Regional differentiation of energy consumption in urban households

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Abstract. The paper considers a very important problem for modern world - the energy consumption and energy saving. Nowadays households consume more than a quarter of global energy consumption (29%), which means that this sector has great savings potential. However, this potential for savings can only benefit upon development of proper structural policy measures and laws and implementation of appropriate energy-saving measures. This requires information on the future trends of energy demand and on the factors influencing this demand and the actual energy consumption. The main challenge for researchers presents the fact that energy consumption in the regional aspect is extremely uneven, structurally heterogeneous, which assumes the different measures for the energy saving in each region of the country. Besides, we were unable to find publications describe the contribution of various factors to the dynamics of the energy consumption of the regional economy at the municipal level. Hence, the paper analyzes stream-lined trends in the energy consumption in households of Germany which is one of the world leaders in these issues. So the paper highlights some factors as well as some trends affecting the energy consumption in households in the Perm region.

1. Introduction

1.1. Problem setting

In the modern world in terms of the energy consumption (excluding the coronavirus pandemic), there is a noticeable trend of an increase in domestic energy consumption in accordance with an increase in the population, an increase in its income and requirements for comfort; however, measures taken to improve the quality of new houses being built, energy savings, and the emergence of new, more efficient appliances lead to a decrease in the energy consumption per household [1]. Increasing the energy efficiency both at enterprises and households is characterized by legislative, regulatory, scientific, technical, technological, professional, organizational, marketing, investment, and other characteristics that are due to factors that act under conditions of uncertain and incomplete data [2].

The Russian Federation is also interested in reducing energy consumption in households, so the state takes measures to implement the energy saving policies. Particularly in 2009, there was adopted the federal law "On energy saving and on increasing energy efficiency and on amendments
to certain legislative acts of the Russian Federation". It (Art. 2 FZ-261) realizes the energy saving as “the implementation of organizational, legal, technical, technological, economic and other measures aimed to reduce the volume of energy resources used while maintaining the corresponding beneficial effect from their use (including the volume of manufactured products, works performed, services rendered)”. In accordance with part 14.2 of article 6 of Federal Law-261, they prepare annually a state report on the state of energy saving and energy efficiency in the Russian Federation [3]. However, according to Part 5 of Art. 11 FZ-261, state requirements for energy efficiency do not apply to religious buildings and facilities; on buildings, facilities, structures that are classified as objects of cultural heritage (monuments of history and culture) in accordance with the legislation of the Russian Federation; on objects of individual housing construction, garden houses, etc. Nevertheless, the indirect impact of the state on energy consumption by households occurs through the implementation of “measures to save energy and to increase the energy efficiency in relation to the common property of flat owners in an apartment building, bans or restrictions on production and turnover in the Russian Federation of the goods with a low energy efficiency, if the goods that are similar in terms of use and have high energy efficiency, are used in quantities that meet the demand of consumers” (Article 11 FZ-261) and some other measures.

Although the state poses a problem of reducing the energy intensity of GDP, over the past ten years, the energy intensity of the Russian Federation’s GDP has decreased by only 9%, and over the past four years, the energy intensity of GDP has not decreased [3]. At the same time, energy consumption in the territorial aspect is extremely uneven, structurally heterogeneous, which does not allow the use of the same type of recipes for the energy saving in all the regions of the country [4].

1.2. The subject field description

Energy consumption in households is a part of the entire energy consumption. At present, a household energy consumption includes several important elements: the power demand, heat energy (wood, coal, fuel oil, gas and other sources can be used as energy sources), hot water, cold water. In turn, electrical energy is spent on lighting, cooking, heating the room, ensuring the operation of household appliances, including television sets, computers, chargers and much more. However, the energy consumption in households varies considerably both across countries and across regions within countries, and even intra-regional differentiation of the energy consumption is large. The analysis shows that “the long-term trends in the energy consumption in households in Russia generally correspond to global trends. The low per capita energy consumption in the sector indicates the incomplete process of the housing electrification” [1].

