KAUNAS
UNIVERSITY OF
TECHNOLOGY

VIDAS LEKAVIČIUS

Modelling the Impact of Changes in Energy Supply on the National Economy

Summary of Doctoral Dissertation
Social Sciences, Economics (04S)

2013, Kaunas

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LITHUANIAN ENERGY INSTITUTE

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The dissertation was prepared at Lithuanian Energy Institute, Laboratory of Energy Systems Research in 2008-2013.

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LIETUVOS ENERGETIKOS INSTUTUTAS

VIDAS LEKAVIČIUS

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INTRODUCTION

Relevance of the research. The role of the energy sector as a branch of country's economy is becoming more and more significant due to growing prices for energy resources and on-going debates on climate change. To highlight its importance, the energy sector sometimes is even called "blood of the economy". Energy-related issues are particularly important for energy importing countries, such as Lithuania.

In the majority of current economic models, the energy sector (especially technological alternatives and physical constraints) is depicted not sufficiently. Therefore, the energy sector as well as its impact on other branches of the economy can be analysed only in a fragmentary way. This problem is especially relevant in the case of research which aims at evaluating the impact of energy supply changes on the national economy. Any shift in energy supply firstly affects the energy sector itself but has further effect on entire economy. Further effect on the country's overall economic performance heavily depends not only on the supply of primary energy resources, but also on energy peculiarities, transformation capacities that are suitable for particular energy resources, and other non-economic factors.

Contemporary energy planning models, which are implemented in Lithuania as well as in other countries, are based on the partial economic equilibrium principle and fail to assess macroeconomic impacts of changes in the energy sector. For the purpose of really comprehensive analysis, there is a necessity to develop flexible hybrid energy economy models. Such models, on the one hand, should retain sufficient level of energy sector elaboration and reflect important constraints, which exist within the energy sector. On the other hand, they should be able to assess interaction among energy and other branches of economy.

Investigation level of the scientific problem. The problems of energy supply changes are tried to be analysed using different methodological approaches, which have been exhaustively discussed in the theoretical part of this dissertation. In the researches of positive economy, energy-economy nexus is analysed using econometrical methods. It is especially worth to mention scientific works carried out by Apergis and Payne (2011) as well as Huang, Hwang, and Yang (2008), in which relationships between energy consumption and economic growth are assessed. The researches dealing with this issue are summarized by Ozturk (2010) and Payne (2010b). An exhaustive review on the relationships between electricity consumption and growth of the economy is provided by Payne (2010a). The relationships between consumption of natural gas and economic growth are analysed and other researches on this topic are reviewed in Apergis and Payne (2010). Significant attention on energy related issues in the context of country's economic growth is paid by Bobinaite, Juozapaviciene, and Konstantinaviciute (2011b), who also analysed the impact of increasing usage of renewable energy sources on the growth of Lithuanian economy (Bobinaite, Juozapaviciene, & Konstantinaviciute, 2011a).

Another research paradigm that deals with the changes in energy supply is closer to the approach of normative economics. It seeks not only for description of existing relationships but also for introduction of measures that would be suitable for alteration to the degree or even nature of these relationships. Models of future development of the energy sector (see Connolly, Lund, Mathiesen, and Leahy (2010) for a broad review of such models) represent this paradigm applying the so called bottom-up approach. However, many of these models employ partial equilibrium principle, which is unable to reflect the complexity of energy-economy interdependence. For more comprehensive analysis, top-down macroeconomic models are created. A very large group is formed by general equilibrium (CGE) models. These models are used for such research problems as economic evaluation of impact of biofuels on climate change (Timilsina & Mevel, 2012), economic effects of energy generating units replacement (Bretschger, Ramer, & Zhang, 2012), impact of oil price shocks on the economy (Aydın & Acar, 2011), shift to a low carbon economy (Böhringer & Rutherford, 2013), and other energy economy research topics. Notwithstanding its versatility, the top-down approach has serious disadvantages looking from the technological point of view.

In order to overcome drawbacks of above mentioned approaches, relatively new and promising trend of hybrid modelling began in the field of energy economics. These models tend to integrate positive sides of bottom-up and top-down approaches. Despite the lack of researches that involve hybrid modelling, it is worth to mention scientific articles written by Böhringer and Rutherford (2008) and Jaccard (2009). Topicality and comprehensiveness of hybrid models can be illustrated by the fact that *The Energy Journal*, one of the most prestigious scientific energy economy journals, has devoted the entire issue for hybrid models (Hourcade, Jaccard, Bataille, & Ghersi, 2006).

In Lithuania, economic implications of changes in energy supply were also analysed. Employing computable general equilibrium modelling,Vilkas (1997) has performed the analysis of the impact of increased utilization of energy capacities, Galinis and van Leeuwen (2000) have analysed different scenarios of future continuation of nuclear power in Lithuania, Kalinauskas and Tamošiūnas (2000) have explored the impact of increase of oil price, Kuodis (2001) has evaluated possible outcomes of closure of Ignalina Nuclear Power Plant. Štreimikienė and Mikalauskienė (2004) have analysed possibilities to use partial and general equilibrium models for evaluation of environmental policy measures on the energy and economy.

Despite the fact that the topicality of problems related to economic consequences of changes in energy supply is widely acknowledged, there is no single research methodology accepted, since different methodological approaches have their own advantages and drawbacks.

The research problem: how to model and evaluate comprehensive impact of changes in energy supply on the national economy?

The object of the scientific research: the impact of changes in energy supply on the national economy.

The aim of the scientific research: to develop and implement in Lithuanian case a model for analysis of changes in energy supply and their impact on the national economy.

In order to reach this aim, the following **research tasks** have been formulated:

1. To inspect relationships between energy and remaining economy as well as mechanisms of changes in energy supply from theoretical and empirical point of view.
2. To analyse the description of energy-economy relationships in various types of energy planning models and the possibilities to use them for analysis of changes in energy supply.
3. To develop a hybrid energy economy model for comprehensive analysis of impact of energy supply changes on the economy.
4. To prepare the database and to develop additional tools, which are needed for practical implementation of the model under Lithuanian conditions.
5. To evaluate the impact of changes in natural gas and electricity import prices on the Lithuanian economy taking into account structural changes of the energy sector.
6. To perform sensitivity and uncertainty analysis of the modelling results.

The structure as well as logical composition of the material has been determined by the tasks of the research (see Figure 1). According to classical structure of a thesis, accomplishment of the above mentioned tasks is provided in three parts of the dissertation.

In the first part of the dissertation, there are analysed relationships between the energy sector and the remaining economy, mechanisms of energy supply changes and their impact on the economy. Considerable attention is paid to the research methods, especially to the possibilities of reflection of energy-economy relationships in various types of models applied in energy planning.

