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International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2021, 11(2), 413-419.

Does Digitalization Reduce Electricity Consumption? Evidence from Spatial Analysis

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Received: 22 August 2020 **Accepted:** 10 December 2020 **DOI:** https://doi.org/10.32479/ijeep.10500

ABSTRACT

This survey addresses the issue of assessing and identifying the role of digital transformation in electrical energy consumption. It is shown that spatial effects in the level of electricity consumption among Russian regions are significant. The work is based on regional data for 2010-2018. Research methods: construction of the Moran and Geary indices, estimation of spatial regression panel models with fixed effects. The Implementation of digital technologies in Russia is at the initial stage, so their impact on energy consumption is ambiguous. The model with a spatial autoregressive lag revealed that the change (increase or decrease) of the electricity consumption level in the one region entails a change of energy consumption in other regions. Since the results indicate the importance of the spatial factor in electricity consumption, the government can implement a differentiated regional policy aimed at improving the efficiency of energy use in certain regions.

Keywords: Spatial Panel Data Models, Electricity Consumption, Digital Transformation, Energy Saving, Russian Regions
JEL Classifications: O1, Q4, R1

1. INTRODUCTION

Energy saving in Russia is a potential source of improving the population quality of life and protecting the environment from harmful emissions. Energy intensity of GDP in Russia exceeds world level by 46% [IEA]. Taking into account the significant territory of Russia and the differentiation of its regions by the level of economic development, we can assume that there are spatial effects in energy consumption. These differences must be considered in the development and implementation of state policy in this area.

In Russia, relatively recently, energy efficiency and energy saving have been proclaimed as one of the program goals at the state level. In 2009, Federal Law No. 261-ФЗ "On Energy Saving and Improving Energy Efficiency and Amending Certain Legislative Acts of the Russian Federation" was adopted. In the next year, 2010, the Ministry of Energy developed the state program "Energy Saving and Energy Efficiency Improvement for the Period until 2020". The main goal identified in the Program is to reduce energy costs per unit of GDP by 40%. To achieve the goal, it was supposed to improve the culture of energy consumption.

However, according to the annual report of the Ministry of Economic Development of the Russian Federation "over the past 10 years, the energy intensity of the GDP of the Russian Federation has decreased by only 9%, over the past 4 years, the energy intensity of GDP has not decreased. The goal of reducing the energy intensity of GDP of the Russian Federation by 60% while maintaining the current pace will be achieved only in 2043 with a significant lag behind the plan " (Ministry of Economic Development of the Russian Federation, 2019).

By 2020, the maximum reduction in energy consumption can reach 195 million tons of standard fuel, which is 20% of energy consumption compared to the level of 2012. Electricity and the housing sector have the greatest potential for energy saving, followed by the public sector and the services, hydrocarbons and manufacturing sectors. Russia and the CIS countries as a whole are characterized by a stable excess of energy intensity compared to the global average. Halperova's work shows that "energy efficiency for heating in residential buildings in Russia is lower than in the USA by 24%, and by 29-35% than in Canada, Slovakia, Latvia, Finland, Holland and Sweden" (Galperova, 2019). The main reason for such dynamics is inadequate energy consumption with insufficient attention to the problem of energy efficiency. In addition, the energy intensity of Russia exceeds the world average intensity by 2.19 times and by 3.08 times exceeds the comparable indicator for the countries of the European Union (Matraeva et al., 2019).

The serious lag of Russia from the world level in energy saving and energy efficiency is associated with a weak degree of technical equipment of the households residential sector with metering devices. The installation of collective metering devices was supposed to be completed in 2012, however, at present, only 61% of apartment buildings have installed collective metering devices. Moreover, more than half of all apartment buildings existing in the country (54%) consume twice as much energy as their modern counterparts. So, the level of introduction of modern technologies in the field of energy conservation is very low.

The influence of digital technologies on electricity consumption can be justified on the basis of a microeconomic approach, when the introduction of technologies and innovations is accompanied by an increase in production capabilities. However, at the initial stage of the application of innovation, there is an increase in fixed costs associated with the restructuring of the production process under the new technological standard. For example, the use of collective and individual metering devices allows you to save on electricity costs, however, the payback takes 7-8 months, which is dictated by the cost of the meter itself, its installation and maintenance. The spread of the Internet does not have a direct effect on electricity consumption. At the same time, access to a worldwide network for both households and enterprises involves the purchase and monthly maintenance of computer equipment, mobile phones, and computer programs for collecting, processing, and storing data. Mass Implementation Phase of Internet technologies in everyday life and in production activities leads to an increase in capital costs.