The Ministry of Economic Development of Russia believes that “the technological factor is a key potential driver in reducing the energy intensity of the GDP of the Russian Federation in the most energy-intensive sectors of the economy: power engineering, manufacturing, transport and housing and communal services” [3]. According to K. Karpov, “the basic factors influencing the volume of the energy consumption are as follows: the level of the economic development, the technological structure, the dynamics of households’ income and consumption in whole – everything that is commonly called economic well-being and is measured by the gross domestic product (GDP)" [4].

It has already been repeatedly noted that “... there is not being studied the contribution of various factors to the dynamics of the energy consumption of the regional economy at the municipal level” [6].

For research purposes, we studied the situation with energy consumption in Perm region as well in Salzland region [7], especially the public utilities Schönebeck, Aschersleben, Staßfurt and

1 [http://www.consultant.ru] - Official site of the reference legal system "Consultant Plus" of Russian Federation
Bernburg as well as Erdgas Mittelachsen GmbH (EMS), the State Statistical Office of Saxony-Anhalt, MitNetz Gas and MitNetz Strom and also various sources on the Internet or, for example, the city of Nienburg were requested and used. A period of approx. 2008-2018 was relevant for the research.

2. Related Work

2.1. Theoretical source

The need for a differentiated approach to the analysis of energy consumption, including electricity, has already been raised in the academic literature. Using the example of the Vladimir region, T. D. Belova recorded a significant scatter of the energy efficiency indicators both at the level of the Russian Federation and at the municipal level [8]. L. Yu. Bogachkova et al. developed a method for the formation of a rating of regional municipalities in terms of the energy efficiency in housing and community amenities and the state-financed organizations and applied it on the example of the Volgograd region [9]. These authors carried out a decomposition analysis of the increase in the energy consumption in the Russian regions according to the main factors: economic activity (gross regional product growth (GRP)), structural and technological factors [6]. A group of authors led by L. Yu. Bogachkova proposed a method for cluster analysis of municipalities based on the analysis of gross municipal product [10]. N. I. Danilov and S. R. Bikbulatov described a method for studying the energy efficiency of municipalities in the Sverdlovsk region [11]. O. S. Chernyavsky et al. proposed a method for a rating assessment of the energy efficiency and the ways of the energy saving of buildings, structures, facilities for a set of objects united by an organizational principle [12].

A. I. Khisamova’s and E. A. Tretyakova’s correlation analysis showed (using the example of the Perm Region in 2000-2008) that they observed a strong connection in the equation of the relationship between the energy consumption and the volume of investment in fixed assets (the coefficient of determination is 0.9171), between the energy consumption and the GRP, retail trade turnover, average per capita income of the population (the coefficients of determination exceed 0.8) [13].

The Russian literature describes conflicting trends in the energy consumption in Germany. On the one hand, since 2002, there has been a decrease in energy consumption for heating and preparation of hot water in the private sector, on the other hand, there is a constant increase in the energy consumption due to the spread of information technologies and communications in everyday life [14, 15]. The German literature explains this fact according to the limitation of the annual heating requirement for new buildings due to the requirements of the Thermal Insulation Ordinance and Energy Saving Ordinance [16, 17]. But after 2010, there was a new increase of power demand for hot water while there is a trend to decrease of power demand by electrical devices after 2007 (see Figure 1). Moreover, the rapid increase of power demand for cooking is to observe since 2007. Another reason to this trend is given in a study by the Federal Environment Agency [16] which indicates that the reduction in power demand for heating could also be due to an overall downward trend for the annual day temperature.

In 2013 the household sector in Germany accounted for 28% of total final energy consumption. In 1990-2013, the average energy consumption in the housing sector was more than 721 TWh/a, with fossil fuels mainly being used to provide with energy, primarily for heating. In the German household sector, heating has the largest share of total energy consumption: for example, in 2013 it made 499 TWh/a, which corresponds to around 69% of the total energy consumption in the German household sector (compared to 81% in 1990). In addition to the above-mentioned building insulation, an important factor in reducing the total energy consumption in this sector is, above all, improving the degree of utilization of systems and devices. According to the Institute
for Energy Economics and the Rational Use of Energy, the power demand needs would decrease by 10% by 2030 compared to 2007 \[17\].