The second part presents the hybrid model that has been developed by the author of the dissertation. This model combines properties of the bottom-up and top-down models and allows comprehensive analysis of impact of changes in energy supply on the national economy. In this part of the dissertation, the architecture of the model, data sources, peculiarities of social accounting matrix (SAM) preparation, and software implementation of the model are discussed.

Third part of the dissertation is devoted to the practical application of the model in the Lithuanian case. It presents the analysis of changes in prices of imported electricity and natural gas under three different structural conditions of the energy sector.

The conclusions summarise the main results achieved by the author of the dissertation.

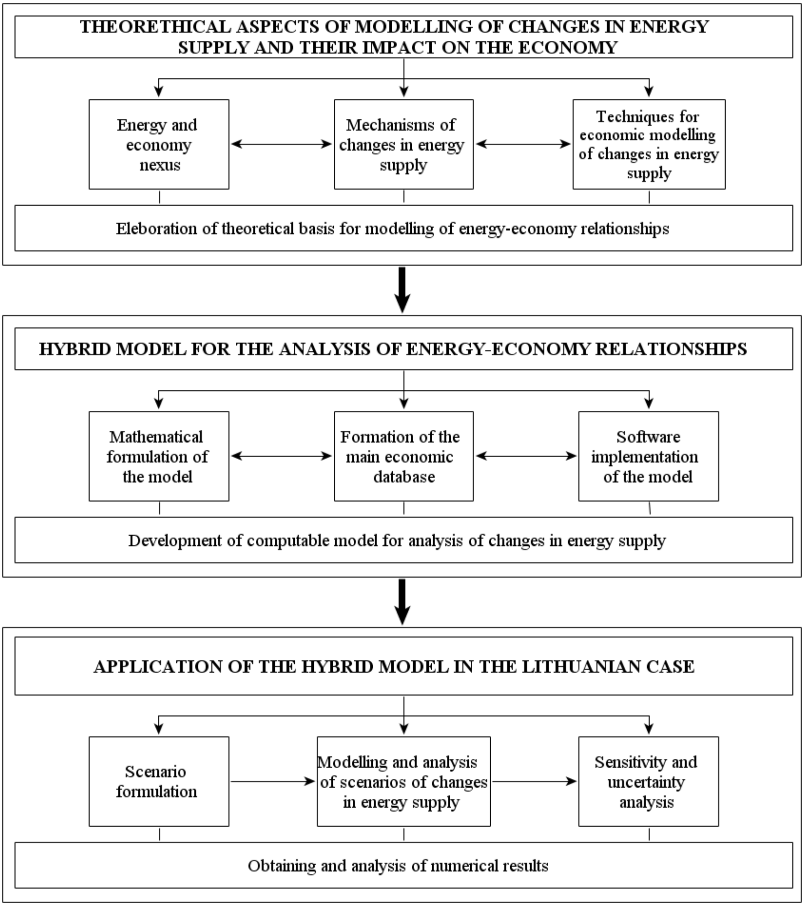

Figure 1. The structure of the dissertation

Methods of the research. Analysis and synthesis have been applied for theoretical exploration of changes in energy supply and their modelling possibilities presented in scientific literature. For development of the hybrid model, techniques of mathematical modelling of economic processes have been employed.

In the present research, several advanced software packages have been used. For data processing (correlation and regression analysis of primary data etc.), software package STATISTICA has been utilized. For modelling of the energy sector as well as for testing of modelling solutions developed, MESSAGE package, distributed by International Atomic Energy Agency, has been used. Hybrid energy economy model and additional tools that are necessary for its practical implementation have been developed under GAMS algebraic modelling software package. However, Gtree has been used instead of standard GAMS-ide user interface. Microsoft Excel 2010 along with integrated VBA tools has been employed for creation of operation interface and for results processing. Finally, SimLab 2.2.1 software, distributed by the Joint Research Centre of the European Commission, has been used for sensitivity and uncertainty analysis.

The **scientific novelty and theoretical significance** of the work as well as author‘s contribution to the field of research is revealed by the following research results obtained:

- The role of the energy infrastructure in the spreading of energy shocks to other areas of the economy has been identified as a result of the detailed analysis of mechanisms of changes in energy supply.
- Original principles have been developed for general equilibrium modelling and integration of CGE with energy models.
- New hybrid model, which allows flexible representation of the energy sector and analysis of macroeconomic consequences of changes in energy supply taking into account intersectoral relationships and structure of the energy sector, has been developed.
- Using the model developed, evaluations of changes in energy supply have been performed under Lithuanian conditions. The impact of energy infrastructure and import price changes was evaluated in a comprehensive way.

Practical value of the work can be grounded on possible implementation areas of the model:

- *ex-ante* and *ex-post* analysis of changes in energy supply;
- the analysis of relationships between the energy sector and other branches of the economy in countries with similar structure of economy;
- assessment of external social and economic effects (costs and benefits) related to the choice of energy generation sources;
- evaluation of energy security from the economic point of view;
- formation of energy and economic policy, strategic decision making;
- integration of future energy technologies into energy system, etc.

Practical adaptability of the results obtained is validated also by the fact that some elements of the model presented in the dissertation have been tested under successfully accomplished contractual research projects for different institutions. It could be mentioned the assessment of social and economic impact of wider biomass usage in the research work “Preparation of Complex Investment Programme 2011–2020 for District Heating Sector and Development of Implementation Means” (Lithuanian District Heating Association), creation of Kaunas city district heating development model (AB “Kauno energija”), modelling of energy-economy relationships in the project „Development of Methodology for Optimal Integration of Future Technologies into Energy Sector“ (Lithuanian Research Council), etc.

Research limitations and further research directions. Reliability of the empirical results presented in this work might be limited by the choice of 2008 as the base year in the model. From the economic development point of view, this year was not typical. However, while performing the research, 2008 was the only year for which it was possible to get most of the data consistent with NACE Rev. 2 classification system. Nevertheless, data preparation and handling algorithms described in this dissertation are universal. Therefore, more stable time period will be possible to choose as a base year in future research. In the case of analysis of some specific projects, the applicability of the model can also be limited by availability of relevant data and computational capacities.

In this work, standard CGE modelling praxis has been followed and elasticity parameters have been taken from scientific literature. In addition, their impact on uncertainty of modelling results has been evaluated by performing sensitivity analysis. Thus, estimation of substitution elasticities under Lithuanian conditions would be one of important further research steps. Other possible further research areas include preparation and testing of different specifications of the model (including detailed representation of households and labour force groups), modelling of integration into the energy system of advanced energy technologies that can be done combining the model presented in this dissertation with detailed model of energy system future development.

The structure of the dissertation. The dissertation consists of introduction, three parts, conclusions, list of references and annexes. The volume of the work 150 pages (164 pages with annexes). There are 21 table, and 29 figures in the dissertation. The list of references consists of 177 titles.