The digital transformation of enterprises involves the implantation of energy-saving and energy-efficient technologies that can increase labor productivity, on the one hand, and, on the other hand, not increase the cost of production, while maintaining its competitiveness.

The share of households with access to the Internet from 2010 to 2018 significantly increased from 44.4% to 75% on average in Russia (Rosstat, 2019). However, in the territorial context, there is a differentiation by this indicator among the regions of Russia. In addition, there is a constant increase in electricity tariffs, which forces enterprises and households to use innovative technologies for processing and metering electricity consumption.

The high differentiation of Russian regions in terms of economic development, population, industrial production contributes to regional differences in the level of electricity consumption. The results of a research conducted by Mukhametshin et al. (2019) show fundamental differences in the consumption and use of energy resources in all regions of Russia: almost 60% of electricity consumption is in 3 out of 8 federal districts (Central, Siberian and Volga). The prevailing consumption in certain regions defined by the location of large-scale energy-intensive industries. Deficit of own electricity production was observed in two federal districts - Volga and Siberian.

Hypotheses of this survey formulated as follows:

H_1: There are spatial effects in the level of electricity consumption among the regions of Russia.

We assume that in Russia the implantation of digital technologies is at the initial stage, which requires capital investments from both households and enterprises, so we can formulate the following hypothesis:

H_2: At the initial stages, digitalization contributes to the growth of electricity consumption at the level of Russian regions, however, as energy-saving technologies develop, and labor productivity increases, energy consumption will fall.

2. LITERATURE REVIEW

A large share of research in the field of electricity consumption is conducted from the perspective of analyzing the impact of economic growth and industrial structure and technological progress on electricity consumption.

The most controversial factor is technological progress. Some believe that it leads to an increase in power consumption. A number of authors believe that it leads to lower energy consumption. Technological progress leads to the introduction of energy-saving technologies. This in turn reduces energy consumption (Li et al., 2013).

Energy serves as the basis for economic growth, and economic growth cannot continue without sufficient energy consumption; therefore, energy consumption must maintain a long-term equilibrium with economic growth. However, the relevant literature gives conflicting results when describing the dynamic nature of such relations and how they affect the development path of countries. For Russia, the results of Zhang (2011), confirmed this hypothesis. It was shown that energy consumption in Russia is associated with its economic growth, although they do not have static or medium co integration relations. Since 2000, energy efficiency in Russia has increased significantly compared to previous decades, mainly due to the adjustment of the industrial structure and technological progress.

Ang (2007), examined dynamic causal relationships between pollutant emissions, energy consumption, and product output using France as an example. He showed that there is a fairly strong long-term relationship between these variables. Therefore it can be said that economic growth has a causal effect on the growth of energy consumption and increased pollution of the environment in the long term. The results also indicate a unidirectional causal relationship going from increasing energy consumption to increasing production in the short term. Ozcan et al. (2020), using a sample of 35 OECD countries for the period 2000-2014, found that economic growth and energy consumption models contribute to improving the level of environmental performance of countries.

Narayan (2016) four different hypotheses of the existence of a causal relationship between energy consumption and economic growth are identified. First, a one-way causal relationship from energy consumption to economic growth describes the "growth hypothesis." Secondly, the "conservation hypothesis" suggests a one-way causal relationship between economic growth and energy consumption. Thirdly, the "feedback hypothesis" implies a bi-directional (mutual) causal relationship between energy consumption and economic growth. Finally, the "neutrality hypothesis" suggests that there is no significant causal relationship between economic growth and energy consumption.

Azam et al. (2016) empirically discovered (according to data from 1975 to 2013) that income, trade, urbanization, foreign direct investment and existing infrastructure are the main macroeconomic determinants of energy demand.

Lin and Zhu (2020), analyzed the factors affecting China's electricity consumption. The following results were obtained: per capita income, urbanization, population, the share of secondary industry and the price of electricity have a significant impact on electricity consumption. Optimization of the industrial structure helps to increase the efficiency of electricity consumption, while an increase in the level of electrification will lead to a decrease in the efficiency indicator.

It should be noted that household characteristics also influence energy consumption. Household electricity consumption is positively related to disposable income, age and number of employed members in the household. Households with large share of people with higher education have a higher social status and a different lifestyle than households with a lower level of education. They use electric appliances and IT equipment more intensively (Kostakis, 2020).

