga (31.1%) and Ural Federal Districts (28.9%). The smallest share of heat pipelines that need to be replaced is in the Central Federal District (22.8%) and Far Eastern Federal District (24.3%).

According to Rosstat, heat losses in the municipal heating networks in the Russian Federation for the period from 2012 to 2016, increased by 2 percent. Increased losses occurred in all federal districts of Russia (figure 18). The growth indicates the deterioration of heating networks, outdated and inefficient thermal insulation of pipelines. It should be noted that the volume of heat supply over this period also increased from 662 to 852 million Gcal.

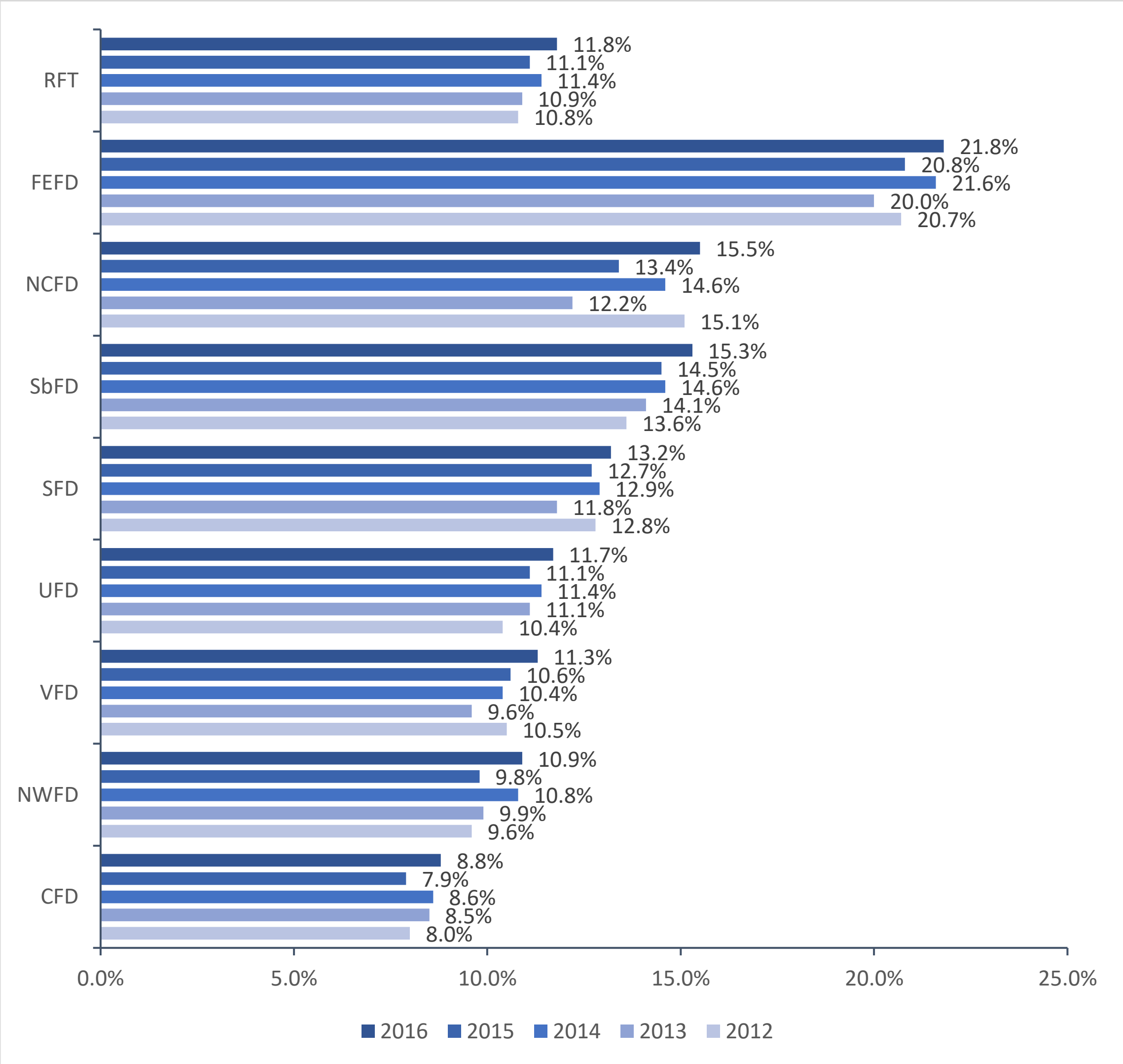

Figure 18. The share of thermal energy losses in the volume of thermal energy output in 2012-2016 (FGBU "REA" Ministry of Energy of Russia, 2018).

2.4.2 Improvement of insulation of the heat distribution system

The heat losses in the heat distribution system are determined by the temperature difference between the inside of the media pipe T_2 and the surrounding environment T_1 (figure 19).

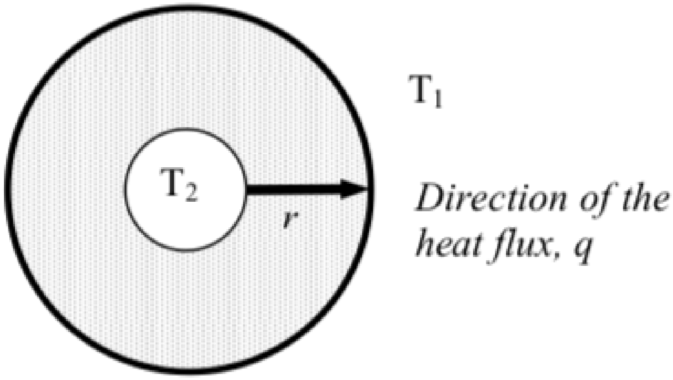

Figure 19. Heat flux in heat distribution system.

In case the material isotropic and homogeneous, the heat flux can be calculated according to Fourier's low equation 2.

$$q = -\lambda \cdot \frac{\partial T}{\partial r} \qquad (2)$$

, where q – heat flux, W·m^{-2};

T – Temperature, °C;

r – distance, *m*;

λ – thermal conductivity, W·m^{-1}·K^{-1}.

The less thermal conductivity of the pipe insulation, the less thermal energy losses along the pipe.

According to experts, lack of adequate insulation is one of the main reasons of high losses in Russian heat distribution system. The thermal insulation of most pipes is done in the old-fashioned way, by means of glass wool or other piercing materials, protected from the outside with isolate, polymer tapes, brizol or reinforced foam concrete. Heating mains with this type of insulation do not provide reliable and economical heat supply to consumers due to the greater frequency of damage by reason of its wetting and destruction.

Nowadays, the most effective method of thermal insulation of pipes is use of polyurethane (PUR) foam. Polyurethane is a widespread material. In European countries polyurethane accounts about 2.7 million tons (5%) of the total annual plastic consumption (Mangs, 2005). Polyurethane utilization for the district heating pipes insulation has following benefits:

- Long lifetime (up to 50 years);
- Heat losses reduction by up to 30%;
- Lower operating costs;
- Polyurethane foam insulation can be applied with a system of operational remote control, independently notifying of a violation of insulation in a specific area;

There are three main PUR insulation techniques:

- PUR shells;
- The “pipe in pipe” method;
- Spray polyurethane foam.

Polyurethane shells are also called semi-cylinders. They are made by filling of PUR in forms. The resulting semi-cylinders (figure 20) are fastened to each other in various ways by ties, clamps, polypropylene tapes, wire. Key benefit of this method is an easy installation.

Figure 20. PUR shells (www.tutmet.ru).

"Pipe in pipe" method is used to isolate pipes made of stainless and galvanized steel, polypropylene and polyethylene. The method is as follows: on the pipe that will be transported the substance is worn another, larger diameter (figure 21). Polyurethane foam is poured into the resulting cavity between the pipes, which foaming and hardening forms a heat-insulating layer.

Figure 21. Pipe in pipe method (www.vsetrybu.ru).

In the application of the "pipe in pipe" technology, there are important requirements. Firstly, the insulated pipe must be of perfect quality due to the fact that in case of damage, it will have to be changed along with the insulation. Secondly, the inner pipe must be equipped with electronic control devices (every 200 meters of length), otherwise it is impossible to localize leakage in case of destruction.

The third method of thermal insulation is spraying polyurethane foam with use of special equipment (figure 22). The method is suitable for on-site insulation of small sections of pipelines. Since this method is quite expensive, the disadvantage is a significant overrun of components when sprayed on pipes of small diameter. Therefore, it is used for pipelines of large diameter and small length.

Figure 22. Spraying polyurethane foam with use of special equipment (www.stroyday.ru).

Renewal and improvement of thermal insulation of heat distribution system of Russia with the use of modern materials is a necessary step to reduce total heat energy losses. According to McKinsey & Company estimations (McKinsey & Company, 2009) the thermal insulation improvement measures are able to reduce the losses in heat distribution system of Russia by 2 times.

2.5 Opportunities for improvement on a demand side

End-use consumption side in residential buildings of the heating energy supply chain is the key point with the highest energy efficiency improvement potential. While, improvements on the supply side and distribution network intend only to measures connected with technological enhancements (repairs, renovation, better insulation, etc.), improvements on a demand side mean not only advanced building's energy efficiency but also changing consumers behavior. According to researches, energy efficiency investments in Russian residential housing sector could save up to 68.8 mtoe annually (IFC, 2013) while results of consumer's behavior transition to a more sustainable and responsible heat end-use are difficult to estimate in numbers, however, not less important.

The opportunities for improvement on the heat demand side in Russian residential building are studied through the prism of building's energy efficiency, introduction of heat metering and changing people's behavior pattern.

2.5.1 Energy efficiency of residential buildings

The Russian housing sector is characterized by a long service-life and high wear rate. In 2009 the average age of a Russian residential building was 42 years (State corporation - fund of assistance to reform of housing and public utilities, 2015).

Heat energy losses in residential buildings during the cold period of the year are primarily related to the architectural and construction characteristics and heat-shielding properties of the building envelope. Heat losses in the cold period of the year, associated with the architectural and construction characteristics of the building, can be significantly reduced by the following passive methods: the correct orientations of the buildings, considering the terrain, sides of the world, wind direction, the choice of building shape. In addition to architectural and construction characteristics, the heat-shielding properties of enclosing structures play an important role. The main document that determine requirements for the heat-shielding properties of enclosing of residential buildings in Russia is the Code of Rules 50.13330.2012 "Thermal performance of the buildings". The Code of Rules states the maximum allowed values of the heat transfer through the building’s thermal insulation.

The use of modern materials for external enclosing and exterior walls coatings and ceilings insulation, can significantly reduce the heat loss of buildings in the cold season. In addition, the use of double-glazed windows with a several chambers and the filling of the chambers with gases (air, argon, krypton) can significantly improve thermal resistance to heat transfer and reduce heat loss in the cold period of the year. However, this virtually eliminates the flow of outside air due to infiltration.

Nowadays, there is a classification of apartment buildings energy efficiency in Russia (Russian Federation Government Decree №18 “On Approval of the Rules for Establishing Energy Efficiency Requirements for Buildings and Requirements for the Rules for Determining the Energy Efficiency Class of Apartment Buildings” adopted in 2011). According to the classification, there are 5 energy efficiency classes (table 3).

Table 3. Energy efficiency classes of apartment buildings (Ministry of Construction of Russian Federation, 2016).

Class	Class name	The deviation of the calculated value of the specific characteristics of the consumption of thermal energy for heating and ventilation of the building from the normalized, %
A++	Very high	less than – 60
A+		from – 50 to – 60
A		from – 40 to – 50
B+	High	from – 30 to – 40
B		from – 15 to – 30
C+	Normal	from – 5 to – 15

Table 3. Energy efficiency classes of apartment buildings (continuation).

C		from + 5 to – 5
C –		from + 15 to + 5
D	Reduced	from + 15.1 to + 50
E	Low	more than + 50

The energy efficiency class of new and reconstructed buildings is assigned by the energy auditor on the basis of project documentation, thermal imaging and energy audit. The class is indicated in the building's energy passport and must be indicated on the facade of the building (figure 23).

Figure 23. Indication of the energy efficiency class on the façade of apartment building (www.dom43.ru).

For new buildings, the energy efficiency class depends on:

- insulation level;
- wall thickness;
- materials used in the construction;
- quality of construction (the presence of heat leaks).

According to the requirements, the design and construction of buildings with energy efficiency class lower than "C" is not allowed since 2012. However, the majority of operated apartment buildings were built according to the requirements of regulatory documents of previous years and do not correspond to the stricter current standard. Therefore, in order to increase the energy efficiency class, reconstruction of such buildings is necessary. Nowadays, the reconstruction actions to reach the higher efficiency class is voluntary and do not widespread. Meanwhile, about 50 000 out of 1 380 000 apartment buildings in Russia have more than 40% wear rate. Total average wear rate of Russian apartment buildings is 31.91%. Table 4 provides average wear rate of apartment buildings by regions of Russia

Table 4. Apartment buildings wear rate by regions (Ministry of Construction of Russian Federation, 2018).

Regions	**Number of apartment buildings**	**Average wear rate, %**
Far Eastern Federal District	107 606	35.03
Volga Federal District	292 036	29.72
Northwestern Federal District	168 718	32.06
North Caucasus Federal District	30 932	33.84
Siberian Federal District	245 115	33.52
Ural federal district	104 426	31.82
Central Federal District	329 987	31.22
Southern Federal District	102 504	33.99
Russian Federation total	1 381 324	31.91

Apartment buildings constructed in the period from 1930 to 1939 have the highest average wear rate of 55.8% (figure 24).

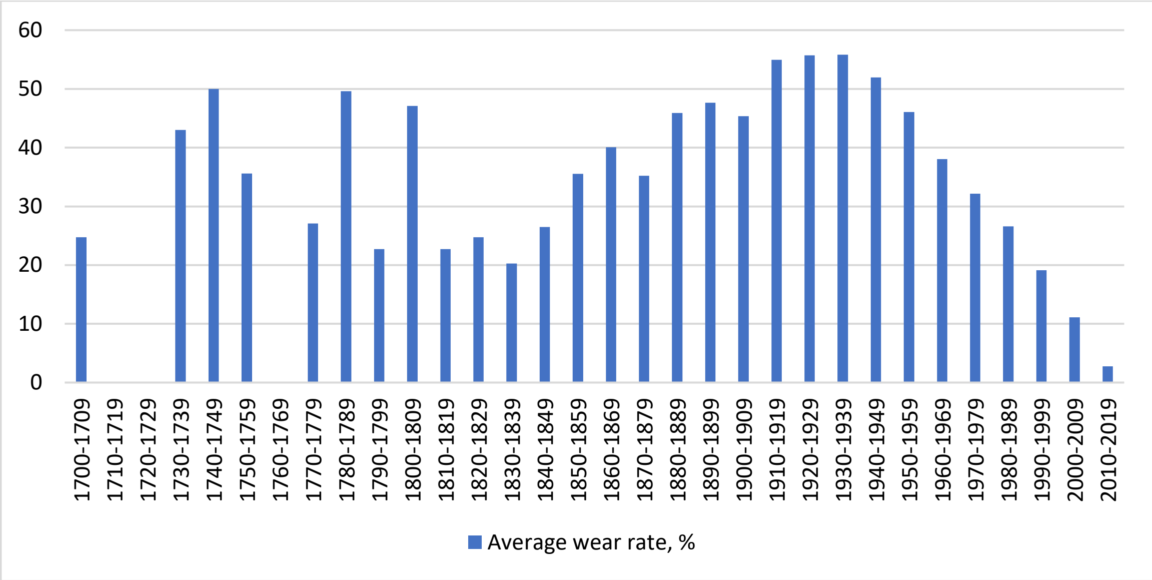

Figure 24. Average wear rate of apartment buildings in Russia by commissioning years (Ministry of Construction of Russian Federation, 2018).