Figure 2 shows the net energy consumption of private households by the area of application. Figure 2 demonstrates the evident reduction in the energy consumption in private households due to the tremendous power demand decrease for heating.

Viewed across Germany, energy consumption in households ranks third in energy consumption in 2017 after gas and heating oil - this trend has been falling since 2010. It should be noted that in the energy concept from 2010, the federal government set itself the goal of reducing energy consumption by 10% by 2020 compared to 2008 \[19\]. The aim of the federal government with regard to energy policy is largely greenhouse-neutral and pollution-free energy generation. In this context, the electrical energy generated in the first half of 2020 shows a downward trend with 248.2 billion kW/h. However, the electrical energy that is generated from renewable sources, with 128.4 billion kW/h, has a significantly increasing share of 51.8%.

In order to reduce increasing energy consumption and thus carbon dioxide emissions, the federal government has set up various funding programs as part of investment and energy saving\[3\]. Energy efficiency and process heat from renewable energies in the economy\[4\]. But the state also offers attractive subsidy programs for private homeowners to reduce energy consumption or even make significant savings. There are grants and subsidies, for example, for better insulation of the house or for a new heating. Energy savers can also count on the financial support from municipalities and local energy providers.

Nevertheless, most German studies only provide averaged data and it is difficult to find out

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\[3\] www.deutschland-machtseffizient.de/KAENEF/Navigation/DE/Unternehmen/Anlagentechnik/anlagentechnik.html
\[4\] www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/Tilgungszuschuss-Strom
the regional differentiation of energy consumption. However, their criteria could be taken into consideration while investigating the situation in Perm region.

2.2. The study sources

The study sources were both the data from the Federal State Statistics Service (hereinafter Rosstat) including the results of the Comprehensive Survey of the Living Conditions of the Population in 2018 [20] and the data from the official statistics of Rosstat [20], as well as data provided by Perm Region State Statistics Service (hereinafter Permstat) including the "Basic Indicators of the Socio-Economic Situation municipalities" and the data posted in the "Database of indicators of municipalities" including tabular data "Specific value of energy consumption in apartment buildings per resident, kWh, indicator value per year", "Characteristics of the living conditions of households for 10- percentage decile groups of the population by the level of per capita money income (Perm Region)", "Provision of households with basic and additional sources of heating by 10 percent decile groups of the population by the level of per capita money income (Perm Region)". "Provision of households with basic and additional sources of heating by 10 percent decile groups of the population by the level of per capita money income (Perm Region)". "Provision of households with communication means and television by demographic and social groups of households (Perm Region)". "Financial situation of households in the Perm Region by 10% decile population groups in terms of per capita income", "Urban and rural population of the Perm Region", "Power supply and the interruptions in its submission by the type of the settlement (Perm Region)", "The volume of investments in fixed assets (excluding budget funds) per person per year, (Perm Region, in rubles)", "Population of private and collective households, homeless households (Perm Region)", "Average monthly wages of employees of organizations (excluding small businesses) (Perm Region), in rubles ", as well as the data from the annual report on the implementation and evaluation of the effectiveness of the Perm Region state program "Development of the Information Society" in 2019 [21].
3. Approach

Methodologically Rosstat explains a household as “a population of persons living in the same dwelling or part of it, both connected and not related by kinship relations, jointly providing themselves with everything necessary for life, fully or partially combining and spending their funds. A household can consist of one person living independently” [20]. The statistics also takes into account collective households (barracks, nursing homes, monasteries etc.) and households of the homeless.

An analysis of statistical data provided by Permstat shows that the level of the energy consumption in the Perm Region between different municipalities differs by more than three times [3]. The same situation exists in Russia as a whole: the specific consumption of heat and power by households in regions with similar climatic conditions differs by up to three times (we have to point out that within this article, we do not consider the issue of the reliability of the data presented for individual municipalities).