CONTENT OF THE DISSERTATION

REVIEW OF THE DISSERTATION CONTENT

Chapter 1. Theoretical aspects of changes in energy supply and modelling of their impact on the economy

The first chapter of the dissertation has been devoted to the theoretical issues of relationships between energy and economy and their modelling possibilities.

1.1. Energy-economy relationships: a positive economics approach

Empirical observations suggest almost direct relationships between development of economy and the energy sector. However, econometrical estimations, reviewed in this chapter, are unable to confirm such opinion distinctly.

There are four main hypotheses that are usually examined in the empirical researches of positive economics (Yildirim & Aslan, 2012; Ozturk, 2010; Payne, 2010a): growth (the uni-directional causality running from energy consumption to economic growth), conservation (the uni-directional causality running from economic growth to energy consumption), neutrality (no causality), and feedback (bi-directional causality). The analysis of the scientific literature has revealed that results of empirical research are diverse. There have been found many papers that identify bi-directional causality between energy consumption and economic growth (feedback hypothesis). Nevertheless, the empirical results diverge in different articles even if the same country is analysed. In the case of electricity, neutrality hypothesis seems to be slightly dominant, but inconsistency of results obtained by different authors is also observed (Payne, 2010a).

This situation as well as other shortcomings of econometric research analysed (high aggregation level, vulnerability to the Lucas' critique, incapability to take into account technological change, lack of economic interpretation) give certain grounds for supposing that detailed analysis of energy-economy relationships and comprehensive approach to the development of energy technologies might be useful not only in the research related to the optimal integration of energy technologies representing the normative approach but also in positive economics, especially if the analysis is carried out retrospectively.

1.2. Economic mechanisms of changes in energy supply

In this section, formation of energy supply changes and its spread through the remaining economy has been discussed. The relationships between world oil prices and activity results of Lithuanian wheat growers have been presented as a good case in point. Oil price changes can affect both expenses and revenue of the farm, but evaluation of final impact on profit requires a comprehensive approach to the relationships between energy and economy, because of possible influence of indirect factors.

It has been stressed that energy resources are rarely used in a raw form. Usually the energy activity consists of various steps including supply of primary energy resources, transportation and transformation processes, and supply of final energy. All these stages involve the interaction with the remaining economy and energy infrastructure, which plays a crucial role in formation and spread of energy supply changes.

The economic mechanism explaining the spread of impact of energy supply changes is depicted in Figure 2. The first stage of this mechanism consists of structural changes within the energy sector. These changes are caused by different factors which have been divided into four categories, namely political, infrastructural, resources, and consumption factors. One also should not overlook the fact that these factors can be considered as both internal and external. Energy supply changes caused by the energy infrastructure are among good illustrations of this: closure of large electricity generation source inside of the country (e.g. Ignalina Nuclear Power Plant in Lithuanian case) would be considered as an internal factor influencing final energy supply, whereas accident in international energy transmission infrastructure in neighbouring country would be treated as an external factor. Thus, external influence is possible but not necessary prerequisite for energy supply change.

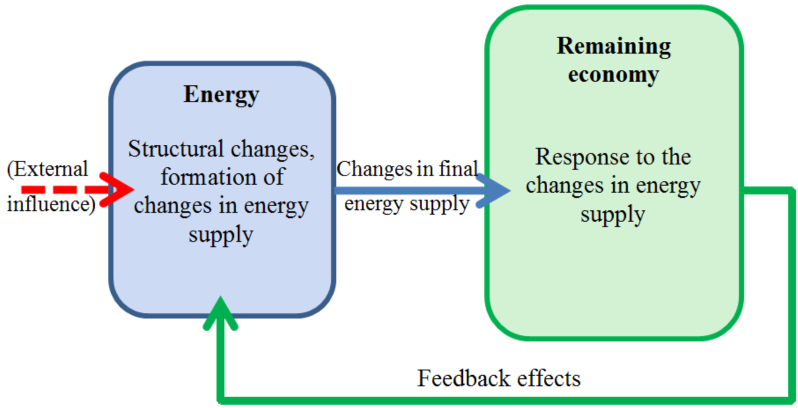

Figure 2. The mechanism of impact of energy supply change on the economy

Next stage is related with the spread of changes in final energy supply to the remaining economy (all other institutional sectors and economic activities except the energy). This stage is essentially shaped by the structure of the economy and energy resources used in the particular activity. Finally, economic feedback effects play indispensable role in the further spread of the energy shock, a vivid example being energy price spiral.

1.3. Possibilities for reflection of energy-economy relationships in energy planning models

Adequate consideration of energy-economy relationships is highly important in energy planning projects but up to now it remains an open question, whether and to what extent should these relationships be included into the model. Analytical standpoints in terms of model's coverage fall generally into the groups of comparative, energy system simulation, and comprehensive approaches. Only the last group of standpoints tends to consider energy-economy relationships as a factor to be modelled while other groups might view them as an exogenous subject. In this case, essential feedback effects are frequently missing.

In respect of the depth of analysis, top-down and bottom-up approaches are distinguished. The latter approach concentrates on the performance of particular elements (e. g., energy technologies), whereas top-down approach devotes more attention to the description of the economy as a whole. Top-down models can be further arranged according to the preponderance of statistical or economic theory in their foundations.

Based on economic theory, the framework of CGE models enables to analyse rebound and other feedback effects as well as sufficient representation of intersectoral relationships. Nonetheless, CGE models retain a number of drawbacks that are also typical for other top-down models. These drawbacks, among others, include high aggregation level and failure to represent complexity of the energy sector. Using three-dimensional system, which was firstly developed by Bataille (2005) and consists of microeconomic, macroeconomic, and technological dimensions, it has been demonstrated that both top-down and bottom-up approaches are unable to perform well in at least one of dimensions: conventional bottom-up models fail to include micro- and macro-economic realities, while conventional top-down models lack ability to represent physical constraints as well as technological peculiarities of the energy system. Thus, it is valid to state that combination of peculiarities of different model types can improve representation of relationships between energy and economy and, consequently, enhance the quality of the analysis.

1.4. Hybrid energy-economy models as a tool for comprehensive economic research

In this section, hybrid models, which combine top-down and bottom-up approaches, are discussed. Depending on the strategy, hybrid models may be created in the following ways: by linking two independently developed models; by adding some properties of the remaining approach to either top-down or bottom-up model (using so called reduced form of other modelling approach); and by creation of fully integrated model. Furthermore, the models based on different approaches might be linked using soft-linking and hard-linking methods. In this connection, the use of uniform software platform is one of factors which facilitate the linking of models.

The analysis of hybrid models presented in the scientific literature has shown that the prevailing trend is hybridisation of top-down models, although full integration strategy becomes more attractive due to the development of solution algorithms for mixed complementarity problems. Comparisons of modelling results obtained using hybrid and pure forms of top-down or bottom-up models have revealed significant improvements of the analysis in terms of thoroughness and representation of general equilibrium effects.