Moreover, there are 17 267 apartment buildings in disrepair. According to the Russian legislation, an apartment building is recognized as in disrepair and subject to demolition or reconstruction in the case of identified harmful factors of the human environment that do not allow to ensure safety.

Nowadays, apartment buildings constructed in the period from 1930 to 1939 have the highest rate of buildings in disrepair – 10.6% (figure 25).

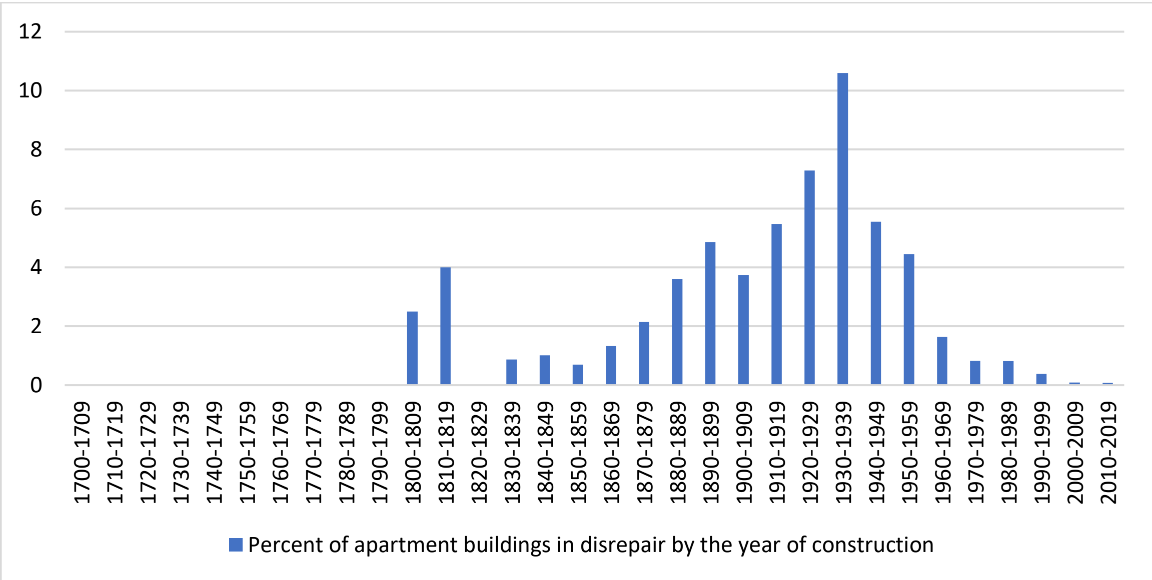

Figure 25. Percent of apartment buildings in disrepair by the year of construction (Ministry of Construction of Russian Federation, 2018).

The analysis of the data of average wear rate of apartment buildings in Russia shows that there are a lot of obsolete buildings that have low energy efficiency (class C and lower) and require energy efficiency improvement measures.

Federal Law №261 from 23.11.2009 “About energy saving and enhancing energy efficiency” provides a tool to enhance energy efficiency of an obsolete apartment buildings in an economic feasible way – energy service contract. An energy service contract is an agreement that results in the implementation of measures and actions aimed at energy saving and energy efficiency. Energy service contracts are concluded with the company managing the apartment building. The number of possible energy efficiency enhancing measures is considerable, amounts to dozens, starting from the insulation of facades and ending with the installation of metering devices.

There are already quite a few specialized organizations in Russia that provide energy services. Energy service institutions must assume the costs of the optimization, and the profits are due to the savings saved by the customer.

This model enables improvement of energy efficiency and reducing energy losses in apartment buildings in an economic beneficial way for both – the resident and service company. It explains the prevalence of this service in modern Russia. For example, during 1-4 quarters of 2018, 866 energy service contracts were signed only in Moscow to save electricity and heat in apartment buildings, of which: 189 contracts on electricity savings in public spaces of apartment buildings and 677 contracts on heat energy savings in apartment buildings. The total amount of energy savings on concluded energy service contracts, during 1-4 quarters of 2018, are estimated at 2 302 486 698.80 rubles for the entire duration of the contracts, of which: 954 180.79 Gcal (2 088 404 842.12 rubles) on the thermal energy savings and 54 542 982.59 kW·h (214 081 856.68 rubles) on the electricity savings (GKU "Energy", 2019).

2.5.2 Heat metering

To ensure high level of energy efficiency on the consumption side, well-developed energy metering system is needed. If no reliable data on energy consumption available, it is impossible to control and limit the energy losses in an effective way.

For many years, there was a lack of heat metering devices in residential buildings in Russia. Residents paid not for their actual energy consumption but for the size of the heated area. This approach led to overconsumption of the thermal energy because of no difference in the energy bill for those who were trying to save energy and for those who were not. People just was not motivated to approach their own energy consumption responsibly. Some apartment buildings were equipped with house-wide metering device that considers the energy consumption of the entire building. In this case, the energy bills for residents were calculated by dividing the total energy consumption of the entire building by resident's apartment area. In other words, the energy bill was still connected not with resident's actual energy consumption but with his apartment size.

The situation has changed with the adoption of Federal Law №261 from 23.11.2009 "About energy saving and enhancing energy efficiency", which claims that every apartment building that is commissioned after 2009 must be equipped not only with a house-wide metering device that counts the energy consumed by the entire apartment building, but also with an individual meters that counts energy consumption of every apartment.
According to Ministry of Construction of Russia, 27.75% of the apartment buildings connected to the district heating system, are equipped with a house-wide heat meter (figure 26) with the highest percentages of 34.51% in Ural Federal District (table 5) (Ministry of Construction of Russia, 2019).

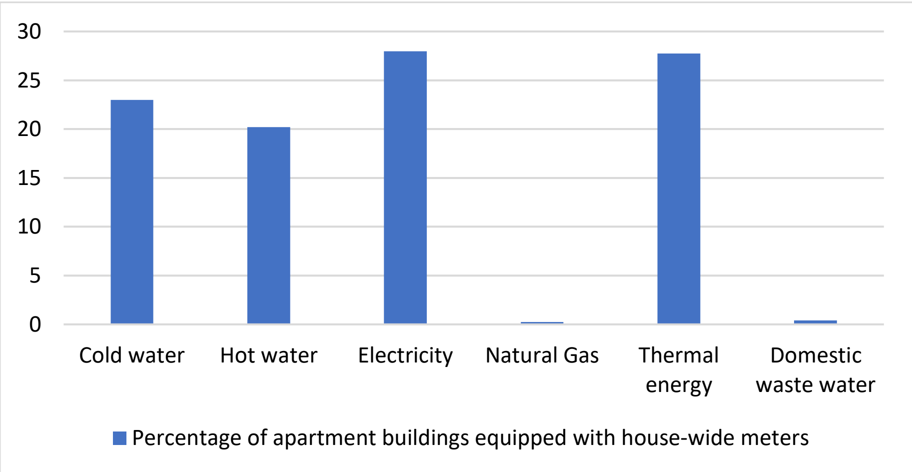

Figure 26. Percent of apartment buildings equipped with house-wide meters (Ministry of Construction of Russia, 2019).

Table 5. Apartment buildings equipped with house-wide heat meters by regions of Russia (Ministry of Construction of Russia, 2019).

Regions	**Number of apartment buildings connected to district heating system**	**Apartment buildings equipped with house-wide heat meters**	
		Number	**Percent**
Far Eastern Federal District	57 774	8 671	15.01 %
Volga Federal District	130 424	43 325	33.22 %
Northwestern Federal District	68 095	18 444	27.09 %
North Caucasus Federal District	13 110	2 538	19.36 %
Siberian Federal District	86 867	27 118	31.22 %
Ural Federal District	75 312	25 987	34.51 %
Central Federal District	148 604	32 979	22.19 %
Southern Federal District	44 490	14 268	32.07 %
Russian Federation total	624 676	173 330	27.75 %

On the background of the number of houses equipped with house-wide heat metering devices, the number of houses with installed individual metering devices seems insignificant – only 1.95 % of apartments buildings have individual heat meters for every apartment (figure 27) with the highest percentages of 5.23 % in North Caucasus Federal District (table 6).

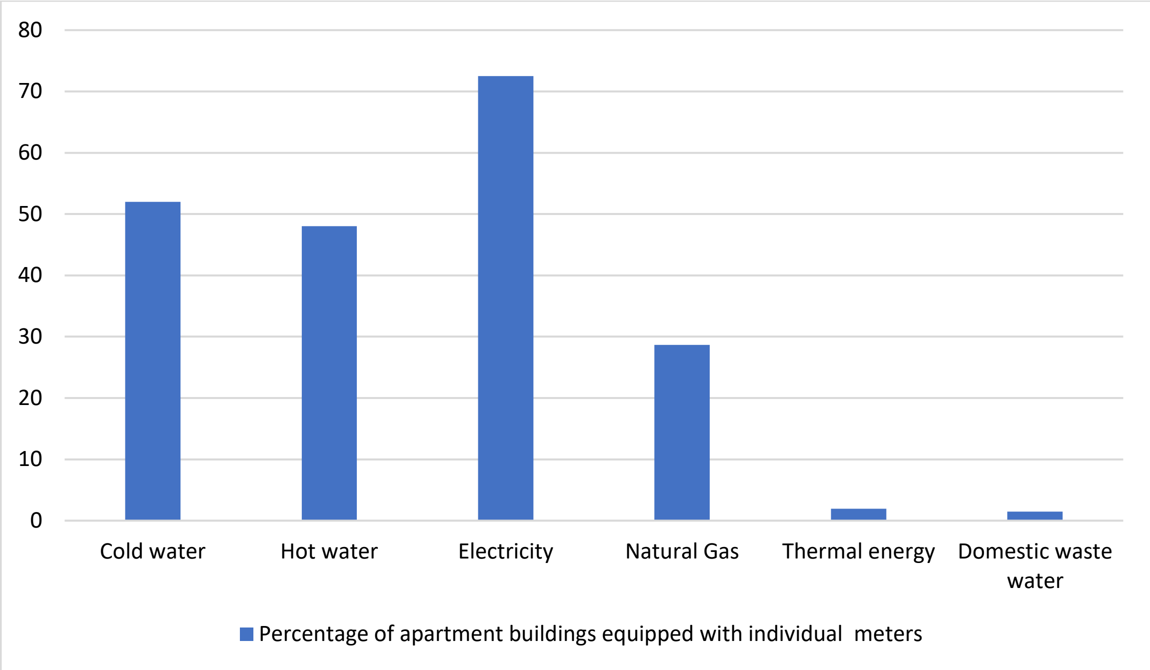

Figure 27. Percent of apartment buildings equipped with individual meters (Ministry of Construction of Russia, 2019).

Table 6. Apartment buildings equipped with individual heat meters by regions of Russia (Ministry of Construction of Russia, 2019).

Regions	**Number of apartment buildings connected to district heating system**	**Number of apartments in the apartment buildings connected to district heating system**	**Number of apartments in the apartment buildings equipped with an individual heat meter**	**Percent of apartments in the apartment buildings equipped with an individual heat meter**
Far Eastern Federal District	57 774	2 302 575	23 308	1.01
Volga Federal District	130 424	8 475 119	105 783	1.25

Table 6. Apartment buildings equipped with individual heat meters by regions of Russia (continuation).

Northwestern Federal District	68 095	4 314 596	140 728	3.26
North Caucasus Federal District	13 110	761 392	39 820	5.23
Siberian Federal District	86 867	4 936 366	61 531	1.25
Ural Federal District	75 312	4 149 598	170 931	4.12
Central Federal District	148 604	9 562 750	119 903	1.25
Southern Federal District	44 490	2 988 575	69 203	2.32
Russian Federation total	624 676	37 490 971	731 207	1.95

Despite the fact that just 1.95 % of apartments connected to the district heating system have an individual heat meter device, installations are growing year by year since 2009. The driver of this growth is the willing of people to save money by adjusting indoor temperature. Such a simple measure can significantly reduce the heat energy bill.

There are three main types of heat meters available on Russian market: mechanical, ultrasonic and magnetic. All of them consists of following parts (Mäkelä, 2016):

- Flow meter;
- Temperature sensors (1 for supply and 1 for return flows);
- Calculator (calculate consumed heat energy based on the temperature difference and the flow rate).

Temperature sensors and calculator works on the same principles in all the types of heat meters. The difference is in measurement of the liquid flow rate.

Nowadays, mechanical heat meters have a dominant position on Russia market due its simplicity and low cost. The main disadvantage of its meter type is high pressure loss caused by impeller on the way of the liquid flow.

2.6 Energy consumption behavior of Russian people

Abundant availability of natural resources, such as cheap fossil fuels, have formed lack of energy saving habits in Russian people. To analyze current energy consumption behavior of Russian people the public survey was conducted. In frame of the survey 50 people (citizens of Saint Petersburg) were interviewed. The age of the interviewers is ranging from 19 to 32 years.

In order to conduct the survey, the participants had been asked to answer the questionnaire presented in table 7.

Table 7. Questionnaire.

№	Question	Answer		
1	What is your age			
2	In what city do you currently live?			
3	Would you like to save money via energy saving?	Yes	No	I find it difficult to answer
4	Are you aware about energy saving tips?	Yes	No	I find it difficult to answer
5	Do you have an individual heat meter in your home?	Yes	No	I find it difficult to answer
6	Do you remember your heat energy consumption for last month (there is no need to mention the value)?	Yes	No	I find it difficult to answer

Table 7. Questionnaire (continuation).