There are many factors affecting the household energy consumption. It is extremely difficult to reduce them to a basic one that would determine the trends and dynamics of the energy consumption. Among the most important factors, we highlight the following:

- **The geographic location of households (northern areas, where colder conditions lead to an increase in energy consumption) and climatic conditions of the area.**: It is obvious that energy consumption in the northern regions may be higher than in the southern regions of the region. And if we take into account that there are quite significant differences in climatic conditions in the Perm Region, then differences in energy consumption can be a significant factor. Thus, the average January temperature in the northeast of the region is -18.5 °C, and in the southwest -15 °C; and the average July temperature in the north-east of the region is + 15 °C, and in the south-west - + 18.5 °C [21]. This factor influences the power consumed for heating.

- **The balance of energy consumption in households**: In modern conditions, central heating has become the main supplier of heat to households: in urban areas, the provision of central heating has reached 88%, in rural areas – 14.5%. Among the households provided with central heating, additional heat sources were used, including boilers, convectors, radiators, heat fans, underfloor heating systems, and other electrical equipment on average in urban areas 23.9% of households, in rural areas – 5.7%. When considering heat supply by decile groups of households, it can be seen that households that indicated that their dwellings are equipped with central heating and use additional heat sources (usually based on energy consumption), in decile groups from the first to sixth, the share is from 13.2% up to 22.2% In decile groups from 7 to 10, the share of such households is consistently above 20%. Research carried out in the region shows that the average amount of electricity (in kWh) consumed per month by households is 161.07 kW/h per capita, including among those using network gas – 147.58 kW/h per capita, among those who do not use network gas – 218.85 kW/h per capita, while in urban areas these indicators are equal to 133.03 and 214.46, respectively; in rural areas – differences in the strategies of energy consumption in the countryside and in the city, depending on the structure of energy sources. Even greater differences in energy consumption exist in households living in apartment buildings: in urban areas these indicators are 123.33 and 248.46, respectively; in rural areas – 245.28 and 221.32.

- **The ratio of the cost of energy resources, incl. electricity, and the level of household income (average wages of the population)**: As specialists noted, “today it is quite obvious that there is a discrepancy between the high cost of energy and fuel provided to households and the relatively low level of per capita income of the majority of the country’s population. As a result, a steady gap has formed between their purchasing power and the
level of prices for services that are necessary for the break-even operation of enterprises serving households" [22]. For the Perm Region (as well as for the Russian Federation as a whole), the increase in electricity tariffs has become constant. For the period 2015-2019 (as of January 1 of the corresponding year) electricity tariffs increased (one-rate tariff for the population, except for rural and some other categories) 1.3 times, the day zone – 1.3 times, the night zone – 1.31 times. For the villagers, the day zone - 1.33 times, the night zone – 1.34 times. At the same time, it is necessary to take into account one more factor – the level of household income, or, based on the professional structure of household members, their average monthly wages. Calculations show that the average monthly wages of employees of organizations (excluding small businesses) for 2015-2019 increased by 1.37 times in the whole region, including in agriculture, hunting, fishing and fish farming – by 1.42 times, in the manufacturing industry – 1.4 times. At the same time, it is necessary to take into account the significant territorial inequality in the level of remuneration: the differences in the average monthly salary of employees of organizations in the field of agriculture, hunting, fishing and fish farming were 3.19 times between municipalities in 2015, and 3.42 times in 2019. In the manufacturing industry, the average monthly salary of manufacturing workers varied geographically in 2015 by 4.27 times, in 2019 - 6.63 times. The situation was similar in other industries. If we introduce a conventional unit “the amount of electricity (in kW/h) that can be bought for the average salary of workers in the industry”, then we will see significant differences. Thus, agricultural workers could spend 7,530 kW/h per capita per month in 2015, 7,783 kW/h per capita in 2019 (calculated at the price tariff for rural areas), and manufacturing workers - 10,101 and 10,952 kW/h per capita, respectively (calculated at city one-way rate).