Chapter 2. Hybrid model for analysis of energy-economy relationships

The second chapter describes the structure, mathematical formulation and practical implementation of the model developed. The model is composed of two modules, namely economic module, and energy module. These modules are run simultaneously using single objective function which may be multicriterial. It is worth to mention that both modules are rather flexible and adjustable according to the needs of analysis and data available.

2.1. Formalisation of the relationships within the economy

The economic module covers all economic relationships which are usually depicted in the social accounting matrix framework. Product formation in the economic module is based on nested structure of constant elasticity of substitution (CES) functions combined with Leontiev function for depicting of intermediate consumption, and constant elasticity of transformation (CET) function for export. The product formation process is shown in Figure 3.

The composite energy resource is formed by coupling (using CES functions) other energy sources, district heat, natural gas, and electricity. This composite energy resource is then coupled with the composite production factor consisting of labour and capital. In all functions efficiency improvements are considered by including special dynamic efficiency index, which is to be set exogenously.

As a small open economy, Lithuania is actively involved in the international trade. Empirical evidence suggests that a large share of certain products (e.g. cars, basic metals, etc.) is re-exported. In order to reflect these real-life conditions avoiding computational difficulties, domestic production has been coupled with import and this composite product then transformed into export and goods for consumption in the domestic market by applying CET functional form. Furthermore, trade and transport margins have been considered as an additional demand, which makes impact on the prices of product that require margins.

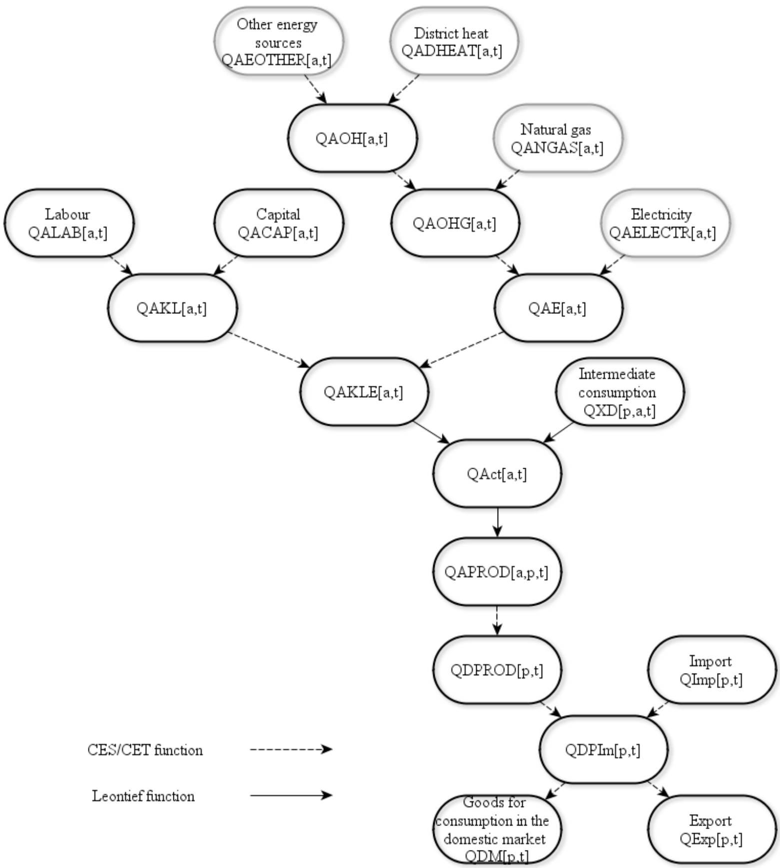

Figure 3. Product formation in the economic module

For modelling labour market, there has been developed a special conception which allows unemployment and adjustment of labour supply taking into account the level of real wage. Final domestic consumption has been represented by households, government, and formation of fixed capital. Moreover, the model also encompasses market clearing conditions as well as other important factors, such as savings, direct and indirect taxes, and social security system.

2.2. Energy technologies' description in the hybrid model

In principle, the energy module shares many features of conventional bottom-up energy planning models, such as MESSAGE, MARKAL/TIMES, Balmorel, etc. However, an additional mechanism has been introduced for evaluation of changes in energy module and their reflection in economy module. The most important property is description of the links to the remaining economy. These links describe the use of inputs from the energy model per arbitrary unit (e. g., megawatt year produced, megawatt installed) and must be depicted next to each technology which is included into the energy module. Options, how energy technologies can be described in the framework developed, are illustrated by Figure 4.

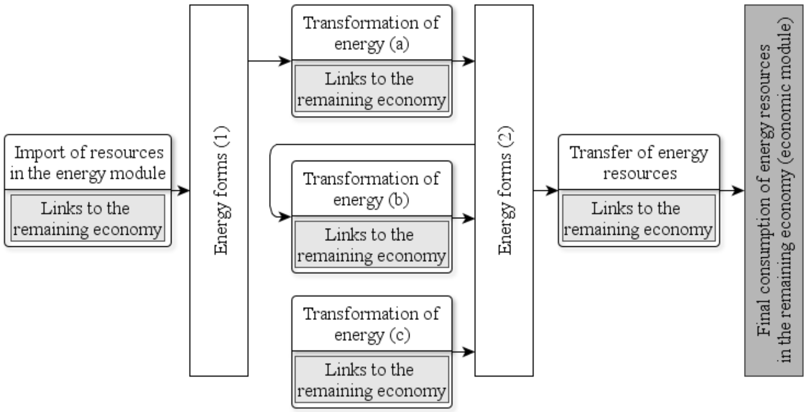

Figure 4. Energy technologies' description options in the energy module

In general, there are three types of transformation technologies considered. These technologies can a) transform imported energy forms; b) transform secondary energy forms to different kinds of energy; c) perform transformation of resources without inputs from the energy module. The last option is applicable not only for technologies which use renewable energy sources, but also in the case when supply of energy resources is modelled in the economic module.

Final consumption of energy resources is another point for linking of modules, inasmuch as output of the energy module refers to energy resources that are used in production process (see Figure 3) as well as in the final energy consumption.

2.3. Preparation of social accounting matrix and other data needed for the modelling

This section has been devoted to the description of the main steps of compilation of social accounting matrix and preparation of other data that are necessary for practical implementation of the model. The SAM compilation algorithm consists of 17 steps which cover creation of different submatrices and balancing of the entire SAM. The algorithm has been developed to ensure fast and uncomplicated renewal of social accounting matrix. The results of careful data availability analysis, which has revealed inconsistency problems in national energy and economic statistics, have also been taken into account.

