Economic Research-Ekonomska Istraživanja

ISSN: 1331-677X (Print) 1848-9664 (Online) Journal homepage: http://www.tandfonline.com/loi/rero20

Economic efficiency and transformation of the Russian energy sector

Evgeny Lisin, Wadim Strielkowski & Ivan Garanin

To cite this article: Evgeny Lisin, Wadim Strielkowski & Ivan Garanin (2015) Economic efficiency and transformation of the Russian energy sector, Economic Research-Ekonomska Istraživanja, 28:1, 620-630, DOI: 10.1080/1331677X.2015.1086886

To link to this article: http://dx.doi.org/10.1080/1331677X.2015.1086886

Economic Research-Ekonomska Istraživanja, 2015
Vol. 28, No. 1, 620–630, http://dx.doi.org/10.1080/1331677X.2015.1086886

Economic efficiency and transformation of the Russian energy sector

Evgeny Lisin[a], Wadim Strielkowski[b]* and Ivan Garanin[c]

[a]*Department of Economics in Power Engineering and Industry, National Research University 'Moscow Power Engineering Institute', Krasnokazarmennaya 14, Moscow, Russia;* [b]*Faculty of Social Sciences, Charles University in Prague, Smetanovo nabr. 6 110 01, Prague, Czech Republic;* [c]*Department of Thermal Power Plants, National Research University 'Moscow Power Engineering Institute', Krasnokazarmennaya 14, Moscow, Russia*

(*Received 6 April 2015; accepted 22 August 2015*)

This paper considers the issues of economic transformation, reconstruction, and technical re-equipment of the energy sector in the Russian Federation. The sector is struggling with economic inefficiency and post-transformation legacy. Energy sector transformation represents a key element in ensuring the energy security and it one of the most troubling questions of energy economics nowadays. It is expected that by 2020 more than half of the energy equipment in Russia would exceed its economic life. Our results show that the main goals of reconstruction might include life extension, increasing production efficiency, and output. We demonstrate that these goals can be achieved through partial replacement of the most worn parts of equipment (e.g. replacement of blades in the turbine), the combination of new and old equipment (such as add-in steam and gas cycle), and full replacement of equipment.

Keywords: economic efficiency; transformation; cogeneration; energy economics; energy sector; Russian Federation

JEL classification: C18, D24, E23, L94, O14, P51, Q48.

1. Introduction

The energy sector represents a key part of the economy of any country and is one of the factors determining economic growth as well as the generation of GDP. The energy sector typically includes a plethora of industries involved in the production and sale of energy, including fuel extraction, manufacturing, refining, and distribution. The energy sector is a crucial part of the infrastructure and maintenance in the economies of developed countries.

The amounts of electricity and thermal energy must either grow faster or at the same rate as the output of goods and services produced in the economy. At the moment, the state of the art in modern technology does not allow the storing of energy in the most efficient way, so the reserves of electric power can be provided through construction and commissioning of new generation facilities. The increase of generating capacity creates space for overall growth of the national economies. Generation of electricity predetermines its consumption, with consumption being a variable that depends on a time of the day as well as the ambient temperature. This consumption is connected to the

---

*Corresponding author. Email: strielkowski@fsv.cuni.cz system at the time of increasing the power load, and thus supplies both large industrial customers, and small household end consumers.

Since the disintegration of the Soviet Union in the 1990s, the issue of the transformation of the obsolete energy sector has been high on the agenda of the economic transformation of the post-Soviet space (Lisin & Strielkowski, 2014; Samarin, Lushin, & Paulauskaite, 2007; Škare & Družeta, 2014; Streimikiene & Klevas, 2007). However, the economic transformation, including the transformation of energy sector was also typical for other post-socialist states as well (see for example Škare & Sinković, 2012). Needless to say, the reconstruction and technical re-equipment of the energy sector in many new EU Member States that bear the Socialist past also represent a major challenge for the energy economics of today (Augutis, Jokšas, Krikštolaitis, & Žutautaitė, 2014).

The widespread use of combined heat and power generation and a centralised district heating from power plants represent one of the peculiarities of the Soviet-style power industry. Heat is produced in about 500 thermal power plants, including industrial and general purpose cogeneration plants. The total capacity and power output of thermal power plant electricity is about 70% of the total capacity and power output in the country. Cogeneration power plants, also known as combined heat and power plants (CHP), are rationally integrated into the national Russian grid and show remarkable operating efficiency.

This paper is structured as follows. Section 2 provides a comprehensive literature review. Section 3 outlines the methodology of our research. Section 4 outlines the empirical model used in our study. Section 5 depicts the main results and discusses the outcomes. Section 6 concludes with some remarks and policy implications.

