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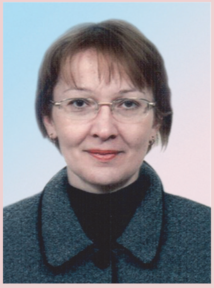
Objectives and Methods of Analyzing Energy Efficiency in the Economy



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Abstract. Energy saving and improving energy efficiency of production are among economic development priorities in Russia and its regions. Energy efficiency issues are given a lot of attention in scientific research on the interrelation of economic and power engineering development. In order to select the methodological tools for regional studies, we have reviewed scientific publications that analyze and evaluate energy efficiency in the economy. As a result of the review, we highlight the relevant research objectives: 1) to clarify the trends and factors leading to changes in energy efficiency of the objects under consideration; 2) to compare the energy efficiency of similar objects, to determine the causes of differences and possible growth potential; 3) to identify the spatiotemporal properties of energy variables and causal relationships between energy consumption and economic growth. In accordance with these research objectives we summarize the approaches and methods of statistical analysis, evaluation, and econometric modeling used to address them. The practical results of the studies carried out for different countries in different time periods are ambiguous. For the most part, the analytical tools used require a detailed statistical database of energy and economic indicators and special software. Not all of the tasks highlighted in this review are equally relevant in regional studies. In the light of the implementation of energy-saving policy in Russia, we consider the following issues to be of top priority: analyzing energy and economic trends in regional development and the factors that have the greatest impact on their formation, using the methods of decomposition, regression and boundary analysis. Interregional comparison with the use of the cluster and boundary analysis is used to clarify the pattern of spatial differentiation of energy efficiency and trends in its temporary transformation. The problems of complex econometric modeling of the regional economy with the detailed description of the dependence of energy variables deserve the greatest attention

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since they can help create a unified system of monitoring, analyzing and forecasting the key indicators of development in each region of Russia.

Key words: energy efficiency of economy, energy intensity, energy consumption, analysis, econometric modeling.

Introduction. Energy efficiency (or energy intensity) analysis receives considerable attention in the studies of economic and energy development trends. This is due to the relevance of interrelated energy and environmental problems of economic growth, understanding the importance of optimizing energy consumption and the need to choose effective measures to manage this process. Improving energy efficiency and energy conservation are among the priorities of development for the economy of Russia and its regions. Proper management requires knowledge of the general laws and interrelations of energy and economy, taking into account their regional, structural and sectoral characteristics, as well as monitoring and analysis of the changes and the consequences of implementation of current energy policy.

In order to select appropriate tools for regional studies, we carried out a review of scientific publications that analyze and evaluate energy efficiency of various objects of macro- and meso-economy. The presence of a large number of foreign scientific publications on econometric methods for assessing energy efficiency of the economy and a relatively small number of similar studies in relation to the Russian economy made it necessary to summarize and systematize the directions and methods, and to carry out a critical analysis of the possibility of their application in the studies of the Russian regional economy.

Results of the survey. Current objectives and methods of econometric studies of the level and dynamics of energy efficiency are concentrated in three main areas *(Table)*.

One of the main areas of research includes the analysis of trends and the assessment of the influence of factors that determine the dynamics of energy efficiency of the economy. It is known that the dynamics of energy efficiency of total production is determined by the quality of economic growth – its pace, structural changes and technological progress. In international practice, index methods of decomposition analysis are widely used to assess the impact of factors that reduce

Objectives and methods of analyzing energy efficiency of economy

Research objectives	Research methods	Publications
Analysis of energy intensity (energy efficiency) dynamics, assessment of the impact of factors	Correlation and regression analysis	[1–7]
	Dcomposition analysis: - index methods (IDA – index decompositions analysis), - structural input-output models (SDA – structural decomposition analysis)	[7–13]
Comparative evaluation: inter-country and inter-regional comparisons; evaluation and analysis of relative energy efficiency	Cluster analysis methods boundary methods: Stochastic Frontier Analisys (SFA) (boundary production potential model) Data Envelopment Analysis (DEA)	[3; 14–20]
Analysis of causal relationship between energy consumption and production of the gross product; evaluation of the properties and dependencies of energy variables	Methods of time series and panel data cointegration analysis: stationarity, cointegration and Granger causality testing, cointegration dependence modeling	[21–31]
	Econometric simulation of the production function including energy factor $P = f(K, L, E)$	[31; 32]