Thus, among the factors affecting electricity consumption, there are: urbanization, the degree of development of the Internet and industry, economic growth, technological progress, real income, and unemployment. At the same time, the impact of digital technologies, with the exception of the Internet, on electricity consumption remains understudied.

The closest methodology to the present work is the study of An et al. (2020). The authors have shown on the statistical data of China the presence of spatial correlation.

The purpose of this article is to identify the effects of digital transformation of Russian society on electricity consumption.

In this paper, in contrast to the selected studies, we will assess the impact of digitalization on electricity consumption in the regions of Russia. Extension and addition of previous studies will be in the following aspects:

- Most of the previous works focus on economic development, especially on the structure of industry. Some of them prove that technological progress leads to lower energy consumption. Our study describes the role of digitalization in this process
- Models of spatial econometrics are used to describe the agglomeration effects, the characteristics of differentiation of regions. However, most spatial model-based energy analysis studies focused on the assessment of consumption in China. As far as we know, such calculations were not carried out for Russia
- Our work not only provides an estimate of the impact of digital technology on the level of energy consumption in Russia, but it also presents an analysis at two levels: households and enterprises.

A further article will be constructed as follows. Section 2 is devoted to a review of the literature. Section 3 will describe in detail the data and methods on the basis of which econometric models are built. Section 4 contains the main results of the analysis of spatial correlation indices, regional clustering, and spatial modeling. Section 5 contains conclusions on the results obtained earlier and recommendations on their practical application.

3. RESEARCH METHODOLOGY

Russian regions are characterized by strong differentiation, differences in economic, demographic, territorial and climatic characteristics. This gives us the opportunity to assume that energy consumption is spatially differentiated. In addition, there is an imbalance in the consumption and production of electricity.

The methodology of spatial econometric modeling allows to take into account the spatial structure of the data by including the spatial lag (weighted value of the indicator in other regions) in the regression model.

The spatial effects of energy consumption were estimated on the basis of statistical data for Russian regions from 2010 to 2018. (Rosstat, 2019).

Based on these data, the global Moran spatial correlation indices were calculated (Anselin, 1995):

n – The number of regions in the sample, X – the value of the indicator in the region, wij – the corresponding element of the weight matrix. As a matrix of weights, we used a matrix constructed on the basis of the "nearest neighbor" principle, that is, if two regions have a common border, then the matrix element is equal to one, otherwise, to zero.

The Geary spatial correlation indices were calculated using the following formula:

Similar to the Moran index, n – the number of regions in the sample, X – the value of the indicator in the region, wij – the corresponding element of the weight matrix, W – the sum of all values wij. If the Geary index takes a value from 0 to 1, then we can state a positive spatial correlation, from 1 to 2 - a negative one.

The following interpretation of the spatial correlation coefficient can be given: if the coefficient is positive, the increase in energy consumption in a given region contributes to an increase in energy consumption among its neighbors; if the value is negative, the increase in energy consumption in this region is due to a reduction in the resources of its neighbors. The insignificance of the coefficient indicates the lack of interconnection of energy consumption in different regions.

The spatial correlation indices are the initial stage of spatial analysis, since they allow us to state the presence of spatial effects, but do not confirm the effect of digitalization on the level of energy consumption in the region. Further assessment is carried out taking into account explanatory variables based on the construction of econometric auto regression models with a spatial component.

The constructed econometric models are a generalization of spatial autoregressive models (SAR):

X – The matrix of explanatory variables, β – the vector of estimated coefficients of factors, W – he weight matrix, ε – he perturbation vector, ρ – the spatial correlation coefficient (its sign and significance characterize the existence or absence of marginal effects). An alternative specification for the SAR model is the spatial error model (SEM):

This model assumes that spatial dependence exists in the unexplained part of energy consumption. Model specification is selected according to the Elhorst scheme (Elhorst, 2014). Spatial panel data models can be evaluated in several ways: using the generalized method of moments, the maximum likelihood method, and the Monte Carlo method. All of these methods provide consistent estimates. However, the application of the method of moments is complicated by the need to search for valid instruments. The Monte Carlo method is quite laborious and time consuming (Semerikova and Demidova, 2016). Therefore, the maximum likelihood method was applied, which is now widely used in evaluating spatial panel data models. During the assessment, a Lee Yu correction was applied.

The choice between the models is based on testing the significance of the corresponding coefficients, before the spatial lags (ρ, λ, γ), and also by comparing the Akaike and Schwartz information criteria.