• Sociodemographic composition of households: It is obvious that the composition of households (quantitative, age, gender, professional, etc.) significantly affects the amount of energy consumption. Thus, it is common for a modern student to receive a significant part of information from the Internet, increasing energy consumption due to the use of computers, laptops and other electronic devices. In the context of the coronavirus pandemic, Internet costs and energy consumption have increased even more. The transition to retirement of one or both spouses (reduction of the income part of the household, change in the daily regime, etc.) significantly affects the amount of energy consumption. So, if the average energy consumption per month per household was 161.07 kW/h per capita, then for households consisting only of pensioners, it was 126.32 kW/h per capita, while in households using network gas this indicator reached only 113. 72 kW/h per capita, and not using network gas - 190.62 kW/h per capita. In households consisting only of people with disabilities, the situation is even more tense: the average monthly energy consumption was 77.82 kW/h, incl. among households that used network gas - 75.23 kW/h per capita, those that did not use network gas - 107.35. On the other hand, in single-parent families, similar indicators are above the average - 177.05, respectively; 157.45 and 225.63 kW/h per capita. Naturally, the number of variations in the composition of households can be large, but the examples given are quite enough to show significant differences in energy consumption. This factor influences the power consumed for all five areas.

• The nature of consumption of household members: as a factor affecting energy consumption is made up of many components. It includes the total income of household members, the level of prices for food and basic necessities, status consumption for a given social stratum and settlement, the ratio of expenditures on energy consumption, etc. As part of the Comprehensive Survey of the Living Conditions of the Population, conducted in 2018, it was revealed that the proportion of households that have the ability to pay for vital (essential) drugs in urban areas was 89.9%, in rural areas - 82.3%. At the same time, 51.4% of households in urban settlements and 51.0% in rural settlements could cope with
unexpected expenses (expenses for urgent housing repairs or replacement of durable goods, urgent medical services, etc.). 19.5% households in urban areas and 21.8% in rural areas paying for housing and communal services indicated that in 2018, due to a lack of funds, they had arrears on these payments. If we consider the financial situation of households by 10% decile population groups in terms of the level of per capita money income, we will see a clearer picture: in the first decile group with the lowest incomes, 48.5 households had arrears on these payments at least once in 2018; in the second decile group - 30.9%, in the third - 31.6%; in the fourth - 28%; in the fifth - 15.6%, and so on downward. Similarly, we can consider the provision of communications and television, which are one of the most important groups of devices for energy consumption. If the level of provision with color televisions for almost all social groups is at the level of 96-98%, including for the first decile group in terms of average per capita monetary income, then, for example, a home stationary computer and/or laptop in the first decile group was only in 46% of households (with 65.5% on average for the survey), 36.4% in households consisting only of pensioners, 17.2% - in households consisting only of disabled people. The level of income in households indirectly affects energy consumption in another way. According to statistics, practically for all decile groups of the population in terms of average per capita money income, the presence of a working refrigerator, washing machine has become the norm. However, the maintenance of these and other electrical appliances and devices is not always possible due to lack of funds. So, if necessary, they do not apply for paid services for the repair of household appliances (at all or for a long time) due to the lack of funds from the first to the sixth decile group in terms of the level of per capita monetary income, respectively 28.3%; 10.2%; 4.5%; 12.7%; 23.1% of households. Lack of funds is one of the conditions that restrain the use of power-consuming devices, as well as energy consumption in general. This factor also influences the power consumed for all five areas.

- **Daily rhythms of life of household members** is also an important factor influencing the energy consumption in households. Such elements of their life activity as work in different shifts, "night life", the presence of additional work performed at home, the presence of students who work until late at night and other circumstances affect the change in the structure of energy consumption. This factor mostly influences the power consumed for lightning.

- **The provision of comfortable housing** also affects energy consumption, which is associated with a number of circumstances: as the total living space per household or one member of the household increases, the number of lighting devices, household appliances that are required to serve a larger area (vacuum cleaners, a second TV or refrigerator, etc.). When analyzing the size of the total area per household member for 10 percent decile groups of the population by the level of per capita money income, a quite expected picture emerges: if in the first decile group the total area per household member is 14.3 sq. M, then in the fifth - already 23.5 sq. M, in the tenth - 32.2 sq. M. Each of these factors can influence both an increase and a decrease in energy consumption, and it is hardly appropriate to characterize each trend as “positive”, “progressive” or “negative”, etc.: much depends on the context of the socioeconomic and cultural situation in a country and region and can signal a variety of trends in society and economy. Assessing the impact on energy consumption of various factors and their consequences is a matter of interpreting the results: there is a certain corridor of average energy consumption values for a given area and a given period, within which we can determine the critical minimum of energy consumption required to meet the most important necessary needs of households, and the "average" maximum, which determines the satisfaction of the most reasonable needs of the inhabitants of a given area.