7	Do you know whether your energy consumption is large compare to your neighbors?	Yes	No	I find it difficult to answer
8	Would you like to know whether your energy consumption is large compare to your neighbors?	Yes	No	I find it difficult to answer

The participants have been questioned regarding their energy consumption behavior and habits. According to the survey, most of the people (90%) want to save money via energy savings in their homes, meanwhile only 10% of them knows how they can actually do it (figure 28). The majority (82%) of the respondents have individual heat meter in their apartment or detached house while only 20% of them remember how much heat have been consumed last month (figure 29). Furthermore, 86% of the respondents do not know whether their energy consumption is large compared to their neighbors while 94% of them would like to get this information (figure 30).

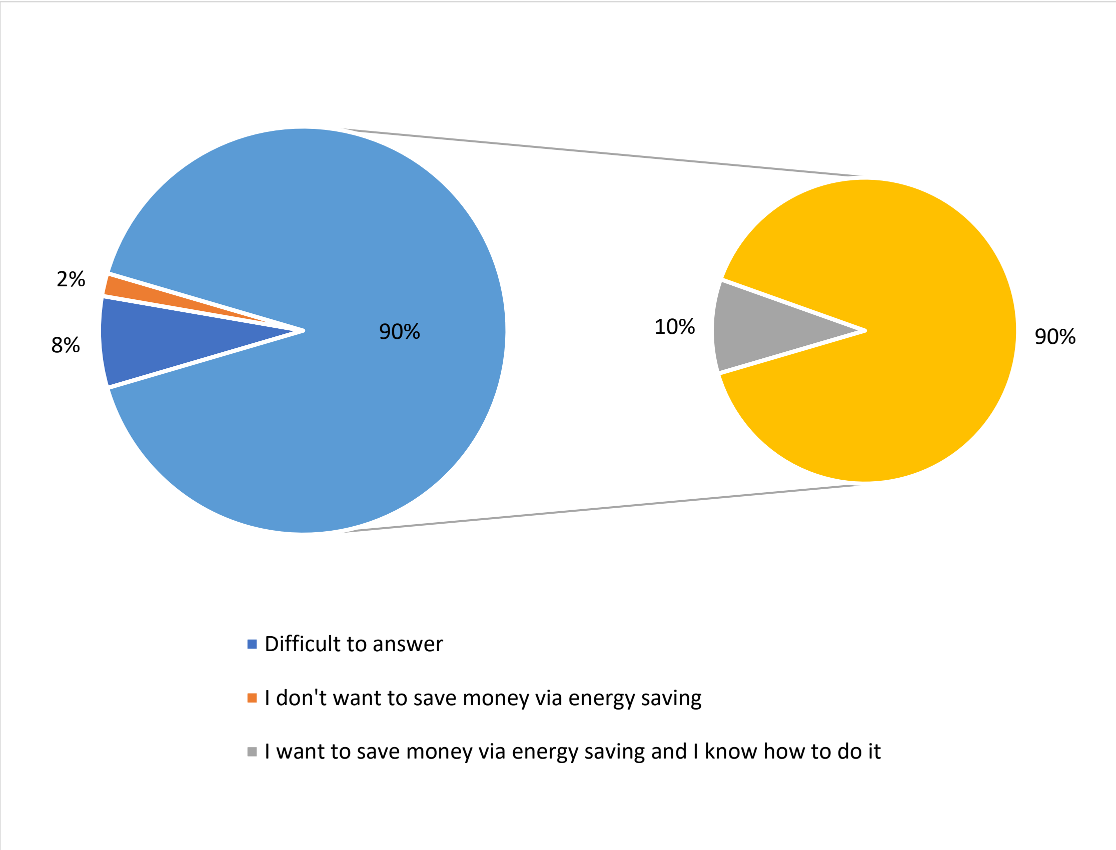

Figure 28. Survey results №1.

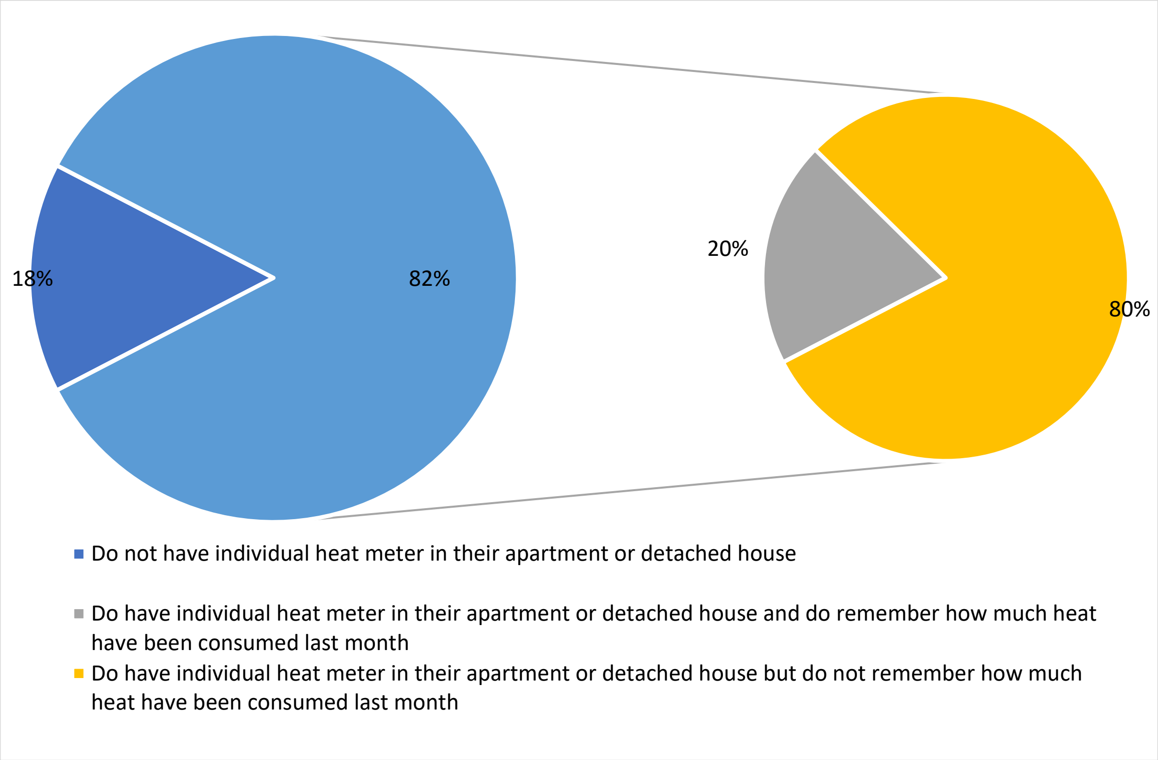

Figure 29. Survey results №2.

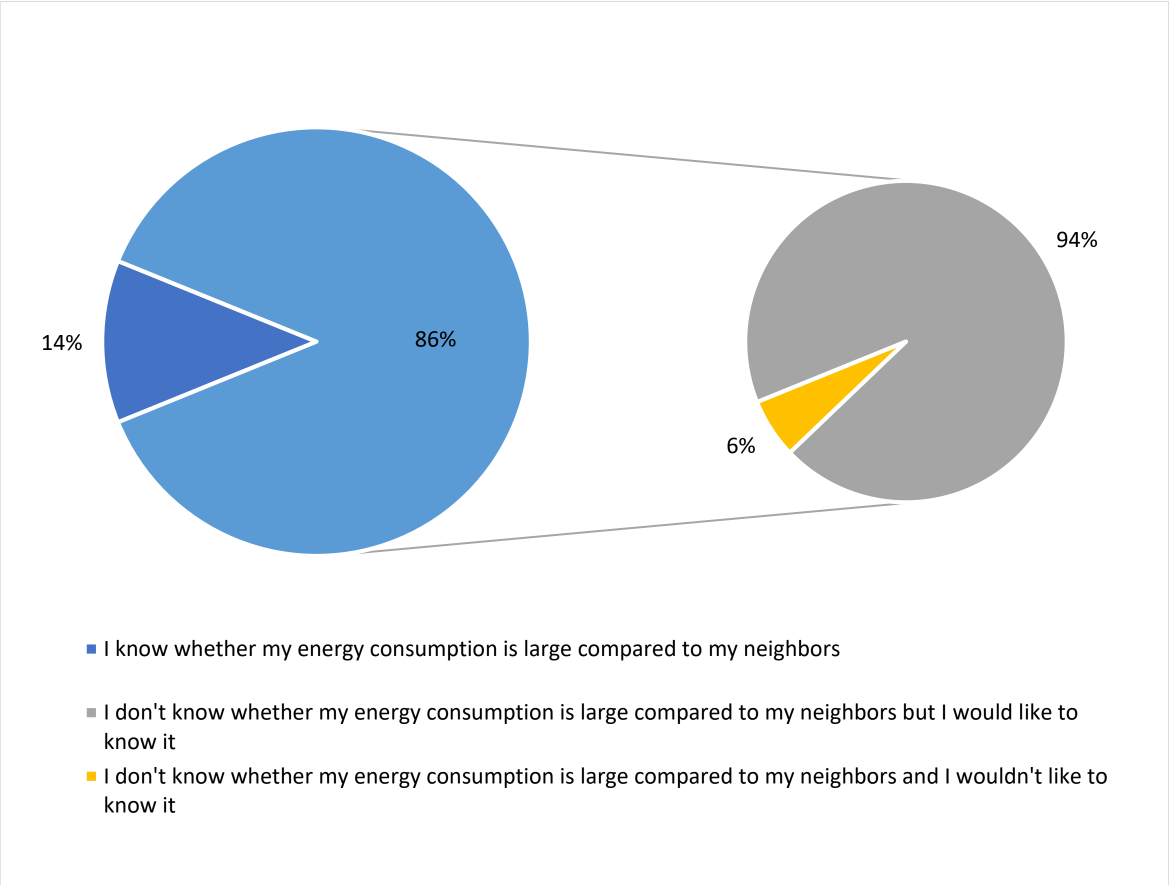

Figure 30. Survey results №3.

The survey revealed the lack of information available for Russian people about their energy consumption such as heat consumption at homes. Meantime the majority of the people would like to get more detailed information along with customized energy saving tips. However, due to the small scale of the survey (focus group of just 50 people) and its limitations from geographical and demographical point of view (all the participants are quite young urban citizens), the results do not reflect the energy consumption behavior of all the Russians but only the youths that live in metropolises.

Historically, people did not care about energy saving due to the inability to save money by consuming less energy. Wide introduction of heat meters has partly solved the problem, but more decisive measures are required to change the energy consumption psychology of Russians.

2.7 Innovative approach to energy metering

To start the transformation of people’s behavior, more data about energy use must become available for residents. Introduction of smart metering is a key to this change.

To allow information sharing between millions end devices (heat meters), a reliable, secure and economically feasible technology is needed. There are a number of networking protocols enables smart metering available on the Russian market nowadays but most of them are either expensive or proprietary hence can not be implemented nationwide. Another problem is the absence of electricity in the places of installation of heat meters. It means that the smart meter has to be energy efficient and powered by the embedded power supply.

Today there are three main technologies on Russian market which are used in frame of smart metering application:

- General Packet Radio Services (GPRS);
- Narrowband Internet of Things (NB-IoT);
- LoRaWAN

Comparison of the main characteristics of these technologies is presented in the table 8.

Table 8. Comparison of the dominant networking protocols for smart metering in Russia (Kumaritova, 2016).

Parameter	**GPRS**	**NB-IoT**	**LoRaWAN**
Coverage area of gateway	1-2 km	Up to 10 km	Up to 10 km
Battery life (2000 mAh)	Up to 2 months	Up to 5 years	Up to 10 years
Need for a frequency band license	License is required	License is required	No license required (868 MHz)
Need for a SIM-card in each end device	SIM-card is needed	SIM-card is needed	SIM-card is not needed

The analysis shows advantages of LoRaWAN technology compare to GPRS and NB-IoT.

The LoRaWAN is a Low Power Wide Area (LPWAN) protocol “designed to wirelessly connect battery operated ‘things’ to the internet in regional, national or global networks, and targets key Internet of Things (IoT) requirements such as bi-directional communication, end-to-end security, mobility and localization services” (LoRa Alliance, 2019). The architecture of the LoRaWAN network is based on star-of-stars topology. Gateway receives messages from end-devices via LoRaWAN network and send them to a central network server via standard IP connections. The gateway is playing a role of a transparent bridge, converting Radio Frequency (RF) packages to IP packets and vice versa. The architecture of LoRaWAN network is presented in figure 31.

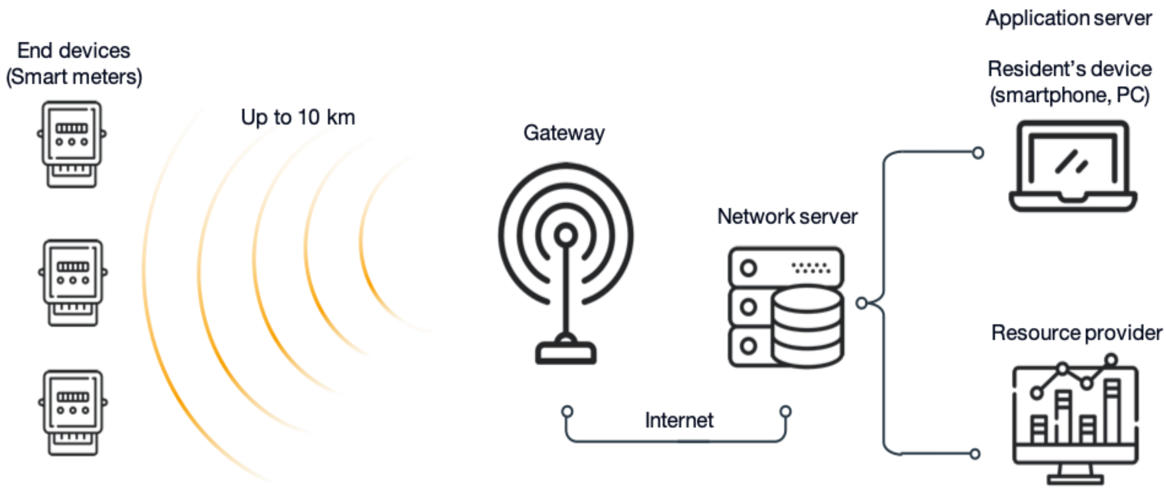

Figure 31. LoRaWAN network architecture (www.impulse-iot.ru).

End Devices

Perform measurement or control and monitoring functions. End devices are located remotely and are usually battery powered. Using the LoRaWAN network protocol, these endpoints can be configured to communicate with the LoRa gateway. Data in the LoRaWAN network can be transmitted in both directions, the endpoints to the server, and back. The points do not transmit data permanently but switch on the transmission only for a certain period of time (usually 1-5 seconds), after which it opens windows for receiving data. The rest of the time, the end devices are either in an inactive state (sleep) or in a receive state, depending on the class of the device (A, B, or C).