2.4. Model's economic parameters estimation

Different techniques have been applied in order to estimate economic parameters of the model. As has been mentioned, SAM is the main database of the economic module. However, only part of the data necessary can be taken directly from the SAM. Therefore, additional calibration procedures as well as decompositions of prices and quantities have been performed. In addition, some parameters, such as elasticities of substitution, have been taken from the scientific literature. Analysis has shown significant differences in the values of these parameters depending on source. Thus, it has been decided to perform sensitivity and uncertainty analysis to ensure reliability of the results obtained.

2.5. Software implementation of the hybrid model

In order to ensure effective implementation of the model, a suite consisting of GAMS package with Gtree user interface and MS Excel has been created. Hybrid model has been formulated as a non-linear programming (NLP) problem. Therefore, it requires good initial values to be chosen. A special iterative routine has been established to manage the model when long time period or scenarios with large deviations from the base case are analysed.

In addition, an algorithm for even more sophisticated analysis of energy sector with regard to its relations to the economy has been developed. The main principle of this algorithm is shown in Figure 5.

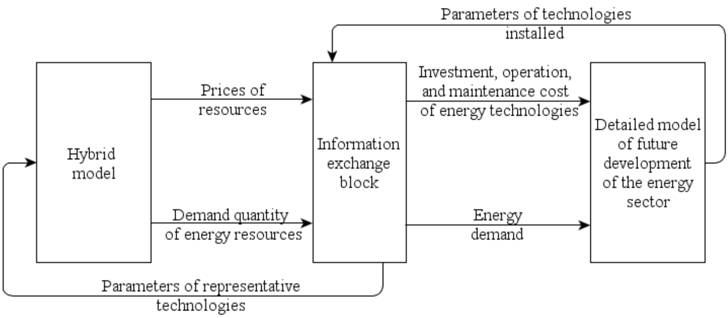

Figure 5. Common application of the hybrid model with the detailed model of future development of the energy sector

Detailed analysis of the energy sector is usually performed using linear programming (LP) models which allow avoidance of many computational difficulties, which appear using NLP models. Thus, for the deep analysis of energy technologies, hybrid model presented in this dissertation is able to be combined with LP model of the energy system through information exchange block.

Chapter 3. Analysis of energy supply changes in the Lithuanian case

In the third part, practical implementation of the model is illustrated applying it in the case of Lithuania. This part covers brief description of the situation in the Lithuanian energy sector, scenario formulation, analysis of the results, sensitivity and uncertainty analysis.

3.1. Formulation of scenarios of energy supply changes

Analysis of the current energy situation in Lithuania has shown that after closure of Ignalina nuclear power plant electricity generation in Lithuania declined considerably. As a consequence, country's dependency on imports of energy resources increased. Therefore, economic analysis, which has been performed using the model developed, covers these important issues. The main scenarios analysed as well as logics of scenario formulation is presented in Table 1.

Table 1. The key scenarios analysed

<table>
<tr><td colspan="2" rowspan="2">Prices for imported energy resources
Attributes of the energy sector structure</td><td>Prices for imported energy resources remains at the level of the structural scenario (see the left column)</td><td>Price for imported electricity increases by 20%</td><td>Price for imported natural gas increases by 20%</td></tr>
<tr><td></td><td>E20</td><td>D20</td></tr>
<tr><td>Energy structure reflects the situation in 2008</td><td>Bazinis</td><td>Bazinis</td><td>BazinisE20</td><td>BazinisD20</td></tr>
<tr><td>Energy structure is close to the situation in 2011: shutdown of Ignalina NPP, increased electricity import and prices for imported electricity, expanded role of RES in heat and electricity production</td><td>S1</td><td>S1</td><td>S1E20</td><td>S1D20</td></tr>
<tr><td>Energy structure as in S1 group of scenarios, but electricity import can grow only up to 50% of 2011 level</td><td>S2</td><td>S2</td><td>S2E20</td><td>S2D20</td></tr>
</table>

There are two general properties of the main scenarios: energy structure, and prices for imported energy resources. These properties reflect different mechanisms of changes in energy supply: alterations in energy structure are mainly caused by internal factors, while import price changes are determined by external factors, insofar as Lithuania is considered as a small open economy. The base case (*Bazinis* scenario) or benchmark scenario represents structure of the energy sector as it was in 2008, because this year is the base year of the model. Other scenarios represent structural deviations from the base case. The same principle has been applied for analysis of results which have been compared to the situation in base case.

3.2. Impact analysis of energy supply changes caused by internal and external factors

In this section, detailed results of scenario modelling have been presented and discussed. These results include, among others, changes in relative prices, output, international trade, and final demand.

Impact on output of economic activities differs depending on scenarios formulated. In all key scenarios analysed the output of agriculture, food, paper, plastic, chemical products, other non-metallic and mineral products and services decreases, whereas output of forestry, textile and transport increases. Change of output in wood and other industries depends on the nature of changes in energy supply. Increase of prices for imported electricity and natural gas has negative impact on output of wood sector in the case of unchanged structure of energy sector. However, changes in energy structure analysed in group of scenarios S1 have positive impact on the output of both forestry and other industries' products even in case of growing prices for imported electricity and natural gas.

For general comparison of the scenario results, Hicksian equivalent variation (HEV) has been employed. This indicator shows welfare losses (or benefits) expressed as amount of money which should be added to (or deducted from) the consumers' income in order to ensure a utility level equivalent to the utility in the benchmark scenario. The comparison of welfare losses in different scenarios is shown in Figure 6.

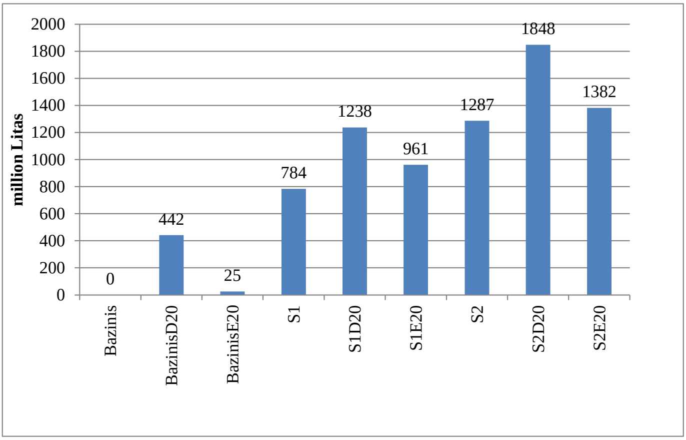

Figure 6. Welfare loss due to different scenarios of energy supply changes

All scenarios analysed have negative impact on economic welfare. The largest loss of welfare is observed in the scenario S2DE20 which expresses conditions of S2 energy structure and increase of both electricity and natural gas prices.

3.3. Sensitivity and uncertainty analysis of modelling results

Sensitivity and uncertainty analysis has been performed using SimLab package. Taking into account the fact that there is wide variety of values of elasticity parameters in the scientific literature, it has been decided to perform this analysis by changing values of elasticities.