energy intensity of gross product. As a rule, there are three main factors affecting energy consumption: total volume of activity, sectoral structure and the values of specific energy intensity by type of activity (goods and services) [10]. It is obvious that the result of assessing the contribution of the factors depends on the thoroughness of decomposition of the economy and energy consumption. The difficulty of using index methods of decomposition analysis consists in the availability of a detailed statistical database of the initial data (which is described in [33]). Even more detailed information on the production, intermediate and final consumption of energy resources is necessary for the construction of input-output models of fuel and energy balance. The lack of necessary regional statistics limits the use of index methods in energy efficiency studies of the regional economy of Russia: either in relation to the analysis of electricity consumption only ([9]), or in case of independent development of fuel and energy input-output models of regions ([8]). Thus, the use of decomposition analysis methods for assessing the dynamics and energy efficiency factors in the Russian regions is possible, but it is time-consuming at the primary stages of data collection, especially it concerns reliable information on the structure and dynamics of the use of fuel and energy resources (FER) in relation to the changes in economic indicators in the allocated areas of industrial and household energy consumption.

Correlation and regression analysis widely used in the studies of energy-economic dynamics can be also used in the monitoring of regional trends in energy efficiency when there is an available statistical base. "Econometric characteristics of the model ensure that the model designed is adequate and meaningful, and help make at least a rough estimate of the contribution of each of these model factors in the final result – the variation of the dependent variable" [34, p. 15]. Regression analysis of energy consumption dynamics is the most practical approach in empirical studies of energy efficiency in Russian regions. Properties of the total regional energy consumption such as relative stability and a significant share of the basic energy needs (conditionally constant), low coefficients of year to year variations and elasticity to the growth rate of gross output, allow us to approximate the dependence of the dynamics of energy consumption on the main macroeconomic variables (in the period of 5–15 years) with the help of linear or close to linear models. If the set of explanatory variables takes into account the specifics of the structure of energy consumption and economic development of the region in the period under review, then the meaningful interpretation of regression models allows us to explain the trends and main drivers of energy efficiency dynamics in the regional economy [35].

<u>Another large-scale research direction is the problem of comparing the energy efficiency of similar objects with the analysis of the causes of differences and assessing the potential for improvement.</u> In the world practice of comparative analysis of economic efficiency the boundaries of production capabilities are assessed with the help of Data Envelopement Approach (DEA) and Stochastic Frontier Analysis (SFA). Depending on the formulation of the problem, these methods help compare the relative efficiency of several similar objects or evaluate changes in the functioning of one selected object at different times. Both methods of boundary analysis are used in benchmarking to compare the energy efficiency of objects of different levels (countries, industries, firms, technologies) [36]. In terms of research capabilities and substantive analysis of the results, a parametric SFA approach may be preferred [37]. The difficulty of

its application lies in the substantiated choice of the best specification of the production function for a particular task. Underdeveloped pre- and post-analysis does not allow us to formalize properly the necessity and correctness of the use of SFA-models in each case, so the research on diagnostic tools of models and criteria of their quality continues [38].

At the same time, the DEA methodology in the practice of comparative evaluation of energy efficiency is becoming more and more popular. This is clearly demonstrated by detailed reviews [39; 40], which generalize the thematic areas, consider the main applications, variants of the models, and highlight advantages and disadvantages. DEA models do not require specifying the type of production function, allow for multi-factor input and output, and optimization in the costs or performance. The method allows comparing different-scale objects, determining the potential and directions of efficiency improvement, taking into account its multicriterion nature, which is important for a comprehensive analysis of energy and environmental aspects of economic development [17] or production facilities. The disadvantages of the nonparametric method include the sensitivity of the results to erroneous data, the problematic statistical testing of hypotheses and the significance of variables [36]. One of the factors in the popularity of DEA as a research method is the availability of affordable software that allows reducing the complexity of solving real practical problems to a minimum [41]. The existence of two competing boundary analysis methods (DEA and SFA) makes it possible to use them together to solve a single problem in order to verify the consistency of the results obtained.