2. Literature review

Existing combined heat and power plants in Russia can be divided into three types (Bogachko, Pechenkin, & Timofeeva, 2005; Fujimitsu, 2001; or Sokolov & Kovylyanskii, 1990): (a) CHP initial subcritical steam parameters, (b) CHP initial supercritical steam parameters, and (c) CCGT (Combined Cycle Gas Turbine) CHPs.

The transition from one technology combined production of electricity and heat to another leads to different economic effects. In general, an increase in the initial parameters and the transition to combined cycle increases the efficiency of CHP. For example, the difference between the amount of power produced by the steam power unit and combined-cycle unit in condensing mode can reach 84 gce/kWh (see Vasiliev, 1993; or Zeigarnik, 2006).

For CHP, the transition to a more technologically advanced technology is not as straightforward as in the case of condensing power plants. This is due to the fact that most of the CHP electricity is released with a significant heat load. The share of electricity in the summer months with respect to the annual output of many Russian CHPs does not exceed 17%. Additionally, there is another interesting aspect: the replacement of equipment with increasing parameters or switching to combined cycle and maintaining the same installed capacity reduces the thermal power (Bogachko et al., 2005; or Zeigarnik, 2006).

All these factors lead to the need for a detailed study of the influence of the type of power station on the effectiveness and efficiency of production of heat and electricity in order to select the optimal alternative and increase the competitiveness of CHP in a market environment.

As variants, we consider the main power equipment units on the basis of cogeneration turbines T-110–130, T-255–240 and power units CCGT-450 (420), the most common representatives of various types of plants with combined heat and power production in Russia (Zeigarnik, 2006).

These power units are typical representatives of the implementation of the various technologies of combined production of heat and electricity. Turbine unit T-110–130 is the basis of steam-powered CHP subcritical parameters, T-255–240 – a steam-powered CHP plant with supercritical parameters, CCGT-450 and CCGT-420 – a combined cycle power plant (CCGT-CHP).

Cogeneration is one of the main directions of the energy policy of the Russian Federation, holding a course on energy efficiency. Cogeneration is a centralised power delivery technique based on joint production of heat and electricity in a single process. Centralization means that multiple heating and electricity consumers are supplied over the grid from a single source. In our case, the grid includes cogeneration power plant and interconnected electricity/heating distribution networks that together depend on continuous process modes of electricity and heat production, transformation, transportation and distribution.

As the available physical resources deplete and it becomes impossible to use them any longer, a need for new technologies arises. The existing CHPs were mostly built in the 1960s and the 1970s and their equipment is worn and obsolete (increased scope for repair and maintenance activities, a great number of maintenance personnel, or increased emissions into the environment). Obsolete and low-efficiency equipment should be taken out of operation and replaced with promising equipment that allows a significant reduction in the heat & power generation costs, reduced fuel consumption and staffing ratio, decreased environmental emissions and maintenance costs (Konova, Komarov, & Lisin, 2012; Maximov & Molodyuk, 2008; or Zamula & Kireitseva, 2013).

For gas-fired CHP, the transition to advanced energy-efficient technologies means the phasing out of steam power plants and replacement with combined cycle plants (Konova et al., 2012). It is expedient to build combined cycle power plants using standardised projects that meet up-to-the-date standards. To implement these projects, a new regulatory and technical framework that takes into account the evolution of technology solutions in the power industry and power engineering shall be developed.

Coal-fired CHP upgrade aims to increase the efficiency of turbines and boilers, reduce emissions into the environment, and decrease losses. In addition, a significant increase in the CHP efficiency is possible following the commercial development of coal gasification combined cycles: combined-cycle plants, developed based on this technology, ensure a significant increase in the overall plant efficiency (Lykova, Lisin, & Kocherova, 2012; Maximov & Molodyuk, 2008).

In the short and medium term, it is also necessary to consider the development of advanced power generating technologies. For this purpose, it is advisable to conduct feasibility studies for such solutions as the development of hybrid power plants based on fuel cells and coal-fired units with supercritical steam parameters, and to develop pilot plants with CO_2 removal from the energy cycle and disposal.

Due to the loss of a notable part of the industrial, scientific and technical potential, a technological re-equipping of the industry looks an extremely difficult task. To allow Russian power generating equipment manufacturers to boost their production capacities, long-term agreements with energy companies, which prefer using more efficient foreign technologies, are required. In market conditions, these agreements may be achieved through localization of production of major power generation equipment and components, thus increasing a technological level and industrial potential of the domestic power-plant engineering industry.