The results of uncertainty analysis in the case of S2D20 scenario are provided in Figure 7.

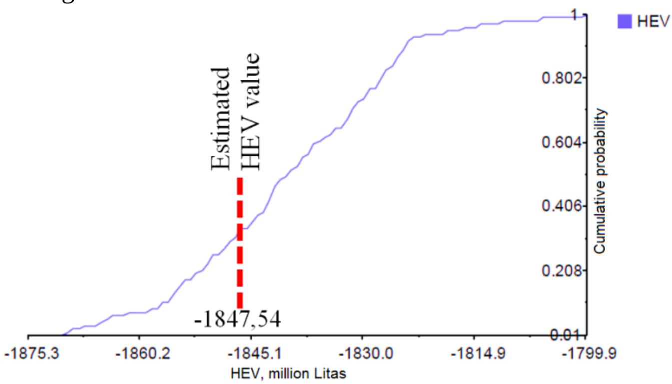

Figure 7. Uncertainty of Hicksian equivalent variation in the case of S2D20 scenario

Due to these results, it can be reasonably argued that change of elasticity parameters used in the model have only moderate impact on the results of modelling.

CONCLUSIONS

1. Despite of the fact that empirical data allows identification of close relations between economic crises and oil price changes as well as other energy-related factors, critical review of empirical studies, dealing with relationships between energy consumption and economic growth, has revealed significant incompatibility of results obtained using econometrical methods. One of fundamental reasons for the incompatibility identified is development of energy technologies which has notable impact on changing nature of energy-economy relationships. Therefore, retrospective analysis of energy technologies can be applied for positive economic research.

2. Changes in energy supply are caused by political, infrastructural, resource and consumption factors. It has been established that the impact of changes in energy supply depends not only on their nature and scale but also on the mechanism of energy shock transfer to the remaining economy. This mechanism is largely determined by the structure and changeability of the energy sector, inasmuch as the energy infrastructure plays crucial role in economic adjustment process to the changes of primary energy resources supply.

3. Analysis of economic models, presented in the scientific literature, has shown that, on the one hand, traditional bottom-up energy planning models fail to reflect energy relationships with the remaining economy. Therefore, their assumptions about energy demand are incapable of full description of impact of energy structure changes on the development of the national economy. On the other hand, top-down models, characterized by the high aggregation level of the energy sector, are unable to allow analysis of energy technologies and their economic properties.

4. In order to model energy-economy relationships in an appropriate way, there are some attempts to create hybrid models which would combine characteristics of bottom-up and top-down models. Mostly, such models are developed either by extending one of above mentioned model types or by soft-linking two different models. It has been shown that these strategies also cause partial loss of information or limit possibilities to model the behaviour of particular energy technology in a complex energy system.

5. The solution that has been developed in this work is a fully integrated hybrid energy-economy model which can be combined with a detailed model of the energy system. Economic module of the hybrid model is designed as a dynamic CGE model, whereas energy module consists of simplified energy system development model based on the principle of flexible and transformable

oriented graph. This model allows sufficient resolution of the energy sector structure and comprehensive analysis of impact of changes in energy supply on the remaining economy.

6. Developed algorithm for creation of social accounting matrix can be applied for any country in the case if its national accounting system is close to the international (ipso facto Lithuanian) standards of statistics. Moreover, additional tools for practical implementation of the hybrid model presented in the dissertation can be used in order to ensure efficient performance of other computable models.

7. After analysis of energy supply change scenarios presented in the dissertation, it has been found that their impact differs with respect to the particular branches of the economy:

a) in all key scenarios analysed, the output of agriculture, food, paper, plastic, chemical products, other non-metallic and mineral products and services decreases, whereas output of forestry, textile and transport increases
b) change of wood and other industries output depends on the nature of changes in energy supply. Increase of prices for imported electricity and natural gas has negative impact on output of wood sector. However, broader usage of renewable energy sources in the energy sector has positive impact on the output of both forestry and wood sectors.

8. Impact of energy supply change scenarios on economic welfare has been evaluated using Hicksian equivalent variation indicator. It has been found that:

a) changes of energy supply have negative impact on general economic welfare in all scenarios analysed. This negative impact, depending on scenario, may reach 25-1940 million Litas (0.03-2.63% of base level);
b) the impact of increase of imported natural gas price has stronger negative impact than impact of increase of imported electricity price in all scenarios analysed.
c) greater negative impact is on the scenarios of changes in energy structure rather than on the analysed scenarios with import price change only. Impact on the HEV of shift from energy structure in 2008 towards the structure similar to 2011 is estimated to be 784 million Litas.
d) limitation of imported electricity in the case of changed structure of the energy sector would increase negative impact on HEV to 1287 million Litas.

9. Sensitivity and uncertainty analysis of modelling results revealed that change of elasticity parameters used in the model have only moderate impact on the results of modelling in terms of Hicksian equivalent variation.

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REZIUMĖ

Mokslinių tyrimų aktualumas. Brangstant energijos ištekliams, sprendžiant klimato kaitos klausimus didėja energetikos sektoriaus, laikomo šiuolaikinės ekonomikos pagrindu, vaidmuo. Tai ypač aktualu tokioms didžiąją dalį energijos išteklių importuojančioms šalims kaip Lietuva.

Daugumoje esamų ekonomikos modelių energetikos sektorius atspindimas nepakankamai (ypač technologinės alternatyvos bei fiziniai ribojimai), todėl energetika ir jos poveikis kitoms ūkio šakoms gali būti

nagrinėjama tik fragmentiškai. Ši problema itin aktuali bandant įvertinti energijos išteklių pasiūlos pokyčių poveikį, kadangi pasikeitimai pirmiausiai vyksta energetikos sektoriuje ir priklauso ne tik nuo energijos išteklių pasiūlos, bet ir nuo energetikos specifikos, energijos išteklių transformavimo pajėgumų ir panašių veiksnių.

Šiuo metu Lietuvos ir kitų šalių praktikoje taikomi energetikos planavimo modeliai geriausiu atveju yra paremti dalinės ekonominės pusiausvyros principu ir neįvertina pokyčių energetikoje makroekonominio poveikio. Išsamiai analizei reikalingi lanksčios struktūros hibridiniai modeliai, kuriuose būtų įvertinama sąveika tarp energetikos ir kitų ūkio šakų, išlaikant pakankamą energetikos sektoriaus detalizavimo lygį.