Gateway

It plays a role of a bridge between end devices and network server, receiving data from the endpoints via LoRaWAN protocol and transmitting it to a network server via Internet.

Network Server

Each LoRaWAN packet of data sent by the end device contains a unique AppEUI application identifier belonging to the application on the service provider's server for which it is intended. This identifier is used by the central LoRaWAN network server to further route the packet and process it on the application server.

Application server

It receives and processes a data packet from a network server and represents information in a clear and convenient form for the end user (graphs, tables, etc.).

There are already several companies in Russia that provide services for smart metering of energy, including heat, for end customers based on LoRaWAN M2M communication network. Among them “Impulse-IoT” (www.impulse-iot.ru), “Er-Telecom” (www.iot-ertelecom.ru), Lar.Tech Telecom (www.lar.tech) and some others. The system allows to provide access to comprehensive information on energy consumption on a smartphone or a laptop of a tenant and to pay energy bills. An example of user interface is shown in figure 32. Moreover, the system is capable of giving energy saving tips.

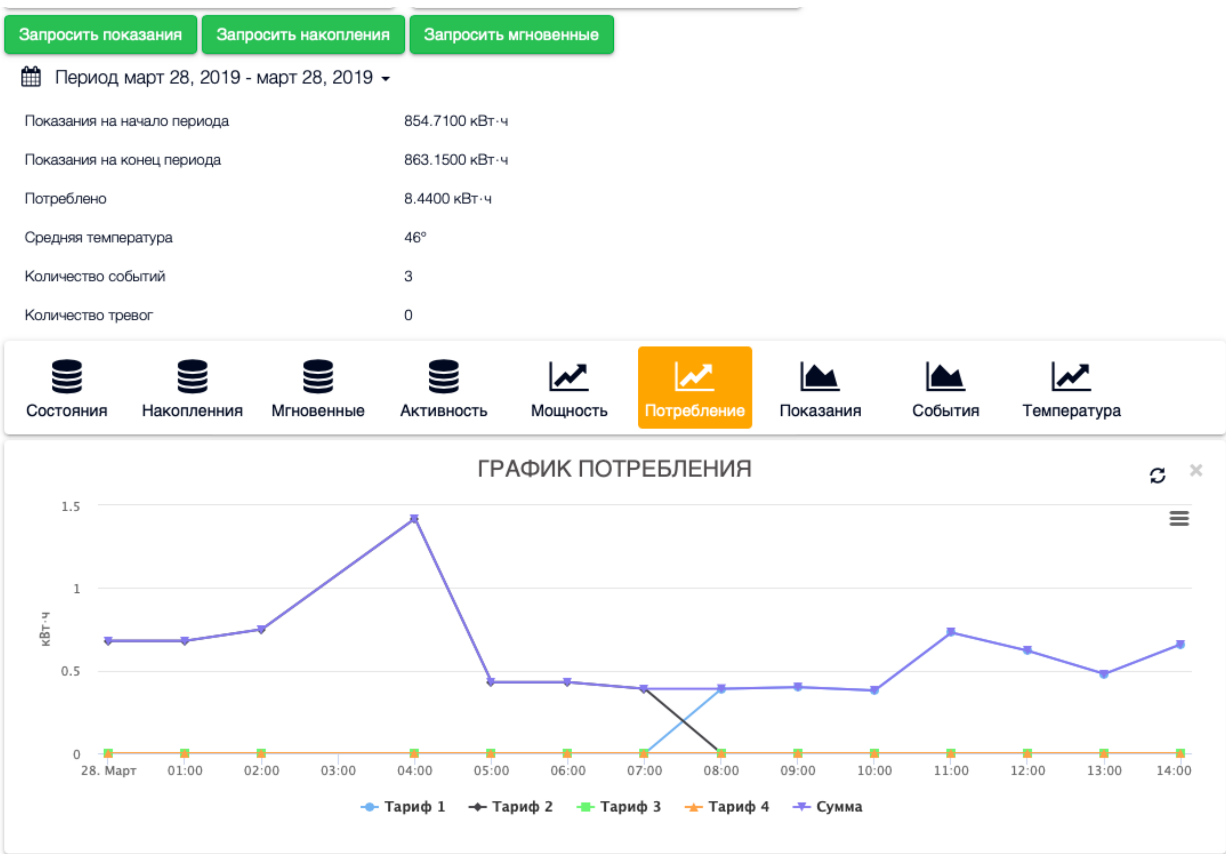

Figure 32. An example of user interface of smart energy metering system.

To prove the economic feasibility of smart heat metering system based on LoRaWAN in Russian conditions, 6 apartment buildings located in Murino district, Saint Petersburg with 6000 apartments in total have been chosen as a pilot site. Installed heat meters had M-Bus interface and were equipped with M-Bus-to-LoRaWAN converters (figure 33). To provide LoRaWAN network in the area, the LoRaWAN gateway with antenna (10 dBi) was installed on the roof of one of the six apartment buildings (figure 34).

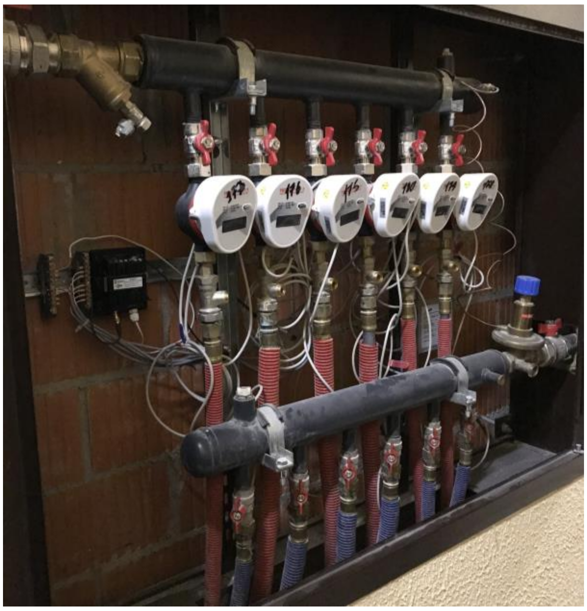

Figure 33. Heat meters with M-Bus interface equipped with M-Bus-to-LoRaWAN converter (Murino district, Saint Petersburg).

Figure 34. LoRaWAN gateway with antenna 10 dBi (Murino district, Saint Petersburg).

The Capex of the project was 4 630 000 rubles. It is expected that the access to comprehensive data about thermal energy consumption and saving tips generated by the application will help to reduce the total consumption by 15-20%. The expected payback period of the system is ranging from 1.5 to 2.5 years.

3 CO_2 REDUCTION SCENARIOS AND ECONOMIC BENEFITS

Reduction of CO_2 emissions is one of the main priorities of world politics. Russia can play a key role in the implementation of international emission reduction programs because of its size, population, energy-intensive economy, as well as the presence of obsolete and relatively inefficient production capacity.

Environmental pollution and greenhouse gas emissions often come from the same source — for example, both occur when burning fossil fuels. Because of this, reducing greenhouse gas emissions often has the additional effect of reducing other harmful substances such as nitrogen oxides (causing to smog), sulfur dioxide (causing acid rain), particulate matter and heavy metals.

As was shown in the previous chapters, residential heating is the central element of Russian domestic energy consumption with high energy efficiency improvement potential. Russia can, without prejudice to economic growth, implement a range of measures to improve energy efficiency in housing sector and reduce greenhouse gas emissions. Thus, basic programs, such as improving the insulation of buildings, can provide up to 50,000 seasonal or permanent jobs. In addition, emission reduction programs will also have an indirect economic effect, which undoubtedly is an argument in decision making (McKinsey & Company, 2009). This could be checked throughout the manuscript.

3.1 Background data and methods

Scenarios of greenhouse gas emissions in the Russian Federation until 2030 will be primarily determined by the macroeconomic situation in Russia and in the world, GDP growth rates, policies and measures for the development of the energy sector and other sectors of the economy, as well as the results of the implementation of specialized measures to limit and reduce greenhouse gas emissions. It is very difficult to predict a combination of the mentioned factors. Hence, some assumptions have been made during the scenarios calculation.

In frame of the research the scenarios of CO_2 emission reduction related only to the heating of the residential sector are built and estimated. The effect of the improvements proposed in the previous chapters is expressed in energy efficiency improvement on the demand side (renovation of the buildings, better insulation, responsible energy use), energy efficiency improvement in the heat transmission network (repair of outdated pipes, better insulation) and increase in renewable sources utilization (biomass and geothermal) for heat production on the supply side. All those measures are aiming to reduce total environmental effect presented in Million tons of CO_2 equivalent compare to the Baseline Scenario (reflects the situation with no improvements until 2030).

The scenarios are built until 2030. In total 5 scenarios of CO_2 emissions reduction caused by heating in the residential sector are calculated:

1. **Baseline Scenario**

The Baseline Scenario supposes that no improvements in the heating system are made neither enhancing energy efficiency of the system or increasing utilization of renewable sources for thermal energy production. Moreover, it is assumed that the residential construction rate is the same as it was in the period from 1990 to 2017.

Hence, the forecast of thermal energy production for residential heating purposes up to 2030 is based on the extrapolation of the available data about previous years. The information about thermal energy production for the period from 1990 to 2017 is used for the extrapolation (table 9).

Table 9. Available data of thermal energy production for residential heating for the period 1990-2017 (Ministry of Energy of Russian Federation, 2019), (Semikashev, 2008).

Year	Thermal energy production, mln Gcal
1990	485
1995	463
1997	491
1998	484
1999	471
2000	525
2001	543
2002	504
2003	528
2004	524
2005	507
2006	528
2007	509
2013	498
2014	516
2015	490
2016	498
2017	494

According to the made assumptions, the heating energy production in 2020, 2025 and 2030 years are estimated as 513, 517, 522 million Gcal respectively (figure 35). The growth rate for the period under the study (1990 – 2030) is 7,63 %.

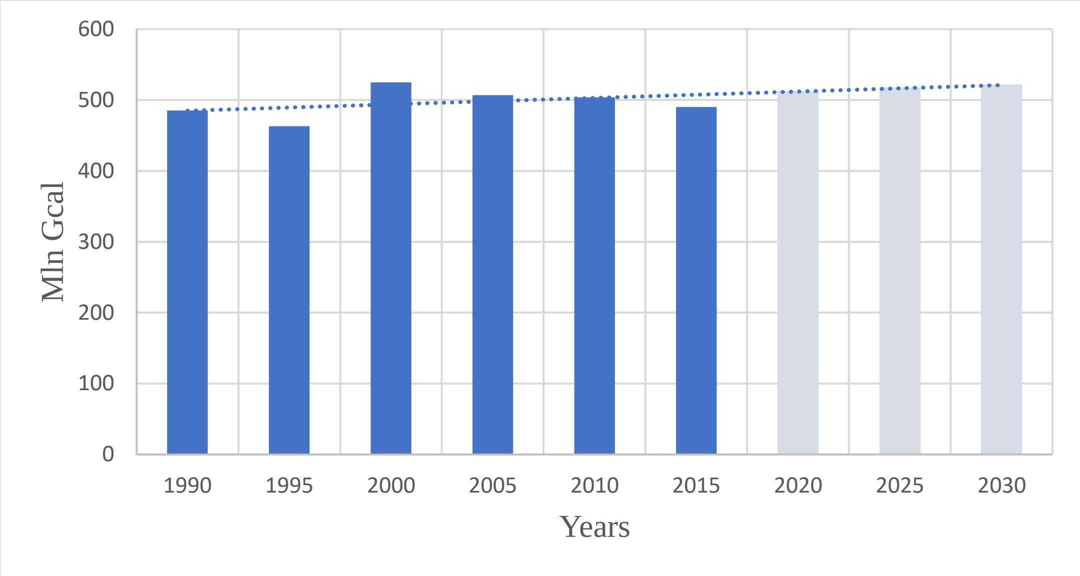

Figure 35. Thermal energy production forecast until 2030.

Due to the fact that in the Baseline Scenario we made the assumption that use of the renewable energy sources for heat generation was not enhanced, the fuel mix for 2030 is assumed the same as it was in 2015. The fuel mix of thermal energy production for residential heating is shown in figure 36.

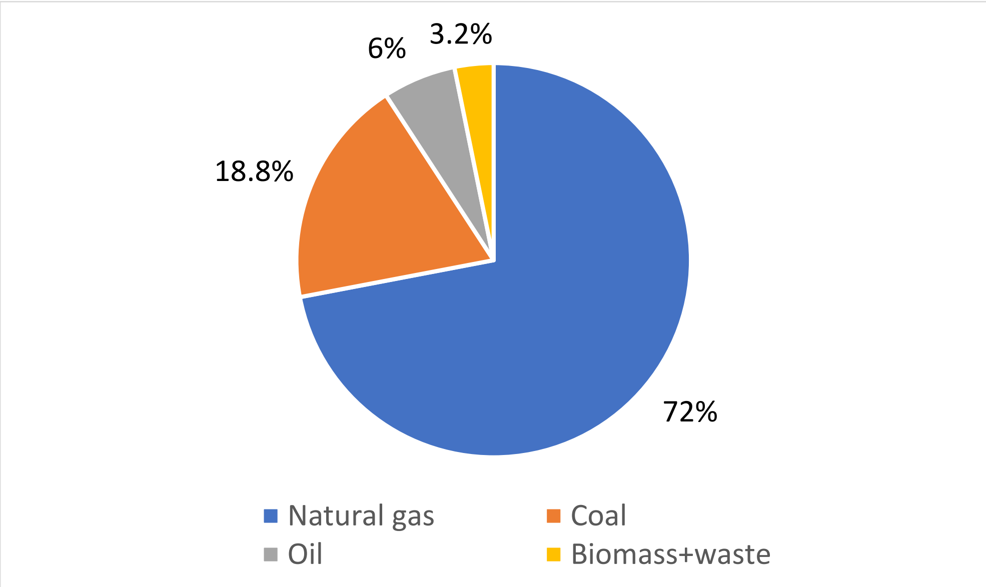

Figure 36. The fuel mix of thermal energy production for residential heating in 2015 (Vanadzina, 2018).

The calculation of the environmental impact of the heat production in the Baseline Scenario is based on the lifecycle greenhouse gas emissions for the primary energy sources included in the fuel mix (figure 37).