Now let’s look at the dynamics of energy consumption (calculations are given for households living in apartment buildings) by quartile for the period 2015-2019. In this case, all municipalities
were divided into quartiles according to the level of the energy consumption per person living in apartment buildings per year. With all the limitations of this indicator, it allows to judge the general trends in the energy consumption in the most urbanized part of the region. The quartile ranges are as follows (in kWh per person per year, on average for the municipality): in 2015: 1 quartile - (298 - 600), 2 quartile - (600-710), 3 quartile - (720-860), 4 quartile - (876-1622); for 2019, respectively, 1 - (274-605), 2 - (605-749), 3- (755 - 876), 4 - (876 - 1982). Note that for all quartiles there was an almost uniform increase in the level of the energy consumption (respectively, from the first to the fourth - by 105.5; 105.6; 106.1; 107.3%. At the same time, the difference in the absolute average values of the energy consumption is clearly visible: in the first quartile, the increase was only by 27 kW/h, in the second - by 36 kW/h, in the third - by 46, in the fourth - by 85 kW/h.

Behind these average values, there is a high internal dynamics: a certain part of municipalities have quite dramatically changed their status in terms of being in quartiles. Thus, at least 6 municipalities moved up two quartiles (from the first to the third, from the second to the fourth, from the first to the fourth). On the other hand, 5 municipalities moved down two quartiles (from the second to the fourth, from the third to the first). Moreover, the change in the position of the municipality in the energy consumption quartiles was accompanied by an absolute decrease in the energy consumption, sometimes by 2-3 times. So, in the Sivinsky municipal district in 2015, the energy consumption by households in apartment buildings was 762 kW/h, in 2019 - only 274 kW/h.

The analysis of energy consumption in the municipalities of the region shows that there is some dependence of the energy consumption on the factors of the economic development. So, if the average energy consumption in the sample was 806 kW/h per capita, then in municipalities that have agreements with LUKOIL (LUKOIL has been operating in the Perm Region since 1991. The company has signed cooperation agreements in 2020 with 25 municipalities of the Perm Region in which it operates. Such agreements have been signed annually for many years) - 837 kW/h per capita, in municipalities where the largest electricity consumers are located - 864 kW/h per capita, in urban districts - 963 kW/hour per capita (for rural municipalities in which according to statistical data, there is no urban population - 685 kW/hour per capita).

Preliminary analysis also shows that it is extremely difficult to identify clear-cut correlations between the development indicators that seem obvious as a factor in the growth of the energy consumption. So, according to our data, the Pearson correlation coefficient between indicators such as the growth rate of energy consumption in apartment buildings per person in 2015-2019 and the growth rate of the volume of investments in fixed assets (excluding budget funds) per 1 person in municipalities for the same period does not show any stable dependence (0.06), at the same time in the fourth quartile in terms of the level of energy consumption it shows a fairly stable relationship (0.76) between the growth of investments in fixed assets and the growth of energy consumption.

4. Conclusion
Thus, fairly stable trends in energy consumption in municipalities can be identified only taking into account the socio-economic situation and the historical basis of their development. The presence of such factors as a developed production with a high energy consumption, a high level of the territory urbanization, a high level of income, a structure of energy consumption, the socio-demographic composition of households, etc. significantly affect the energy consumption. This requires an analysis of energy consumption for each municipality in order to formulate the energy saving strategies, on the one hand, and on the other hand, the elaboration of common approaches to the energy supply development for individual clusters and groups of municipalities depending on the dominant factors affecting the energy consumption. The future work may deal with the practical improvement of the situation in the energy saving field while taking into
account the proposed factors that affect the energy consumption.

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