Mokslinė problema ir jos ištyrimo lygis. Energijos išteklių pasiūlos pokyčių problemos mokslinėje literatūroje bandomos gvildenti naudojant skirtingas metodologines prieigas, aptartas teorinėje šio darbo dalyje. Pozityviajai ekonomikai atstovaujančiuose tyrimuose energetikos ir ekonomikos ryšiai analizuojami taikant ekonometrinius metodus. Paminėtini Apergis ir Payne (2011b), Huang, Hwang ir Yang (2008) darbai, kuriuose nagrinėjami energijos vartojimo ir ekonomikos augimo ryšiai. Energijos vartojimo ryšių su ekonomikos augimu šio pobūdžio tyrimus apibendrina Ozturk (2010) bei Payne (2010b). Labai plačią elektros energijos vartojimo ir ekonomikos augimo ryšių apžvalgą pateikia Payne (2010a). Gamtinių dujų vartojimo ryšius su ekonomikos augimu nagrinėja bei kitų autorių šios srities tyrimus aptaria Apergis ir Payne (2010a). Daug dėmesio energetikos klausimams šalies ekonomikos augimo kontekste skyrė Bobinaite, Juozapaviciene ir Konstantinaviciute (2011b), taip pat nagrinėjusios ir atsinaujinančių energijos išteklių platesnio naudojimo įtaką Lietuvos ekonomikos augimui (Bobinaite, Juozapaviciene ir Konstantinaviciute, 2011a).

Kita energijos išteklių pasiūlos pokyčių tyrimų paradigma yra artimesnė normuojančiosios ekonomikos požiūriui ir siekia ne tik aprašyti realybėje susiklosčiusius ryšius, bet ir numatyti tinkamas priemones jiems keisti. Šiai paradigmai atstovauja energetikos perspektyvinės raidos modelius kuriantys mokslininkai (kai kurių tokių modelių apžvalga pateikiama Connolly et al. (2010) straipsnyje), tačiau daugelyje tokių kylančiuoju požiūriu paremtų modelių naudojamas tik dalinės ekonominės pusiausvyros principas. Platesnį kontekstą apimantiems energetikos ir ekonomikos ryšių analizės darbams kuriami besileidžiantieji makroekonominiai modeliai. Labai stambią grupę sudaro bendrosios pusiausvyros modeliai, kurių panaudojimo laukas, be kita ko, apima ir biodegalų įtakos klimato kaitai ekonominį vertinimą (Timilsina ir Mevel, 2012), energijos generavimo šaltinių pasikeitimų ekonominius efektus (Bretschger, Ramer ir Zhang, 2012), naftos kainų šokų poveikį ekonomikai (Aydın ir Acar, 2011), perėjimą prie nedideliais išmetamų anglies junginių kiekiais pasižyminčios ekonomikos (Böhringer ir Rutherford, 2013) ir kitas energetikos ekonomikos tyrimų sritis.

Išryškėjus minėtų modeliavimo požiūrių trūkumams prasidėjo palyginti nauja perspektyvi tendencija energetikos perspektyvinės raidos modeliavime ir energetikos bei ekonomikos ryšių analizėje – hibridinių energetikos ekonomikos modelių kūrimas. Šiais modeliais bandoma apjungti detaliai energetiką vaizduojančius modelius su platų ekonominį kontekstą apimančiais modeliais. Nors tokių tyrimų nėra daug, paminėtini Böhringer ir Rutherford (2008), Jaccard (2009) darbai. Tokių modelių aktualumą ir sudėtingumą liudija faktas, kad jų apžvalgai vienas prestižiškiausių energetikos ekonomikos žurnalų The Energy Journal paskyrė specialų numerį (Hourcade et al., 2006).

Lietuvoje energijos išteklių pasiūlos pokyčių ir jų įtakos šalies ekonomikai problematika buvo analizuojama palyginti fragmentiškai. Vilkas (1997) ekonominės pusiausvyros modeliavimą taikė padidėjusio energetikos pajėgumų išnaudojimo poveikio analizei, Galinis ir van Leeuwen (1998, 2000) nagrinėjo skirtingus branduolinės energetikos tęstinumo scenarijus, Kalinauskas ir Tamošiūnas (2000) tyrė naftos kainų didėjimo įtaką, Kuodis (2001) vertino IAE uždarymo pasekmes. Štreimikienė ir Mikalauskienė (2004) analizavo dalinės ir bendrosios pusiausvyros modelių panaudojimo vertinant aplinkosaugos politikos priemonių poveikį energetikai ir ekonomikai galimybes.

Apibendrinant mokslinės problemos ištyrimo lygį galima konstatuoti, kad nors energijos išteklių pasiūlos pokyčių poveikio ekonomikai problemų aktualumas plačiai suvokiamas, iki šiol nėra nusistovėjusios tyrimų metodologijos, o naudojamos skirtingos metodologinės prieigos turi savų privalumų ir trūkumų.

Mokslinio darbo problema – kaip įvertinti energijos išteklių pasiūlos pokyčių kompleksinį poveikį šalies ekonomikai?

Tyrimo objektas – energijos išteklių pasiūlos pokyčių poveikis šalies ekonomikai.

Mokslinio darbo tikslas – sukurti bei Lietuvos atveju pritaikyti energijos išteklių pasiūlos pokyčių analizei skirtą modelį.

Iškeltam tikslui pasiekti suformuluoti tokie **tyrimų uždaviniai**:

- Teoriniu ir empiriniu požiūriu išnagrinėti energetikos ryšius su likusia ekonomika bei energijos išteklių pasiūlos pokyčių mechanizmus.
- Išanalizuoti energetikos ir ekonomikos ryšių atspindėjimą skirtingose energetikos planavimui skirtų modelių rūšyse ir jų taikymo energijos išteklių pasiūlos pokyčių analizei galimybes.
- Sukurti hibridinį energetikos–ekonomikos modelį, įgalinantį analizuoti energijos išteklių pasiūlos pokyčių poveikį ekonomikai.

- Parengti duomenų bazę ir sukurti įrankius, reikalingus modelio praktiniam taikymui Lietuvos sąlygomis.
- Naudojant sukurtąjį modelį įvertinti gamtinių dujų ir elektros importo kainų kaitos įtaką Lietuvos ekonomikai, priklausomai nuo energetikos struktūros pasikeitimų.
- Atlikti modeliavimo rezultatų jautrumo ir neapibrėžtumo analizę.

Disertacijos struktūrą ir loginį medžiagos dėstymą lėmė mokslinio darbo tikslas ir jo pagrindu suformuluoti tyrimo uždaviniai. Laikantis klasikinės disertacijos struktūros, tyrimo uždavinių sprendimas pateiktas trijose disertacijos dalyse.

Pirmojoje disertacijos dalyje *Energijos išteklių pasiūlos pokyčių ir jų poveikio ekonomikai modeliavimo teoriniai aspektai* analizuojami energetikos ryšiai su likusia ekonomika, energijos išteklių pasiūlos pokyčių susidarymo ir poveikio visai ekonomikai mechanizmai ir jų tyrimų metodai. Daug dėmesio skiriama energetikos ir ekonomikos ryšių atspindėjimo skirtingų rūšių energetikos perspektyvinės raidos planavimo modeliuose galimybėms.