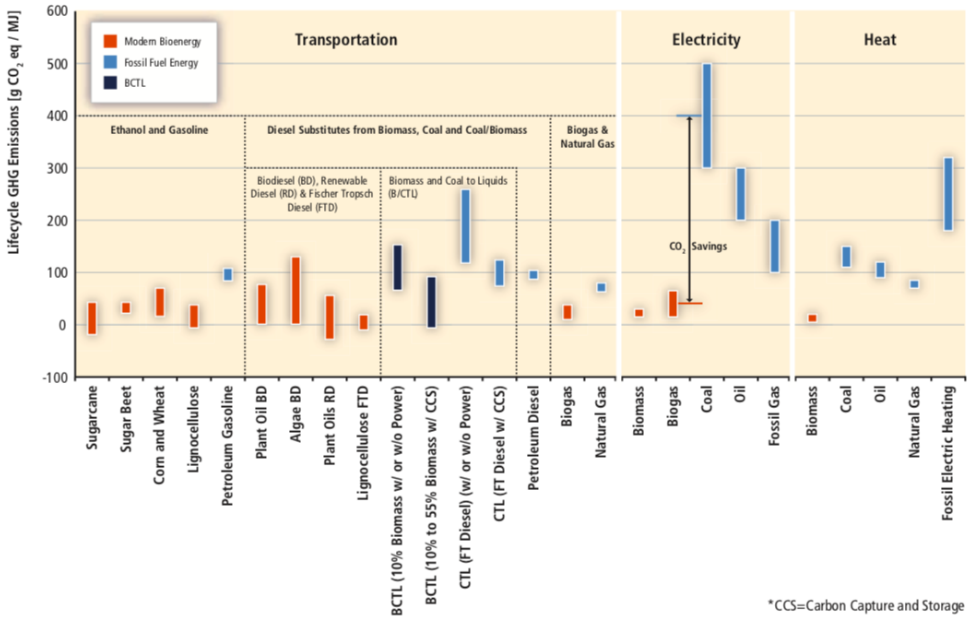

Figure 37. Lifecycle GHG emissions for different sources of primary energy (Chum, 2011).

The average CO_2 intensities of heat generation for coal, oil, natural gas and biomass are 130, 105, 75 and 15 grams of CO_2 equivalent per MJ respectively.

The annual environmental impact in the Baseline Scenario is expressed in Million tons of CO_2 equivalent and calculated according to the equation 3:

$$M_{BL\ year\ j} = E_{BL,year\ j} \cdot \sum Share_{fuel\ mix,i} \cdot CO_{2\ intensity,i} \tag{3}$$

, where $M_{BL\ year\ j}$ – environmental impact in year j, Million tons of CO_2 equivalent;

$E_{BL,\ year\ j}$ – thermal energy production in year j, PJ;

$Share_{fuel\ mix,i}$ – share of the fuel i in the fuel mix, %;

$CO_{2\ intensity,i}$ – CO_2 intensity of the fuel i, million tons of CO_2 equivalent/PJ.

2. Scenario I: Energy efficiency improvements in the distribution network

It is estimated that more than 50% of the 170 000 km heat pipelines network in Russia are outdated, about 25-30% of the network is in critical condition and requires urgent repair (Volokhina, 2019). To keep the system in an adequate condition, upgrading of 10-12% of the network is needed annually but the lack of investments allows to replace only 1% of pipes each year (Kerr, 2012).

The Scenario I supposes that mass repair of the outdated heat distribution infrastructure together with implementation of modern pipes insulation material and technics will lead to decreasing of the heat losses in the thermal energy transmission network from current 25% to 10% in 2030. To reach the 15% decreasing, the reduction rate of 1,25% of total produced thermal energy per year from 2018 until 2030 is required. Losses (in % of the production) in the residential heat distribution network for the period from 2018 to 2030 according the Scenario I are shown in table 10.

Table 10. Losses in the heat distribution network (from the total produced thermal energy) according to Scenario I.

Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Losses, %	23,75	22,5	21,25	20	18,75	17,5
Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Losses, %	16,25	15	13,75	12,5	11,25	10

In Scenario I it is assumed that no increase in renewable energy utilization for the heat generation is expected until 2030. It means that the fuel mix is the same as in 2015 (figure 36).

The calculation of the environmental impact of the heat production in the Scenario I is based on the lifecycle greenhouse gas emissions for the primary energy sources included in the fuel mix (figure 37).

The annual environmental impact in the Scenario I is expressed in Million tons of CO_2 equivalent and calculated according to the equation 3:

$$M_{S1\ year\ j} = (E_{BL,year\ j} - \Delta Losses_{year\ j}) \cdot \sum Share_{fuel\ mix,i} \cdot CO_{2\ intensity,i} \qquad (4)$$

, where $M_{S1\ year\ j}$ – environmental impact in year j, Million tons of CO_2 equivalent;
$E_{BL,year\ j}$ – thermal energy production in year j, PJ;

$\Delta Losses_{year\ j}$ – losses reduction in year j (Scenario I versus Baseline), PJ

$Share_{fuel\ mix,i}$ – share of the fuel i in the fuel mix, %;

$CO_{2\ intensity,i}$ – CO_2 intensity of the fuel i, million tons of CO_2 equivalent/PJ.

Losses reduction (Scenario I versus Baseline) is calculated according to equation 5:

$$\Delta Losses_{year\ j} = E_{BL,year\ j} \cdot (Losses_{year\ j\ BL} - Losses_{year\ j\ S1}) \quad (5)$$

, where $\Delta Losses_{year\ j}$ – losses reduction in year j (Scenario I versus Baseline), PJ

$E_{BL,year\ j}$ – thermal energy production in year j, PJ;

$Losses_{year\ j\ BL}$ – losses in the heat distribution network in year j according to the Baseline Scenario (25% of the total production for all the years), PJ;

$Losses_{year\ j\ S1}$ – losses in the heat distribution network in year j according to the Scenario I (table 10), PJ;

3. Scenario II: Energy efficiency improvements on the demand side

The technical reduction potential of the thermal energy losses on the demand side due to renovation of outdated buildings, better insulation, introduction of traditional and smart metering, is estimated as 711.756 PJ annually (IFC, 2013). It is the main field for improvement in the residential heating system with enormous potential energy efficiency improvement outcome.

Scenario II supposes the gradual implementation of the needed measures which improve energy efficiency performance on the demand side starting from 2018. It is assumed that the annual losses reduction potential of 711.756 PJ is achieved in 2030.

To achieve the set level of the losses, decrease by 2030, the loses has to decrease by 59.313 PJ annually from 2018 until 2030. The values of thermal energy losses reduction on the demand side per year for the period 2018-2030 according to the Scenario II are presented in table 11.

Table 11. Thermal energy losses reduction on the demand side according to Scenario II.

Year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Losses reduction, PJ	59,313	118,626	177,939	237,252	296,565	355,878
Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Losses reduction, PJ	415,191	474,504	533,817	593,13	652,443	711,756

In Scenario II it is assumed that no increase in renewable energy utilization for the heat generation is expected until 2030. It means that the fuel mix is the same as in 2015 (figure 36).

The calculation of the environmental impact of the heat production in the Scenario II is based on the lifecycle greenhouse gas emissions for the primary energy sources included in the fuel mix (figure 37).

The annual environmental impact in the Scenario II is expressed in Million tons of CO_2 equivalent and calculated according to the equation 6:

$$M_{S2\ year\ j} = (E_{BL,year\ j} - Losses\ red._{year\ j}) \cdot \sum Share_{fuel\ mix,i} \cdot CO_{2\ intensity,i} \qquad (6)$$

, where $M_{S2\ year\ j}$ – environmental impact in year j, Million tons of CO_2 equivalent;
$E_{BL,year\ j}$ – thermal energy production in year j according to Baseline Scenario, PJ;
$Losses\ red._{year\ j}$ – losses reduction on the demand side in year j according to Scenario II (table 11), PJ;
$Share_{fuel\ mix,i}$ – share of the fuel i in the fuel mix, %;
$CO_{2\ intensity,i}$ – CO_2 intensity of the fuel i, million tons of CO_2 equivalent/PJ.

4. Scenario III: Renewables utilization

The Scenario III supposes increase of the renewable energy sources share in the fuel mix of the thermal energy production. Meantime, it is assumed that no improvements of energy efficiency neither on the demand side or in the heat distribution network are made. Hence, the decrease of the environmental impact of the residential heating system is achieved not by reduction of the energy production due to losses elimination but by the lower CO_2 intensity of renewables compare to fossil fuels.

The Scenario III assumes that the development of conversion technologies and popularization of renewable energy sources for the thermal energy generation will lead to higher shares of renewables in the total fuel mix for heating. In the previous chapters it was shown that biomass and geothermal energy are the most promising renewable energy sources for residential heating purposes in Russia. The assumed fuel mix of residential heating energy production in 2030 is presented in figure 38.

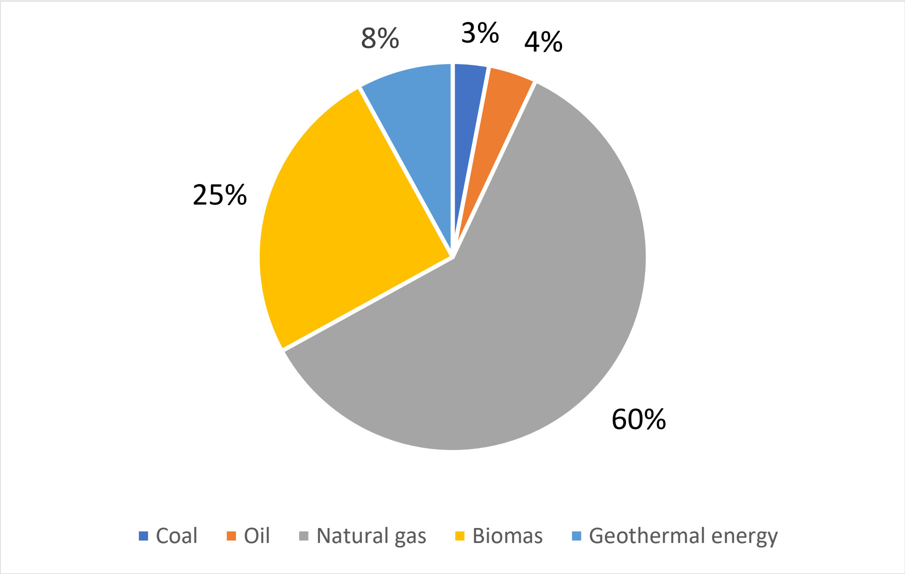

Figure 38. The fuel mix of thermal energy production for residential heating according to Scenario III.

To achieve the fuel mix in 2030 it is necessary to decrease use of fossil fuels and, in same time, increase utilization of biomass and geothermal energy for heat production. According to the Scenario III in the period from 2018 to 2030:

- annual reduction rate of coal is 1.32%;
- annual reduction rate of oil is 0.17%;
- annual reduction rate of natural gas is 1%;
- annual growth rate of biomass is 1.82%;
- annual growth rate of geothermal energy is 0.67%.

The shares of the mentioned primary energy sources in the fuel mix of the residential heating for the period 2018-2030 are presented in table 12.

Table 12. Fuel mix of residential heating according to Scenario III.

Year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Share of coal, %	18,80	17,48	16,17	14,85	13,53	12,22	10,90
Share of oil, %	6,00	5,83	5,67	5,50	5,33	5,17	5,00
Share of natural gas, %	72,00	71,00	70,00	69,00	68,00	67,00	66,00
Share of biomass, %	3,20	5,02	6,83	8,65	10,47	12,28	14,10
Share of geothermal energy, %	0,00	0,67	1,33	2,00	2,67	3,33	4,00
Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**Annual growth rate, %**
Share of coal, %	9,58	8,27	6,95	5,63	4,32	3,00	-1,32
Share of oil, %	4,83	4,67	4,50	4,33	4,17	4,00	-0,17
Share of natural gas, %	65,00	64,00	63,00	62,00	61,00	60,00	-1,00
Share of biomass, %	15,92	17,73	19,55	21,37	23,18	25,00	1,82
Share of geothermal energy, %	4,67	5,33	6,00	6,67	7,33	8,00	0,67

It is assumed that starting from 2019 in addition to using biomass, geothermal energy sources will be utilized to generate heat. The calculation of the environmental impact of the heat production by utilization of geothermal energy is based on the lifecycle greenhouse gas emissions for the source (figure 39).

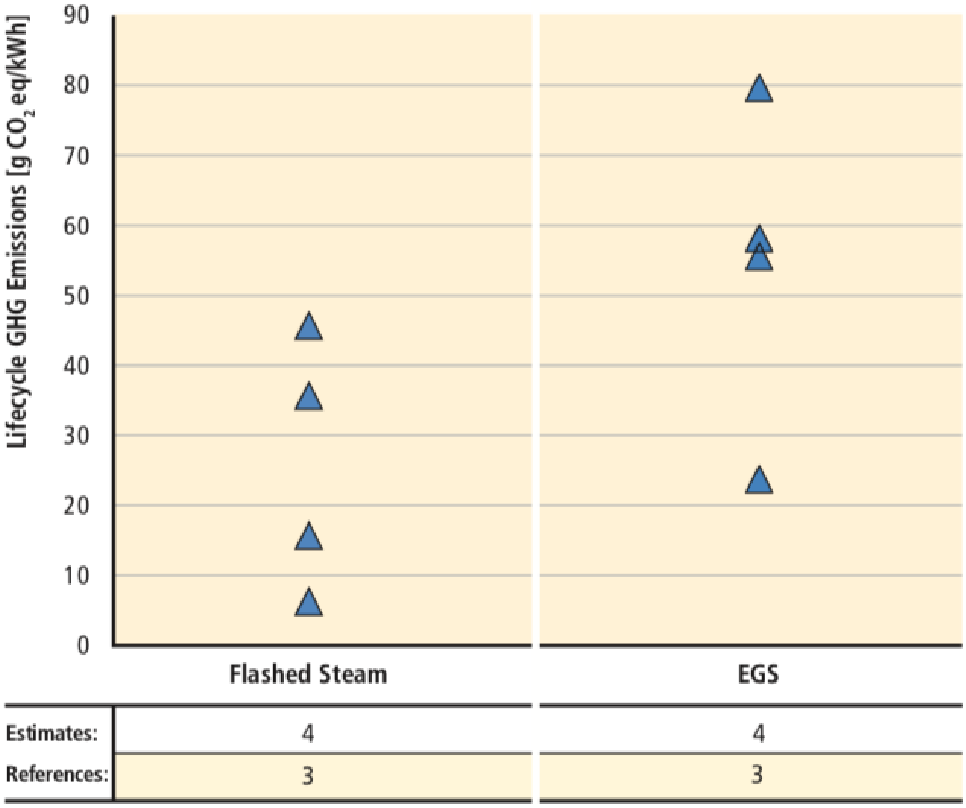

Figure 39. Lifecycle GHG emissions for geothermal energy heat production (Flashed Steam and Enhanced Geothermal System technology) (Goldstein, 2011).