Additionally, is crucial to understand that, in principle, the existing technological base of the power generation industry was not created as a competitive base. Competition among power plants in providing electricity to consumers was not assumed, because simultaneous construction of several power plants, using the state-allocated funds, to supply power to the same consumers did not make any sense in a planned economy. Therefore, the established wholesale electricity market has got, to a great extent, the attributes of a natural monopoly, and this situation is not conducive to competitive pricing. It appears necessary to seek technical and economic solutions that facilitate the decentralisation in the industry; in other words, the emergence of small-sized efficient energy sources, which are capable of competing with large-sized power plants. At the same time, it is necessary to adhere to the country's energy development strategy, gradually making the transition from the pre-emptive use of natural gas to a significant use of fossil fuels (Kasperowicz, 2014; Lisin & Grigoryeva, 2012; Lisin, Strielkowski, Amelina, Konova, & Čábelková, 2014; Maximov & Molodyuk, 2008; Stoft, 2002). The presence of the above problems and major problems of public concern facing the industry in terms of the state course taken to ensure competitive energy markets, determines the relevance of the economic justification of the choice of modern technologies for the combined production of heat and electricity.

3. Conditions for obtaining fuel economy in the combined production of heat and electricity

The steam supplied to a cogeneration turbine may be conditionally viewed as comprising two flows (equation (1)). Both flows perform work together, unless their parameters reach the target values for steam delivered to consumers. At that point, one of the flows leaves the turbine to transfer heat to the consumer while the other is expended in electricity production and then fed to the condenser. Thus, the first flow is responsible for the electricity generation based on heat consumption, while the second flow is responsible for the condensation-stage generation.

$$D_0 = D_h + D_p \tag{1}$$

where D_0 is the flow rate of steam supplied to the turbine; D_h is the flow rate of extracted steam; D_p is the flow rate of steam passed to condenser.

The traditional alternative to a combined heat-and-power plant is a combination of condensing power plant with a boiler house. This combined system, therefore, serves as a comparison benchmark for evaluating savings offered by cogeneration. While retaining the mental division of steam flows, this system can be described as follows (equation (2)):

$$\Delta B_e = E_h(b_p^e - b_h^e) - E_{hp}(b_{hp}^e - b_p^e) \tag{2}$$

where E_h is the amount of electricity produced at the CHP plant using the combined method, i.e. with both flows working together prior to their separation; b_p^e is the specific fuel-equivalent consumption for electricity generation at a condensing power plant; b_h^e is the specific fuel-equivalent consumption of electricity generated using the combined method; E_{hp} is the amount of electricity generated at the CHP plant using the condensation method (utilising the steam flow left after extraction); b_{hp}^{e} is the specific fuel-equivalent consumption for electricity generated at the CHP plant using the condensation method.

Thus, the first component is the fuel savings that result from the combined generation of electricity and heat while the second component is the extra fuel consumed by the CHP plant as a result of resorting to the condensation method for electricity generation.

This excess consumption is the result of b_{p}^{e} always being less than b_{hp}^{e}, even if initial steam parameters are equal. A single formula is used for both variables (Sokolov & Kovylyanskii, 1990):

$$b_{p}^{e} = \frac{0,123}{\eta_{bu}\eta_{t}\eta_{oi}\eta_{ee}} \tag{3}$$

where 0.123 grams is the amount of fuel-equivalent burned to produce 1 kWh of electricity; η_{bu} is the efficiency of the power plant boiler unit allowing energy losses in the pipelines; η_{t} is the thermal efficiency of the condensation cycle; η_{oi} is the internal relative efficiency of the turbine unit; η_{ee} is the electromechanical efficiency.

Moreover, the design and duty-cycle differences between cogeneration and regular condensation turbines imply that $\eta_{oi_p} > \eta_{oi_h}$, and, given that the condensing power plant is usually situated close to available cooling water sources, while CHP facilities are built next to heat consumers, $\eta_{t_p} > \eta_{t_h}$. As a result, $b_{hp}^{e} > b_{p}^{e}$, forcing CHP plants to consume excess fuel when operating in the condensation mode.

At the same time, $b_{p}^{e} > b_{h}^{e}$ because electricity generation based on heat consumption means that the energy of the turbine exhaust steam is utilised by the heating consumer rather than wasted to the environment in the turbine unit condenser:

$$b_{h}^{e} = \frac{0,123}{\eta_{bu}\eta_{oi}\eta_{ee}} \tag{4}$$

where η_{oi} is the internal relative efficiency of the turbine compartment passed through by the steam prior to extraction.

It follows from equations (2) and (4) that savings from the combined generation of electric energy and heat increase with the increased delivery of steam to external consumers. Electricity produced at a CHP plant in condensation mode is too costly to be marketed outside of the peak-load periods.

To summarise, the prerequisites for efficient CHP operation are: (a) utilising the entire cogeneration potential of the turbine unit, i.e. loading all of its heating steam extraction lines, and (b) maintaining a constant heating load as much as possible.