Antrojoje disertacijos dalyje *Hibridinis energetikos ir ekonomikos ryšių analizės modelis* pristatomas disertacijos autoriaus sukurtas hibridinis modelis, apibendrinantis kylančiųjų ir besileidžiančiųjų modelių savybes ir įgalinantis išsamiai analizuoti energijos išteklių pasiūlos pokyčių įtaką šalies ekonomikai. Šioje dalyje aptariama hibridinio modelio sandara, reikalingų duomenų šaltiniai, socialinės apskaitos matricos kaip pagrindinio ekonominių duomenų šaltinio sudarymo ypatumai ir šio modelio programinis realizavimas.

Trečiojoje disertacijos dalyje *Energijos išteklių pasiūlos pokyčių analizė Lietuvos atveju* pateikiama praktinių skaičiavimų naudojant sukurtąjį modelį eiga ir rezultatai Lietuvos atveju. Šioje dalyje išanalizuotas importuojamų gamtinių dujų ir importuojamos elektros energijos kainų pasikeitimų poveikis trijų energetikos struktūros scenarijų atveju.

Išvadose apibendrinami disertacijoje pristatomų autoriaus atliktų tyrimų rezultatai.

Tyrimo metodai. Teoriškai analizuojant energijos išteklių pasiūlos pokyčius ir jų modeliavimo galimybes taikomi mokslinės literatūros analizės ir sintezės metodai. Sudarant hibridinį modelį taikomi matematinio ekonominių procesų modeliavimo, modelio kalibravimo metodai. Modeliavimui reikalingų statistinių duomenų apdorojimui (koreliacinei ir regresinei analizei) naudotas programinis paketas STATISTICA, darbe pristatomiems energetikos sektoriaus modeliavimo tyrimams atlikti ir modeliavimo sprendimams testuoti naudotas Tarptautinės atominės energetikos agentūros platinamas MESSAGE modeliavimo programinis paketas, o darbe pristatomas hibridinis energetikos ekonomikos modelis ir praktiniam jo taikymui reikalingi papildomi įrankiai parengti naudojant GAMS programinį paketą su Gtree vartotojo sąsaja.

Modelio valdymo programinei sąsajai sukurti ir rezultatams apdoroti naudota Microsoft Excel 2010 programa bei joje integruoti VBA programiniai įrankiai. Modelio rezultatų analizė atlikta naudojant Europos Komisijos Jungtinių tyrimų centro platinamą SimLab 2.2.1 programinį paketą.

Darbo mokslinį naujumą ir reikšmingumą bei autoriaus indėlį į nagrinėjamą problematiką nusako tokie gauti rezultatai:

- Išnagrinėjus energijos išteklių pasiūlos pokyčių mechanizmus identifikuotas energetikos infrastruktūros vaidmuo energijos šokų sklaidai į kitas ekonomikos sritis.
- Sukurti originalūs modeliavimo sprendimai, apimantys tiek bendrosios ekonominės pusiausvyros modeliavimą, tiek energetikos sektoriaus ir bendrosios ekonominės pusiausvyros modelių integravimą.
- Sukurtas naujas hibridinis modelis, kuriame galima lanksčiai atspindėti energetikos struktūrą ir analizuoti energijos išteklių pasiūlos pokyčių makroekonominius efektus įvertinant tarpsektorinius ryšius.
- Naudojant šį modelį atlikti vertinimai Lietuvos sąlygomis, tokiu būdu pereinant nuo daliniais metodais pagrįstos prie kompleksinės analizės.

Praktinę darbo vertę pagrindžia galimos modelio panaudojimo sritys:

- energijos išteklių pasiūlos pasikeitimų poveikio *ex-ante* ir *ex-post* analizei
- ryšių tarp energetikos ir kitų ūkio šakų analizei panašios ekonomikos struktūros šalyse
- išorinių socialinių ir ekonominių efektų (sąnaudų ir naudos), susijusių su energijos gamybos šaltinių pasirinkimu, vertinimui
- energetinio saugumo vertinimui ekonominiu aspektu
- energetikos ir ekonomikos politikos formavimui, strateginių sprendimų priėmimui
- ateities energetikos technologijų integravimui į energetikos sistemą ir kt.

Gautų rezultatų praktinį pritaikomumą liudija ir tai, kad atskiri disertacijoje pristatomo modelio elementai buvo testuojami sėkmingai įvykdytuose užsakomuosiuose mokslinių tyrimų darbuose (platesnio biokuro panaudojimo socialinės ir ekonominės įtakos vertinimas Lietuvos šilumos tiekėjų asociacijos užsakymu rengiant Kompleksinę investicinę programą 2011–2020 metams, Kauno miesto integruoto šilumos tiekimo perspektyvinės raidos, įvertinant biokuro platesnio panaudojimo galimybes, modelio kūrimas AB „Kauno energija“ užsakymu, energetikos ir ekonomikos ryšių modeliavimas Lietuvos mokslo tarybos finansuotame projekte „Ateities technologijų optimalaus integravimo į energetikos sektorių metodologijos sukūrimas“ ir kt.).

Darbo apribojimai ir tolesnių tyrimų kryptys. Darbe pateiktų empirinių rezultatų patikimumą gali riboti faktas, kad modelio baziniais metais teko pasirinkti 2008 m. Ekonominės plėtros požiūriu šie metai anaiptol nebuvo tipiniai, tačiau atliekant disertacijoje pristatomus tyrimus šie metai buvo vieninteliai, apie kuriuos pateikiami visiškai suderinami statistiniai duomenys, parengti pagal EVRK 2 red. Darbe aprašyti pradinių duomenų parengimo ir apdorojimo algoritmai yra universalūs, todėl pasinaudojant jais tolesniuose tyrimuose būtų pravartu pasirinkti „stabilesnį“ bazinį laikotarpį. Modelio pritaikomumą (ypač didelės apimties dinamikoje nagrinėjamų problemų atveju) gali riboti ir jo taikymui analizuojant specifinius projektus reikalingas duomenų kiekis bei skaičiavimo technikos ir programinės įrangos pajėgumai.

Kitos galimos tolesnių tyrimų kryptys – pakeitimo elastingumo parametrų Lietuvos sąlygomis nustatymas (darbe, remiantis standartine bendrosios pusiausvyros modelių kūrimo praktika, elastingumo parametrai parinkti pagal literatūros šaltinius, o jų įtaka modeliavimo rezultatų neapibrėžtumui įvertinta atliekant jautrumo analizę), skirtingų modelio specifikacijų (detalizuojant namų ūkių ir darbo jėgos grupes) parengimas ir tyrimas, pažangių energetikos technologijų integravimo į energetikos sistemą modeliavimas apjungiant disertacijoje pristatomą modelį su detaliu energetikos sektoriaus perspektyvinės raidos modeliu.

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