For the further calculations of the environmental impact of the residential heating it is assumed that the average value of lifecycle GHG emissions for geothermal energy is 80 grams of CO_2 equivalent/kWh (the worst case). 80 g CO_2 equivalent/kWh is equal to 2 224 tons of CO_2 equivalent/PJ.

The annual environmental impact in the Scenario III is expressed in Million tons of CO_2 equivalent and calculated according to the equation 7:

$$M_{S3\ year\ j} = E_{BL,year\ j} \cdot \sum Share_{fuel\ mix\ year\ j,\ i} \cdot CO_{2\ intensity,i} \tag{7}$$

, where $M_{S3\ year\ j}$ – environmental impact in year j, Million tons of CO_2 equivalent;
$E_{BL,year\ j}$ – thermal energy production in year *j* according to Baseline Scenario, PJ;
$Share_{fuel\ mix\ year\ j,i}$ – share of the fuel *i* in the fuel mix in the year *j*, %;
$CO_{2\ intensity,i}$ – CO_2 intensity of the fuel i, million tons of CO_2 equivalent/PJ.

5. Scenario IV: Combined effect of all the improvements

The Scenario IV combines the effects of improvements assumed in Scenario I, Scenario II and Scenario III. It means decreasing thermal energy losses on the demand side and in the heat distribution network due to increase in energy efficiency of the infrastructure together with higher shares of renewables in the total fuel mix for heating. In other words, it is the scenario with the highest level of minimizing the environmental impact compared to Baseline situation.

The annual environmental impact in the Scenario IV is expressed in Million tons of CO_2 equivalent and calculated according to the equation 8:

$$M_{S4\ year\ j} = M_{BL,year\ j} - (\Delta M_{S1\ year\ j} + \Delta M_{S2\ year\ j} + \Delta M_{S3\ year\ j}) \quad (8)$$

, where $M_{S4\ year\ j}$ – environmental impact in year *j* (Scenario IV), Million tons of CO_2 equivalent;
$M_{BL,year\ j}$ – environmental impact in year *j* (Baseline), Million tons of CO_2 equivalent;
$\Delta M_{S1,\ S2,\ S3\ year\ j}$ – reduction of the environmental impact in year *j* (Scenario I, Scenario II, Scenario III compare to Baseline), Million tons of CO_2 equivalent.

The reduction of the environmental impact compare to Baseline Scenario is calculated according to equation 9:

$$\Delta M_{SX\ year\ j} = M_{BL,year\ j} - M_{SX\ year\ j} \quad (9)$$

, where $\Delta M_{SX\ year\ j}$ – reduction of the environmental impact in year *j* according to Scenario *x* (I, II or III), Million tons of CO_2 equivalent;
$M_{BL,year\ j}$ – environmental impact in year *j* (Baseline), Million tons of CO_2 equivalent;

$M_{SX\ year\ j}$ – environmental impact in year *j* according to Scenario *x* (I, II or III), Million tons of CO_2 equivalent.

3.2 Results from the CO2 reduction scenario analysis

The results of the modelling of each scenario (Baseline – Scenario IV) according to the developed methodology and the background data for the calculations are presented in this chapter to assess the environmental benefits due to proposed improvements in the residential heating sector of Russia.

1. **Baseline Scenario**

Results of the modelling of the residential heating environmental impact according to the Baseline Scenario that assumes no improvements until 2030 are presented in table 13. The impact is divided either by years and fuel types.

The curve of the residential heating environmental impact according to Baseline Scenario for the period 1990 – 2030 expressed in million tons of CO_2 equivalent is shown in figure 40.

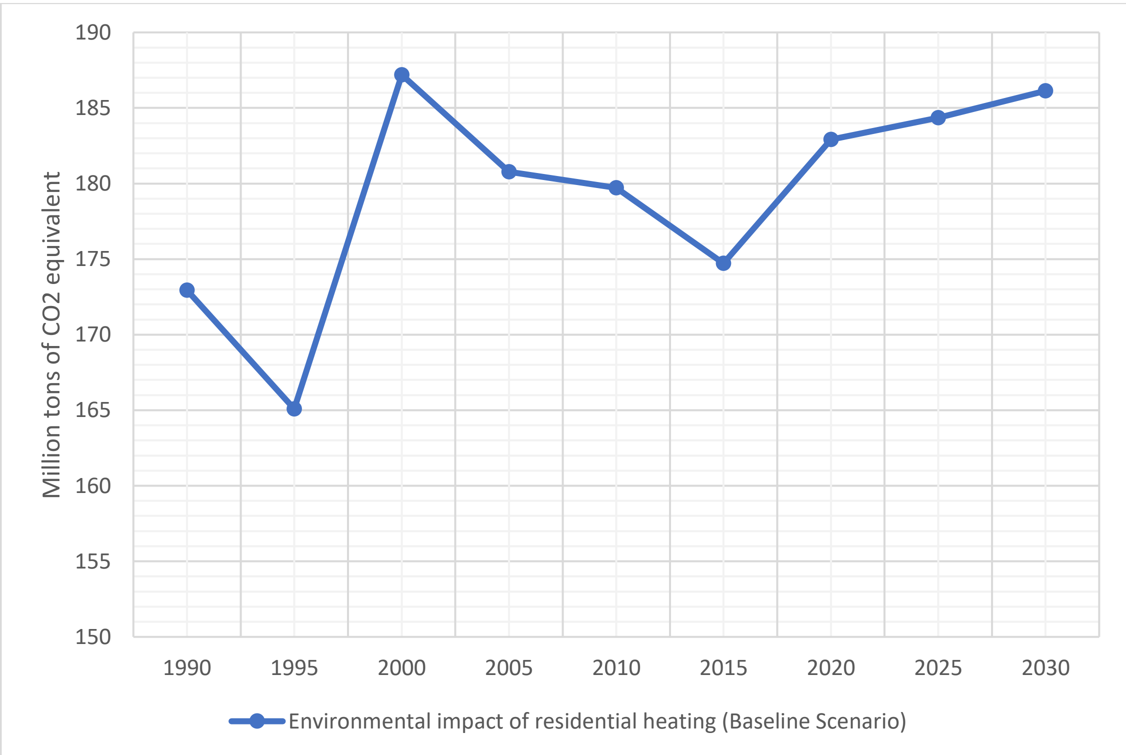

Figure 40. Curve of the residential heating environmental impact according to Baseline Scenario for the period 1990 – 2030.

Table 13. Results of the environmental impact calculation according to Baseline Scenario.

Environmental impact of residential heating (Baseline Scenario)									
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Thermal energy production, Million Gcal	485	463	525	507	504	490	513	517	522
Thermal energy production, PJ	2029,240	1937,192	2196,600	2121,288	2108,736	2050,160	2146,392	2163,128	2184,048
CO2 emissions from Coal, Million tons of CO2 equivalent	49,5946	47,3450	53,6849	51,8443	51,5375	50,1059	52,4578	52,8668	53,3781
CO2 emissions from Oil, Million tons of CO2 equivalent	12,7842	12,2043	13,8386	13,3641	13,2850	12,9160	13,5223	13,6277	13,7595
CO2 emissions from Natural Gas, Million tons of CO2 equivalent	109,5790	104,6084	118,6164	114,5496	113,8717	110,7086	115,9052	116,8089	117,9386
CO2 emissions from Biomass, Million tons of CO2 equivalent	0,9740	0,9299	1,0544	1,0182	1,0122	0,9841	1,0303	1,0383	1,0483
Total CO2 emissions, Million tons of CO2 equivalent	172,9318	165,0875	187,1943	180,7762	179,7065	174,7146	182,9155	184,3418	186,1246

2. Scenario I: Energy efficiency improvements in the distribution network

Results of the modelling of the residential heating environmental impact according to Scenario I that assumes reduction of the heat losses in the thermal energy distribution network from 25% to 10% until 2030 due to mass repair of the outdated heat transmission infrastructure together with implementation of modern pipes insulation materials and technics are presented in table 14. The impact is divided either by years and fuel types.

The curve of the residential heating environmental impact according to Scenario I for the period 1990 – 2030 expressed in million tons of CO_2 equivalent is shown in figure 41.

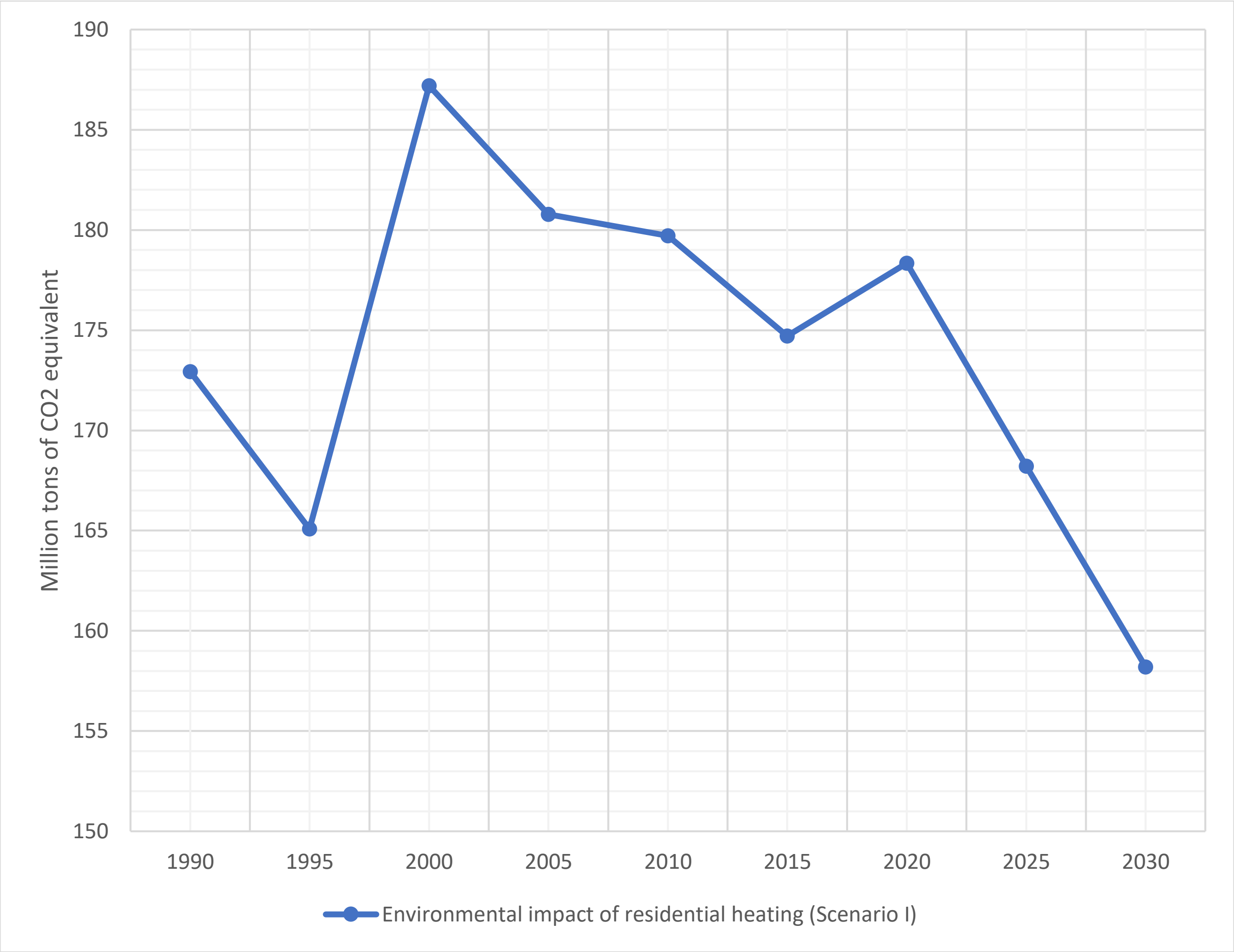

Figure 41. Curve of the residential heating environmental impact according to Scenario I for the period 1990 – 2030.

Table 14. Results of the environmental impact calculation according to Scenario I.

Environmental impact of residential heating (Scenario I)									
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Thermal energy production, (Baseline) Million Gcal	485	463	525	507	503,553	490,266	512,83	517,467	522,106
Thermal energy production (Baseline), PJ	2029,24	1937,192	2196,6	2121,288	2108,736	2050,16	2146,392	2163,128	2184,048
Thermal energy loses in distribution network (Baseline), PJ	507,31	484,298	549,15	530,322	527,184	512,54	536,598	540,782	546,012
Thermal energy loses in distribution network (Scenario I), PJ	507,31	484,298	549,15	530,322	527,184	512,54	482,9382	351,5083	218,4048
Loses reduction (Scenario I versus Baseline), PJ	0	0	0	0	0	0	53,6598	189,2737	327,6072
Thermal energy production (Scenario I), PJ	2029,240	1937,192	2196,600	2121,288	2108,736	2050,160	2092,732	1973,854	1856,441

Table 14. Results of the environmental impact calculation according to Scenario I (continuation).

CO2 emissions from Coal, Million tons of CO2 equivalent	49,5946	47,3450	53,6849	51,8443	51,5375	50,1059	51,1464	48,2410	45,3714
CO2 emissions from Oil, Million tons of CO2 equivalent	12,7842	12,2043	13,8386	13,3641	13,2850	12,9160	13,1842	12,4353	11,6956
CO2 emissions from Natural Gas, Million tons of CO2 equivalent	109,5790	104,6084	118,6164	114,5496	113,8717	110,7086	113,0075	106,5881	100,2478
CO2 emissions from Biomass, Million tons of CO2 equivalent	0,9740	0,9299	1,0544	1,0182	1,0122	0,9841	1,0045	0,9475	0,8911
Total CO2 emissions, Million tons of CO2 equivalent	172,9318	165,0875	187,1943	180,7762	179,7065	174,7146	178,3426	168,2119	158,2059

3. Scenario II: Energy efficiency improvements on the demand side

Results of the modelling of the residential heating environmental impact according to Scenario II that assumes a gradual reduction of the heat losses on the demand side and achievement 711.756 PJ losses reduction in 2030 due to renovation of outdated buildings, better insulation, introduction of traditional and smart metering are presented in table 15. The impact is divided either by years and fuel types.

The curve of the residential heating environmental impact according to Scenario II for the period 1990 – 2030 expressed in million tons of CO_2 equivalent is shown in figure 42.