In regional studies, boundary analysis methods can be used to estimate relative changes in the energy efficiency of a particular region in the period under consideration. When comparing the efficiency of the economy of different regions, it is advisable to cluster them into homogeneous groups, taking into account the specifics of regional energy consumption and production specialization [3; 15]. Then, using boundary methods for the selected "homogeneous" groups of regions it is possible to evaluate relative production efficiency, achievable potential and its growth factors. However, the results of this comparative analysis will be very abstract conclusions due to the conditional comparability of the objects of the study – atypicality and uniqueness of economy of each region of Russia.

Another important thematic area in the research of energy efficiency is the objective of identifying spatial and temporal patterns in the properties of energy variables and their interrelations with economic parameters.

The objectives of the studies of non-stationarity and cointegration of the time series of energy and non-energy variables are the conclusions about the possible (permanent or temporary) impact of active energy saving policies (measures limiting the use of hydrocarbon fuels, nuclear energy, promoting the use of renewable energy sources) on economic growth, assessment of the consequences of any crisis conditions (restrictions on energy supply, price shocks), as well as forecasting the future dynamics of energy and economic development [42]. This set of studies examines the specifics of energy resources consumption and production dynamics for groups and individual countries, in different time periods, on aggregated and disaggregated data (by types of fuel and energy resources, sectors). The results of different statistical methods are compared, methodological features are revealed, as well as the reliability of tests in relation to time series, with and without structural shifts, and the sensitivity of the results to the accounting of additional variables [30; 42]. As a rule, the results of testing demonstrate that economic growth and energy consumption are integrated time series of the first order, between which there is a long-term co-integration relationship [31].

The reviews of the literature on the relationship between energy consumption and economic growth [21; 28; 42; 43] summarize the main features of empirical research: they test the role of energy in stimulating economic growth for different countries and time periods, using different methods and models; they also test four hypotheses causal relationship (conservation, growth, feedback, neutral hypotheses), which are important for the correct choice of the direction of energy policy; the results largely confirm the existence of a statistically significant relationship, but the conclusions about the direction of this relationship vary; there is no consensus on the existence and direction of causality between energy consumption and economic growth. Mixed results of numerous studies lead to an important conclusion that the causal relationship between energy consumption and other variables changes over time and depends on the localization and level of economic development [21; 28; 42]. In other words, the absence of coordinated research results is due to permanent evolution of the economic system itself, structural heterogeneity of energy and economy both in geographical and sectoral terms [44].

Indeed, there is no reason to expect unambiguous conclusions about energy economic regularities in very different conditions of different countries and in different time periods. The existence of direct correlation between economic growth and consumption of energy, a necessary resource of activity, in the long-term period does not require confirmation. In the world economy, the positive correlation between the growth of production and consumption of energy resources is maintained, although the elasticity of energy demand in terms of output is changing [44] depending on the stage of development, specialization and regionalization of the economy. The opposite effect – energy consumption → economic growth – is also objective in virtue of the temporal and inter-industry linkages, although it is not unambiguous, it is manifested mostly indirectly, with time lags, it depends on the stage of development and specifics of the national economy (country as an exporter/importer of energy resources; economic structure, growth and interconnection of energy intensive and energy-saving production in the considered period of time). In the conditions of advanced development of the sphere of energy efficient production and services and active introduction of new technologies, the transition to energy-independent economic growth becomes real. Manifestations of decoupling (decoupling or neutrality hypotheses) of economic growth and energy consumption are also confirmed in empirical studies of the latest trends in the development of the world economy [21; 28].

When studying energy-economic relationships we should also highlight the urgent task of analyzing the dynamics of energy prices, in particular, their impact on economic growth, energy consumption and inter-fuel competitiveness. The conclusions of this research block, as a rule, at the level of national economies, point out the impact of energy prices on economic growth, low price elasticity of energy consumption, low level of interchangeability of the main types of fossil fuels and significant price interconnections [24; 27; 44].