The marginal effects obtained in spatial models can be divided into direct, indirect and total effects (LeSage and Pace, 2009). The direct effect is defined as the average change across all regions in the level of energy consumption in the region when the level of digitalization in the same region changes. An indirect effect is the average change in the level of energy consumption in a region when the level of digitalization in all other regions changes. The total effect is the sum of direct and indirect effects, that is, the average change in the level of energy consumption in a given region when the level of digitalization in all regions changes. The list of control explanatory variables is based on the following works: Azam et al. (2016), Lin and Zhu (2020), An et al. (2020). Main variables used in the survey are presented in Table 1.

Different types of indicators can be a dependent variable: electricity consumption, growth rate of electricity consumption and electricity consumption per capita. Following Dong and Hao (2018), Jiang et al. (2015), we have chosen the last indicator.

4. RESULTS AND DISCUSSION

4.1. Regression Results

We estimated the Moran and Geary indices for the indicator “electricity consumption per capita” (Table 2) for each year from 2010 to 2018.

The significance of the Moran and Geary indices (Table 3) shows the presence of spatial correlation. This means that the analyzed

Table 1: Variable List

Electro	Electricity consumption by regions of the Russian Federation the (per capita)
Int	Share of households with Internet access
IntOrg	Organizations Using Broadband Internet
PC	Number of personal computers per 100 households
Urban	Share of urban population in the total population
PCorg	Number of personal computers per 100 employees
Sot	Number of mobile phones per 100 households
IPP	Industrial Production Index
Unemp	Unemployment rate
crisis	A dummy variable that takes a value of 1 for 2015
lnGRP	Gross regional product

Table 2: Moran and Geary Indices

Variable	Moran indices		Geary indices	
Electro2010	0.203***	(0.075)	0.782*	(0.130)
Electro2011	0.201***	(0.075)	0.786*	(0.126)
Electro2012	0.210***	(0.075)	0.777*	(0.128)
Electro2013	0.193***	(0.076)	0.796*	(0.124)
Electro2014	0.200***	(0.076)	0.785*	(0.123)
Electro2015	0.206***	(0.076)	0.778*	(0.124)
Electro2016	0.206***	(0.076)	0.774*	(0.125)
Electro2017	0.206***	(0.076)	0.772*	(0.124)
Electro2018	0.206***	(0.076)	0.773*	(0.125)

0.01***; 0.05**; 0.1*

Table 3: Regression analysis

Переменные	SAR		SEM	
Int	−0.0002	(0.002)	−0.0002	(0.003)
PC	0.006***	(0.002)	0.006***	(0.002)
Urban	0.093***	(0.026)	0.096**	(0.026)
IntOrg	0.011***	(0.003)	0.012***	(0.003)
PCorg	−0.025***	(0.007)	−0.023***	(0.008)
Sot	0.001	(0.002)	0.003	(0.002)
IPP	0.003	(0.002)	0.003	(0.002)
Unemp	−0.008	(0.022)	−0.012	(0.022)
lnGRP	−0.181	(0.231)	−0.161	(0.244)
crisis	−0.070	(0.057)	−0.086*	(0.064)
R2	0.19		0.20	
Spatial λ	0.15***		0.12***	
N (obs)	624		624	
N (groups)	78		78	

0,01***; 0.05**; 0.1*

regions can influence each other, the spatial structure of the Russian economy is significant. The values of the global spatial correlation indices of Moran confirm the presence of a positive spatial correlation, when regions with high levels of electricity consumption contribute to an increase in energy consumption in neighboring regions.

In order to evaluate the effect of digital technologies on the level of electricity consumption that interests us, spatial panel models were evaluated.

The spatial correlation coefficients are significant: the corresponding estimates are positive ($\lambda = 0.16$, $\lambda = 0.12$). It can be concluded that if electricity consumption increases in one region, then it will grow in another region (neighbor). The variables that were included in the model were tested for multi collinearity. Paired correlation values do not exceed 0.54. For SAR models, the coefficients are not interpreted, only their signs are analyzed, therefore, it is necessary to calculate the marginal effects (Table 4).

The signs of the control variables have the expected direction: the crisis and unemployment are negative, the industrial structure (IPP) and the share of urban population are positive. However, only the latter is significant. It has a positive effect on energy consumption with elasticity of 0.096 and 0.093 in SEM and SAR models, respectively. Moreover, the indirect effect is also significant, i.e. neighboring regions influence each other, and a change in the share of urban population in one affects the consumption of electricity in the other.