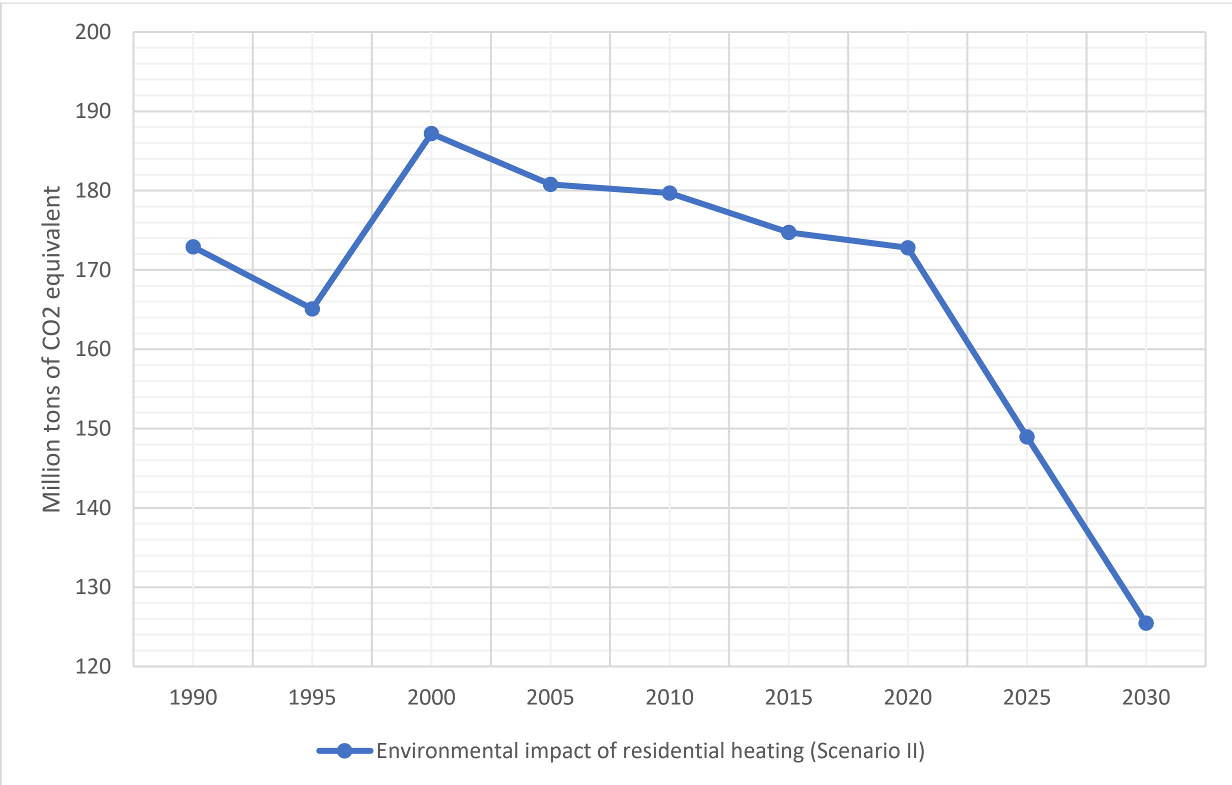

Figure 42. Curve of the residential heating environmental impact according to Scenario II for the period 1990 – 2030.

Table 15. Results of the environmental impact calculation according to Scenario II.

Environmental impact of residential heating (Scenario II)									
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Thermal energy production (Scenario II), PJ	2029,24	1937,192	2196,6	2121,288	2108,736	2050,16	2027,766	1747,937	1472,292
CO2 emissions from Coal, Million tons of CO2 equivalent	49,5946	47,3450	53,6849	51,8443	51,5375	50,1059	49,5586	42,7196	35,9828
CO2 emissions from Oil, Million tons of CO2 equivalent	12,7842	12,2043	13,8386	13,3641	13,2850	12,9160	12,7749	11,0120	9,2754
CO2 emissions from Natural Gas, Million tons of CO2 equivalent	109,5790	104,6084	118,6164	114,5496	113,8717	110,7086	109,4994	94,3886	79,5038
CO2 emissions from Biomass, Million tons of CO2 equivalent	0,9740	0,9299	1,0544	1,0182	1,0122	0,9841	0,9733	0,8390	0,7067
Total CO2 emissions, Million tons of CO2 equivalent	172,9318	165,0875	187,1943	180,7762	179,7065	174,7146	172,8062	148,9592	125,4687

4. Scenario III: Renewables utilization

Results of the modelling of the residential heating environmental impact according to Scenario III that assumes increase of the renewable energy sources share in the fuel mix of the thermal energy production development of conversion technologies and popularization of renewables with no improvements of energy efficiency neither on the demand side or in the heat distribution network are presented in table 16. The impact is divided either by years and fuel types. The forecasted fuel mix of the residential heat production according to Scenario III is 60% Natural gas, 25% Biomass, 8% Geothermal energy, 4% oil, 3% coal.

The curve of the residential heating environmental impact according to Scenario III for the period 1990 – 2030 expressed in million tons of CO_2 equivalent is shown in figure 43.

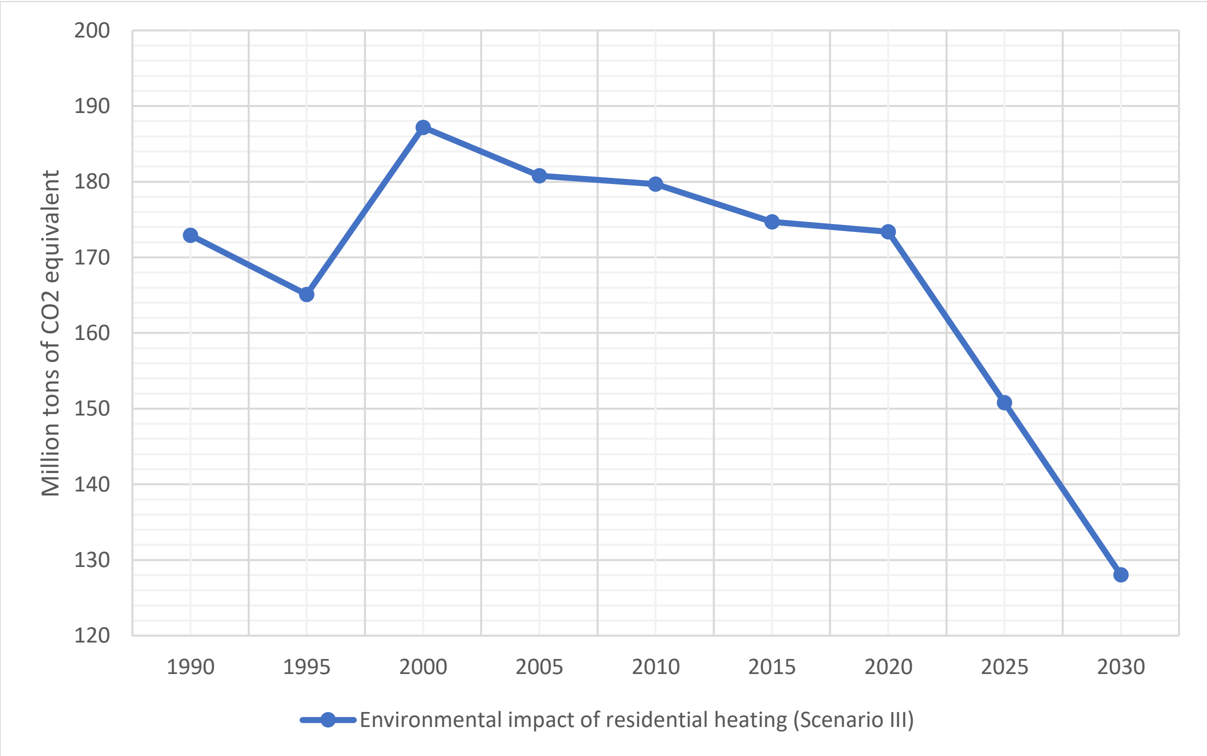

Figure 43. Curve of the residential heating environmental impact according to Scenario III for the period 1990 – 2030.

Table 16. Results of the environmental impact calculation according to Scenario III.

Environmental impact of residential heating (Scenario III)									
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
CO2 emissions from Coal, Million tons of CO2 equivalent	49,59	47,34	53,68	51,84	51,54	50,11	45,11	26,95	8,52
CO2 emissions from Oil, Million tons of CO2 equivalent	12,78	12,20	13,84	13,36	13,29	12,92	12,77	10,98	9,17
CO2 emissions from Natural Gas, Million tons of CO2 equivalent	109,58	104,61	118,62	114,55	113,87	110,71	112,69	105,45	98,28
CO2 emissions from Biomass, Million tons of CO2 equivalent	0,97	0,93	1,05	1,02	1,01	0,98	2,20	5,16	8,19
CO2 emissions from Geothermal energy, Million tons of CO2 equivalent	0,00	0,00	0,00	0,00	0,00	0,00	0,64	2,24	3,88
Total CO2 emissions, Million tons of CO2 equivalent	172,93	165,09	187,19	180,78	179,71	174,71	173,40	150,79	128,05

5. Scenario IV: Combined effect of all the improvements

Results of the modelling of the residential heating environmental impact according to Scenario IV that combines the effects of improvements assumed in Scenario I, Scenario II and Scenario III and means reduction of thermal energy losses on the demand side and in the heat distribution network due to increase in energy efficiency of the infrastructure together with higher shares of renewables in the total fuel mix for heating are presented in table 17.

The curve of the residential heating environmental impact according to Scenario IV for the period 1990 – 2030 expressed in million tons of CO_2 equivalent is shown in figure 44.

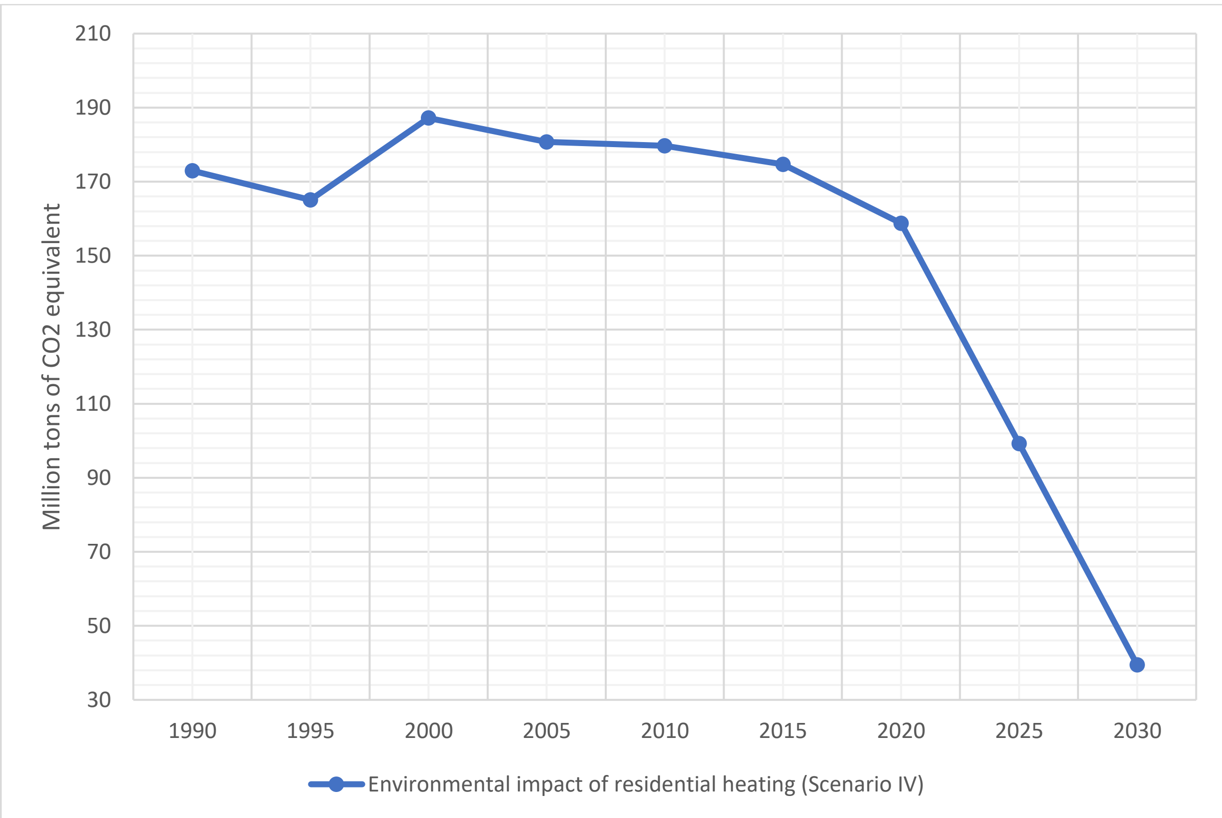

Figure 44. Curve of the residential heating environmental impact according to Scenario IV for the period 1990 – 2030.

Table 17. Results of the environmental impact calculation according to Scenario IV.

Environmental impact of residential heating (Scenario IV)									
Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Scenario I CO2 emissions reduction, Million tons of CO2 equivalent	0	0	0	0	0	0	4,57288816	16,1299047	27,9186856
Scenario II CO2 emissions reduction, Million tons of CO2 equivalent	0	0	0	0	0	0	10,1093077	35,382577	60,6558463
Scenario III CO2 emissions reduction, Million tons of CO2 equivalent	0	0	0	0	0	0	9,51283796	33,5545425	58,0783791
Scenario IV CO2 emissions reduction, Million tons of CO2 equivalent	0	0	0	0	0	0	24,1950338	85,0670242	146,652911
Baseline CO2 emissions, Million tons of CO2 equivalent	172,9318328	165,087502	187,194252	180,776163	179,706482	174,714635	182,915526	184,341768	186,124571
Scenario IV CO2 emissions, Million tons of CO2 equivalent	172,9318328	165,087502	187,194252	180,776163	179,706482	174,714635	158,720492	99,2747439	39,4716595

3.3 Conclusions of the scenario analysis

Analysis of the residential heating environmental impact reduction scenarios until 2030 caused by energy efficiency improvements on the demand side, in the heat distribution network and increased renewables utilization (biomass and geothermal), revealed the great potential of CO_2 emissions decrease in Russia. Table 18 summarizes the effects of the built scenarios (I-IV) compared to Baseline forecast.

The curves of the residential heating environmental impact of Baseline Scenario, Scenario I, Scenario II, Scenario III and Scenario IV for the period 1990 – 2030 expressed in million tons of CO_2 equivalent are presented in figure 45.