A common approach in the study of the relationship between economy and energy is the construction of production functions. When modeling long-term macroeconomic dependencies, it has become a norm to represent the production function of the gross product as a function of capital, labor, and energy consumption [42]. As part of the so-called CLEMS approach [Capital, Labor, Energy, Materials, Services], databases are formed and trends in the world economy are analyzed [37]. Often, in the studies of the impact of the energy factor, the specification of the production function model is supplemented with arguments specifying the features of economic development of countries (international trade, foreign investment, political instability, R&D costs). Modeling the interrelation of production factors is used to identify economic and environmental implications of energy efficiency growth. In particular, attention is paid to the possible "ricochet effect" from the implementation of large-scale energy-saving measures, as a result of which the conditions can be formed that stimulate the growth of energy consumption [45]. In regional studies, the simulation of production functions can be used to assess qualitative features and parameters of economic growth and medium-term forecast of macroeconomic dynamics.

Concluding observations. Summarizing the review of publications, we should emphasize their mainly methodological orientation. This feature of the studies of the relationship between energy consumption and economy was noted by L.M. Grigor'ev and A.A. Kurdin: "... The discussion largely turned into a debate on econometric methods, and this apparent bias is preserved until now, including in the specialized scientific journals on energy economics. At the same time, conceptual changes concerning the formation of new points of view directly on the subject of research, in particular in connection with the fundamental changes of the object itself – the world energy system – are not so often featured in the cited articles on the subject of mutual influence of economic growth and dynamics of energy consumption" [44, p. 393]. It may be added that the findings of the analysis of economic processes are often axiomatic. These include, in particular, the statements that energy is as important a factor in economic growth as labor and capital; the development of the economy in the long term leads to an increase in energy consumption; the nonlinearity of the relationship between energy consumption and gross production is associated with the influence of structural changes (exogenous shocks, technological progress, economic cycles); and various crises in the energy markets have a negative impact on the economy. Besides, it is often concluded that technologically advanced countries can implement energy-saving policies without fear of impeding long-term sustainable economic growth; that costs are reduced with increasing energy efficiency – this increases productivity and stimulates economic development, and the growth in energy prices activates energy conservation.

In general, the substantial conclusions of the research are not always adequate to the complexity and labor intensity of the applied methodological tools. In addition, we should bear in mind that the conclusions obtained by formal statistical analysis procedures are not necessarily reliable; errors can be caused by incorrect model specification or by flaws in the empirical database.

The authors of the review of publications on methods of analysis of energy-economic relationships [42] are concerned about the redundancy of applied research that does not add anything new to what is already known: "Our key message is the need to avoid "redundancy" of research in these areas, since most applied research no longer add anything new to what is already known" [42, p. 351]. Along with this suggestion, we agree with the statement that the results of research in this area received "even with the most refined econometric tools... require to be updated continuously" [44, p. 405] due to ongoing structural shifts in the economy, new trends in the field of energy efficiency, energy supply and prices, and energy policy factors.

Conclusions. In conclusion, we summarize the relevance of the considered research objectives and methods of analysis in regional energy efficiency studies of the Russian economy. It was noted that the use of most of the methodological approaches for the analysis and modeling of the economy of the Russian regions is difficult due to the insufficient database of statistical observations of energy consumption both in time and in structural detail. Therefore, it is important to create a full and reliable information database on fuel and energy consumption in the regions - the necessary basis for the analysis of energy intensity indicators, assessment of potential and drivers of energy efficiency growth. Not all of the above are equally relevant in regional studies. In the light of the implementation of the energy-saving policy of Russia, the analysis of energy-economic trends of regional development and the factors that have the greatest impact on their formation with the use of the methods of decomposition, regression and boundary analysis should be attributed to the priority issues. Interregional comparison by cluster and boundary analysis methods is useful for the purposes of clarifying the picture of spatial differentiation of energy efficiency, factors and trends of its temporary transformation. The greatest attention should be paid to the problem of complex econometric modeling of the regional economy with the detailed dependence of energy variables to create in each region of Russia a single system of monitoring, analysis and forecasting of key indicators of development.

The presented article is of a review nature. Attention is drawn to the extensive amount of publications of foreign studies in the field of scientific analysis of energy-economic relations and the relatively low activity of Russian researchers with the undoubted relevance of this topic for the domestic economy. This circumstance served as a justification for the review. The analysis of thematic publications allowed to generalize and systematize actual tasks and the main methods of the conducted econometric researches of energy efficiency of economy. The scientific novelty of the review, according to the author, is the specification of the problem field and the possibility of choice of methodological tools applied to energy efficiency studies of the regional economy of Russia.

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