The digital factors in the models are presented at two levels: households (the share of households with Internet access; the number of personal computers per 100 households) and firms (organizations that used broadband Internet access; the number of personal computers per 100 employees). In SEM and SAR, the elasticity of Internet use is significant for enterprises and is equal to 0.012 and 0.011, respectively. The use of computer technology is significant for both enterprises and households.

Estimates of the overall effects (SAR model) indicate that a larger number of: "personal computers per 100 workers;" "organizations using broadband Internet access" in one region correspond to lower energy consumption in this and other regions. The direction of influence is in line with what was expected: the use of information technology leads to an increase in labor productivity, and reduces the time to perform routine operations. For the variable "number of personal computers per 100 households," we observe the opposite effect. Thus, the growth of this indicator in one region leads to a higher level of electricity consumption in this region and neighboring regions. This can be explained by the low level of energy-saving technologies among households.

A further investigation of indirect effects shows that the same variables are significant: the number of personal computers per 100 households; organizations that have used broadband Internet access; the number of personal computers per 100 employees; share of urban population.

4.2. Regional Differentiation of Energy Consumption

The consumption of thermal and electric energy in the housing sector in regions with similar climatic conditions varies up to 3 times (The Ministry of Economic Development of the Russian Federation, 2019). Figure 1 shows the level of energy consumption in the regions of Russia for 2018. The figure shows the uneven distribution of electricity consumption per capita throughout Russia: an increase in specific indicators from the south of the territory to the north, where the population density is much lower.

Large indicators of electricity consumption per capita are observed in the Urals Federal District. The indicator for the period under review does not change significantly. A high mark can be traced

Figure 1: Electricity consumption per capita in Russian regions (billion kWh)

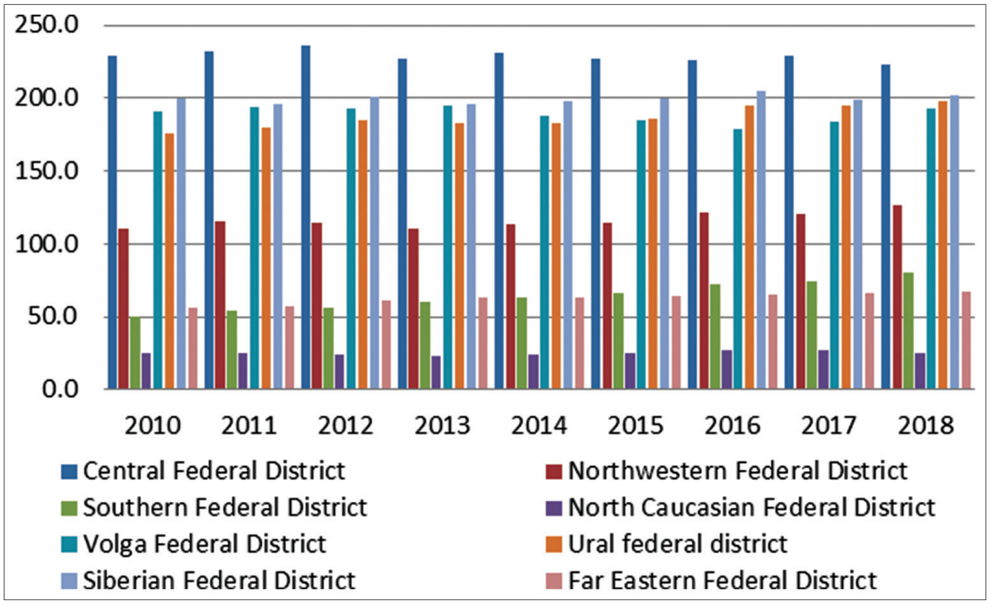
Source: Built by the authors based on Rosstat data. No data are available for the Khanty-Mansiysk Autonomous Okrug, the Nenets Autonomous Okrug, the Yamalo-Nenets Autonomous Okrug, the Republic of Crimea and the city of Sevastopol.