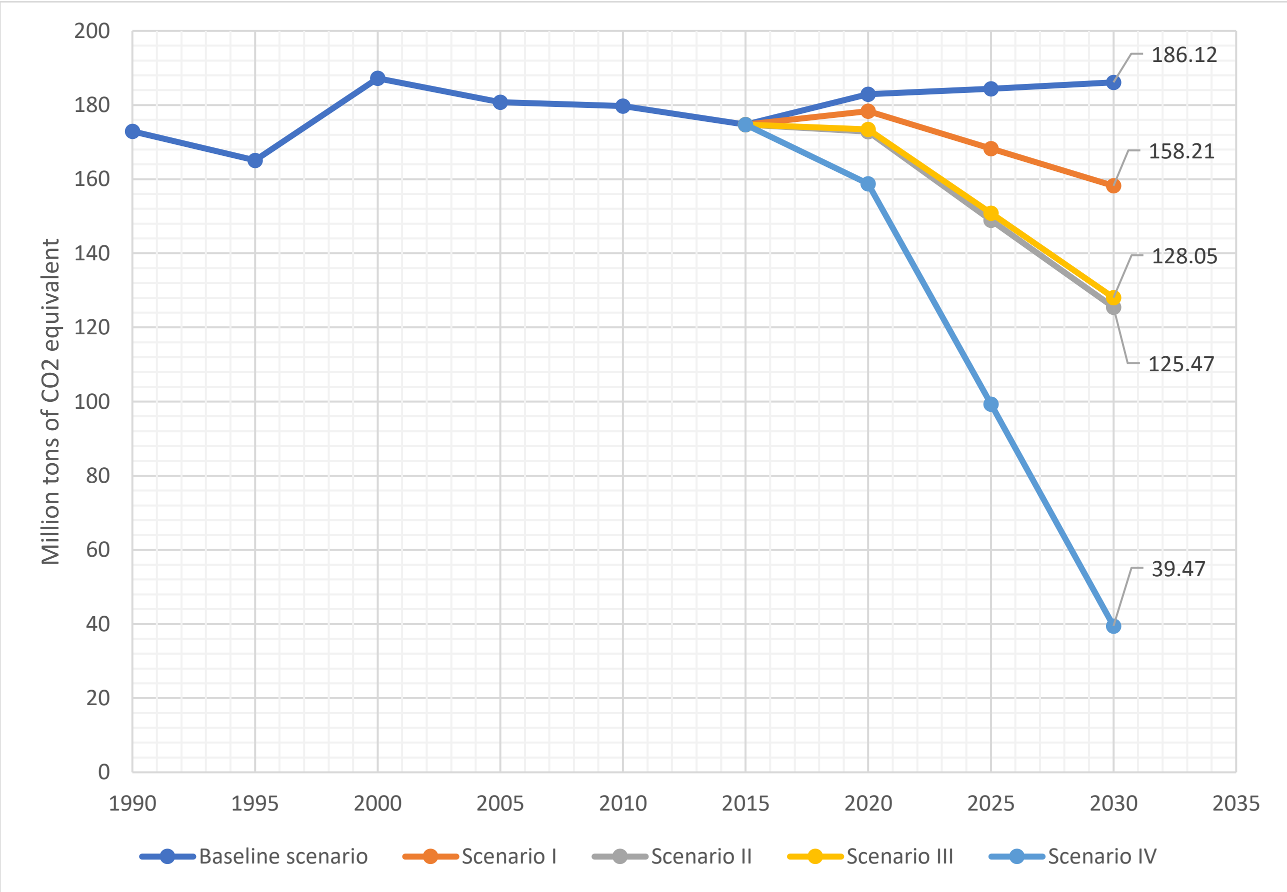

Figure 45. Curves of the residential heating environmental impact of Baseline Scenario, Scenario I, Scenario II, Scenario III and Scenario IV for the period 1990 – 2030.

Table 18. Environmental impact reduction for the developed scenarios compared to Baseline.

Year	**2020**	**2025**	**2030**	**In total 2020-2030**
Scenario I, Million tons of CO2 equivalent	4,57	16,13	27,92	48,62
Scenario I, %	2,5	8,75	15	-
Scenario II, Million tons of CO2 equivalent	10,11	35,38	60,66	106,15
Scenario II, %	5,53	19,19	32,59	-
Scenario III, Million tons of CO2 equivalent	9,51	33,55	58,08	101,15
Scenario III, %	5,20	18,20	31,20	-
Scenario IV, Million tons of CO2 equivalent	24,20	85,07	146,65	255,91
Scenario IV, %	13,23	46,15	78,79	-

According to the scenarios modeling, implementation of all the improvements related to the residential heating sector is able to decrease GHG emissions by 255.91 million tons of CO2 equivalent for the period until 2030. However, this is an ideal non-realistic scenario.

Unfortunately, the scenario IV is unlikely in practice due to short transition period and large investments needed.

Scenario II which assumes energy efficiency enhancing and losses reduction on the demand side and Scenario III which supposes increased utilization of biomass and geothermal energy sources shows similar GHG emissions reduction effects: 106.15 and 101.15 million tons of CO2 equivalent accordingly. Meantime, energy efficiency improvement on the demand side has already had legislative support in Russia (Federal Law №261 from 23.11.2009). Hence, Scenario II is assumed as the most probable option.

Probability of the Scenario I that assumes renovation of the outdated thermal energy distribution network is difficult to estimate because of unclearly perspectives of funding the renovation projects and lack of the available information about government’s incentives. Potential environmental effect of the Scenario I is GHG emissions reduction by 48.62 million tons of CO2 equivalent for the period until 2030.

However, the most likely future will be some sort of combination of the discussed scenarios but without it’s full potentials.

3.4 Economic benefits

Scenario II is chosen for the economic benefits assessment calculation as the most probable option. The aim of the assessment is to calculate how much money can be saved on residential heating bills in scale of the whole country due to energy efficiency improvements and losses reduction on the demand side.

The annual savings is calculated according to equation 10:

$$Savings_{year\ j} = Losses\ red._{year\ j} \cdot Heat\ tariff_{year\ j} \qquad (10)$$

, where $Savings_{year\ j}$ – savings on the residential heating bills in year j, rubles;
$Losses\ red._{year\ j}$ – losses reduction on the demand side in year j according to Scenario II (table 11), PJ;

$Heat\ tariff_{year\ j}$ – tariff on the residential heating in year j, rubles/kJ.

Forecast of heat tariffs growth for years 2020-2030 is calculated based on available data about heat tariffs in Central, North West, Volga and Siberian Federal Districts for the period from 2012 to 2019 (YouHouse, 2019).

The forecast of the average tariffs of residential heating development is presented in figure 46.

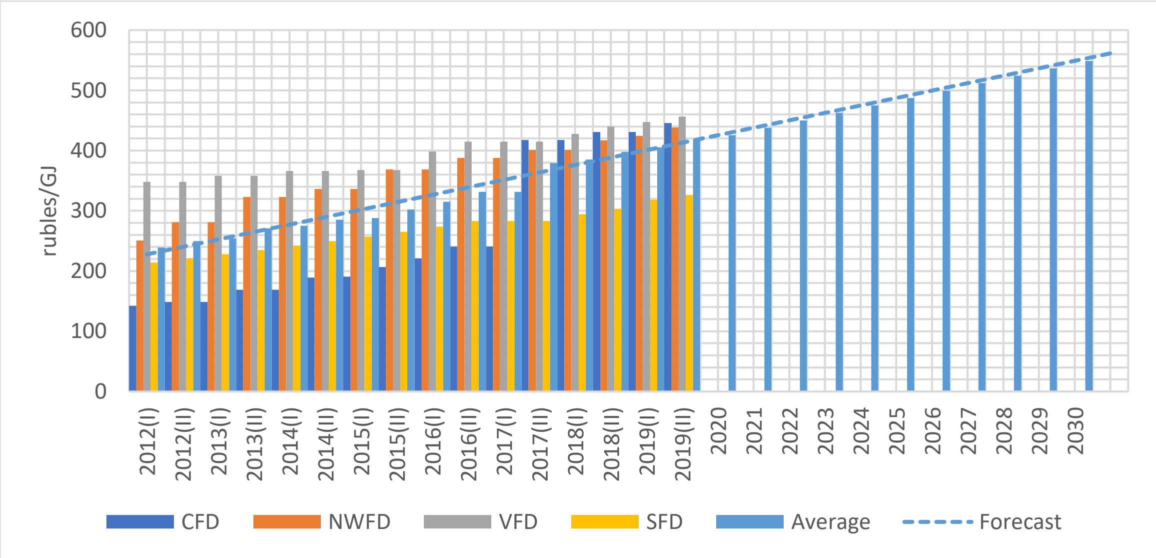

Figure 46. The forecast of the residential heating average tariffs until 2030.

According to the forecast, the annual growth rate of the residential heat tariff is 2.6%. Forecasted tariffs for the period 2020-2030 are shown in table 19.

Table 19. Forecasted heat tariffs 2020-2030.

Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Heat tariff, rubles/GJ	425.47	437.82	450.18	462.53	474.89	487.24
Year	**2026**	**2027**	**2028**	**2029**	**2030**	**Annual growth rate, %**
Heat tariff, rubles/GJ	499.60	511.95	524.31	536.66	549.02	2.6

Total annual savings on the heat bills as well as savings per residential building (both flat and detached house) are presented in table 20. The combined number of residential buildings (both flat and detached house) in Russia which are connected to a heating system is 45 508 504 (Ministry of Construction of Russia, 2019).

Table 20. Economic benefits due to energy efficiency enhancing on the demand side (Scenario II).

Year	Total savings, bln rubles	Saving per residential building (flat or detached house), rubles/year	Saving per residential building (flat or detached house), euros/year	Discounted saving per residential building (flat or detached house), euros/year
2020	50,47	1109	15,2	15,2
2021	77,91	1712	23,4	21,3
2022	106,80	2347	32,1	26,5
2023	137,17	3014	41,2	31,0
2024	169,00	3714	50,8	34,7
2025	202,30	4445	60,8	37,7
2026	237,06	5209	71,2	40,2
2027	273,29	6005	82,1	42,1
2028	310,98	6833	93,4	43,6
2029	350,14	7694	105,2	44,6
2030	390,76	8587	117,4	45,3
Total	2305,88	50669	692,6	382,0

Analysis of the economic benefits due to energy efficiency enhancement and losses reduction on the demand side shows that possible savings on heating of an average residential building in Russia reaches 692.6 euros for ten years (2020 – 2030).

The discounted savings were calculated according to equation 11:

$$DCF = \sum_{I=1}^{n} \frac{CF_i}{(1+r)^i} \quad (11)$$

, where CF_i– cash flow (savings) in year j, euros;

r – discount rate (10%);

4 SUMMARY AND CONCLUSIONS

Energy overconsumption in Russian residential sector, first of all, refers to inefficient heating. Despite the fact that centralized district heating approach that is widespread in Russia might be very efficient in theory, there are many problems which cause heat losses in reality. The situation leads to higher demand of fossil primary energy sources which are dominant in the Russian district heating fuel mix and, as a consequence, large CO_2 emissions and the climate change.

High thermal energy demand cannot be explained only by cold climate of Russia. The analysis of the residential heating structure revealed points of weaknesses along the chain of current heating system in Russia on thermal energy supply, distribution and demand sides. To assess the possibilities of energy efficiency improvements in the chain and CO_2 emissions reduction, required technological and policy measures were proposed.

Despite the fact that the supply side of the residential heating system is characterized by high share of CHP plants, poor management and bad maintenance do not allow to reach adequate efficiency level which is currently well below international averages. Unclarity of the residential heating tariffs regulations causes lack of investments into renovation of outdated CHP plants with high wear rate. The amendments to the Federal Law №190-FZ "On Heat Supply", adopted in July 2017, open the way for systemic changes. It sets equal principles for the calculation of prices for thermal energy appear for all, thus preconditions are created for the inflow of investments into the segment and subsequent modernization. However, the outcome of the new legislation is difficult to estimate at this moment due to the fact that too little time has passed since its adoption. Besides renovation measures, better redistribution of the load of heat sources will benefit the overall efficiency of CHP. Current underuse of generating equipment is a major problem of low energy efficiency as well as high degree of equipment wear.

The reduction of CO_2 emissions from the residential heating can be also achieved by modification of the fuel mix. Shifting to utilization of renewable energy sources, such as biomass and geothermal energy which are vastly available in some regions of Russia, instead of fossil fuels can become a key to decarbonizing of Russian heating sector. This solution is the most relevant in isolated regions of Siberia and Far East where the heating systems are based on coal. The conducted scenario analysis revealed that it is possible to reduce GHG emissions level by 101.15 million tons of CO_2 equivalent for the period 2020-2030 compared to Baseline scenario in case of annual reduction rates for coal, oil and natural gas are 1.32%, 0.17% and 1 % respectively and annual growth rates for biomass and geothermal energy are 1.82% and 0.67% during the forecast period.

Deterioration of the vast thermal energy distribution network is another key reason of low energy efficiency in the sector. According to the estimations, upgrading of 10-12% of the network is needed annually to keep the system in an adequate condition. However, only 1% of the network is renovated per year because of the lack of investments. As a result, heat losses along distribution network in Russia are several times bigger than European averages and reaches up to 25%. In the scenario analysis it was assumed that renovation of the thermal energy transmission network with use of modern insulation techniques can curb the losses to 10% by 2030 resulting reduction of GHG emissions level by 48.62 million tons of CO_2 equivalent for the period 2020-2030 compared to Baseline scenario.

The demand side shows the greatest potential for CO_2 emissions thanks to not only the energy efficiency improvements (renovation of outdated buildings, better insulation, etc.) but also because of changes in residents energy consumption behavior through introduction of smart metering systems and better awareness of the people. Conducted survey revealed willingness of the people to shift to more sustainable energy consumption in their homes. The smart metering technologies needed for the change are already available on the Russian market and are going to become more popular due to essential money savings on energy bills from its implementation. The scenario analysis showed that it is possible to reduce GHG emissions due to discussed measures on the demand side by 106.15 million tons of CO_2 equivalent for the period 2020-2030 compared to Baseline scenario. In addition, the possible savings on heating bills were estimated. According to the calculations based on the current heat tariffs with assumed annual growth rate of 2.6%, for an average residential building it is possible to save 692.6 euros for ten years (2020-2030) on heating bills thanks to the improvements on the demand side.

The combination of the mentioned above energy efficiency improvements on the supply, distribution and demand sides will cause the total reduction of GHG emissions for assessed period by 255.91 million tons of CO_2 equivalent which is less than a quarter of the current GHG emissions level. Moreover, the mitigation of the residential heating environmental impact might benefit to other sectors of Russian economy via better air quality in cities, preservation of biodiversity in fragile Arctic regions, new work places in growing energy efficiency business, etc. The indirect benefits of the effects discussed in the paper are the purpose of further researches in the field.

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APPENDICES

APPENDIX 1. Resource potential of biomass production from MSW by regions of Russia, thous. toe

APPENDIX 2. Resource Potential of biomass from the waste of the agro-industrial complex by regions of Russia, thous. toe

APPENDIX 3. Resource Potential of geothermal energy by regions of Russia.