Table 4: Marginal effects

Variables	Direct effect		Indirect effect		Total effect	
Int	0.00004	(0.003)	0.00001	(0.000)	0.00004	(0.003)
PC	−0.005***	(0.002)	−0.001**	(0.001)	−0.006***	(0.002)
IntOrg	0.011***	(0.003)	0.002**	(0.001)	0.013***	(0.004)
PCorg	−0.026***	(0.007)	−0.004**	(0.002)	−0.030***	(0.009)
Sot	0.0001	(0.015)	0.0001	(0.003)	0.0001	(0.002)
Urban	0.094***	(0.026)	0.016**	(0.008)	0.110***	(0.031)
IPP	0.003	(0.002)	0.001	(0.004)	0.003	(0.003)
Unemp	−0.006	(0.021)	−0.001	(0.004)	−0.007	(0.026)
lnGRP	−0.169	(0.224)	−0.028	(0.041)	−0.197	(0.262)
Crisis	−0.067	(0.056)	−0.012	(0.012)	−0.078	(0.066)

0.01***; 0.05**; 0.1*

Figure 2: Dynamics of electricity production (billion kWh)



in 2018 (0.16 billion kWh). The Siberian Federal District is in second place in terms of energy supply; the values of each year also do not have a large gap compared to each other. In 2018, an increase of 2.1% is observed compared to 2017. The next in terms of electricity consumption is the Northwestern Federal District. A high value is achieved in 2018 (0.09 billion kWh). Next is the Far Eastern Federal District, the maximum electricity consumption was achieved in 2018 - 0.0819 billion kWh. Consumption in the Volga Federal District in 2018 is 0.0656 billion kWh, which is 5.5% more than in 2017.

The lowest value of electricity consumption in comparison with the above districts is observed in the Central Federal District. The maximum value noted in 2012 is 0.0610 billion kWh. In 2018, the indicator decreased by 7.2% compared to 2012. Minimum electricity consumption compared to other districts is observed in the Southern and North Caucasian federal districts.

In federal districts and regions, electricity production is also highly differentiated (Figure 2). For example, in regions with maximum rates (Tyumen region), the values reach 108.8 billion kWh, in regions with minimum rates they fluctuate around zero (Jewish Autonomous Region, Chechen Republic, Altai Republic). This differentiation is due to the natural resources of the territories.

If we consider the indicator of electricity production in the dynamics by region, then for the most part it is stable and remains unchanged. However, there are a number of regions with notable changes. The most significant and stable growth has been observed in the Rostov region since 2014. This can be explained by the commissioning of the 3rd power unit (2015) and the 4th power unit (2018) at the Rostov NPP. In the Republic of Khakassia, the indicators also almost doubled due to an improvement in the hydrological situation and an increase in electricity production at the Sayano-Shushenskaya hydroelectric power station. A stable decline in production capacities is observed in the Moscow, Orenburg and Ryazan regions. In the Republic of Crimea, there is an increase in electricity production due to the commissioning of new thermal power plants.

5. CONCLUSION

Based on the construction of spatial panel data models for the regions of Russia, the survey revealed the role of information technologies in energy consumption. An analysis of the regional differentiation of electricity consumption showed that there are obvious spatial differences in energy consumption between the regions of Russia. It is usually characterized by a high level in the northern regions and a low level in the southern regions. It should be noted that differentiation in the production and consumption of electricity for the Russian economy is a sustainable phenomenon, which allows us to conclude that there is: a path dependence effect; dependence on natural and geographical differences.

The obtained results confirm the hypothesis that there are spatial effects in the consumption of electricity in the regions of Russia. Digital technologies have a multidirectional effect on energy consumption, depending on the subject and level of analysis (enterprise or household). In order to realize the potential in the field of energy saving and achieve the goals declared in the program documents, it is necessary to clearly identify the factors that influence the level of energy consumption. Among them, the following factors should be especially noted: geographical differences, low motivation to switch to energy-saving technologies, insufficient level of development and implementation of technologies and R&D, infrastructure, lack of experience in financing projects; low degree of organization and coordination (Andreas et al., 2016; Pitkänen et al., 2016), the structure of the Russian economy, the level of digitalization.

Identification and registration of the key factors in the sphere of energy consumption; regional differences; spatial differentiation will help reduce energy costs, increase the competitiveness of Russian products in the international arena, improve the environment, which will allow the Russian economy to enter the path of sustainable economic development.

In addition, since the results indicate a spatial aspect of electricity consumption, the government can implement a differentiated regional policy aimed at improving the efficiency of electricity use in certain regions and promoting environmental protection policies in more densely populated areas.

6. ACKNOWLEDGMENTS

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. The reported study was funded by RFBR, project number No. 20-010-00663 “Evolution of the individual and household`s economic behavior model in the digital transformation.”

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