4. Method to study the comparative effectiveness of combined heat and power generation technologies

The basis of our comparative analysis relies on the physical method of distribution of fuel costs, which allows us to calculate the unit cost of production of heat and electricity and is therefore similar to multi-criteria analysis (Zavadskas, Turskis, & Tamosaitiene, 2011). The basis of this method is to calculate the cost of thermal energy based on the amount of heat transmitted to the market consumer. The rest of the thermal energy relates to the production of electricity. All the benefits of cogeneration are transferred to the electricity production (Andryushchenko, 2004; Zeigarnik, 2006).

Fuel consumption attributable to heat production can be calculated as follows:

$$B_h = \frac{Q_y}{Q_p^h \times \eta_{bs}^h \times \eta_b^h \times \eta_{cc}^h} \tag{5}$$

where Q_y is annual residual amount of heat from turbines (GJ / year); η_{bs}^h, η_b^h, η_{cc}^h is net efficiency of boiler shop, boiler, cogeneration compartment; Q_p^h is net calorific value of the fuel.

Annual fuel consumption (B_y) in conventional terms (tonnes/year), is determined by the fuel characteristics for each type of turbine and CHP as a whole according to the following formula:

$$B_{y_i} = \alpha_i h_p + \gamma_{h_i} D_{h_i} + \gamma_{p_i} D_{p_i} + \beta_i E_{y_i} \tag{6}$$

where α_i, γ_{h_i}, γ_{p_i}, β_i are factors specific to each type of turbine; h_p is the number of hours of turbine's work (7700–8000 h per year); D_{h_i}, D_{p_i} is the annual heating steam extraction and production parameters (tonnes/year); E_{y_i} is the annual electricity production of turbine unit (MWh/year).

For estimation, we use the following relations for the distribution of fuel equivalent attributable to the production of heat and electricity (tonnes/year):

$$B_h = 0.088 D_h + 0.102 D_p \tag{7}$$

$$B_p = B_y - B_h \tag{8}$$

where B_h, B_p is the consumption of fuel, related to the production of heat and electricity; D_h, D_p is the annual heating steam extraction and production parameters; 0.088 and 0.102 are coefficients depending on parameters of steam extraction and efficiency.

Specific gross fuel consumption is determined by formulas (9) and (10):

for electricity (g/kWh)

$$b_p = \frac{B_p}{E_y} \tag{9}$$

for heat (kg/GJ)

$$b_h = \frac{B_h}{Q_y} \tag{10}$$

However, in this case, the entire power consumption for the entire power consumption for the needs of CHP refers to the production of electricity and fuel required for the supply of heat. Therefore, it is necessary to distribute the energy consumption between types of products. Electricity consumption for own needs is distributed among types of energy products in accordance with the following relations:

$$E_{own}^p = \frac{E_{cp} + (E_{fp} + E_{bds} + E_{fprep} + E_{ar} + E_{other}) B_p}{B_y} \tag{11}$$

$$E_{own}^h = \frac{E_{hdp} + (E_{fp} + E_{bds} + E_{fprep} + E_{ar} + E_{other}) B_h}{B_y} \tag{12}$$

where E_{cp} is the electricity consumption for circulation pumps; E_{hdp} is the electricity consumption for heat distribution pumps; E_{fp} is the electricity consumption for feeding pumps; E_{bds} is the electricity consumption for the boiler draft system; E_{fprep} is the electricity consumption for fuel preparation; E_{ar} is the electricity consumption for ash removal; E_{other} is the electricity consumption for other needs.

Net specific fuel consumption is determined by the following formulas:

for electricity (g/kWh)

$$b_p^n = \frac{B_p}{E_y - E_{own}^p} \tag{13}$$

for heat (kg/GJ)

$$b_h^n = \frac{B_h + b_p^n E_{own}^h}{Q_y} \tag{14}$$

Annual consumption, taking into account the distribution of electricity for own needs, attributable to heat and electricity, will be:

for heating external customers (ton/year)

$$B_h^{'} = b_h^n Q_y \tag{15}$$

for electricity (ton/year)

$$B_p^{'} = B_y - B_h^{'} \tag{16}$$

Efficiency on heat production from the CHP and electricity output from CHP (%), will be determined according to:

$$EF_h = \frac{34,2}{b_h^n} 100\% \tag{17}$$

$$EF_e = \frac{123}{b_p^n} 100\% \tag{18}$$

5. Comparative analysis of economic efficiency

The efficiency of installations is the most important aspect in comparing the economic efficiency. By virtue of the fact that these units are the cogeneration turbines, the efficiency is distinguished by the absence or low thermal load (such as characteristic of summer mode) and the nominal heat load (winter mode). The greatest difference in the efficiency of these technologies is observed for the summer mode. In summer mode, combined-cycle units provide value efficiency of about 60%, while for the steam power plants this value remains below 40%. It is also worth noting that for the steam power unit's higher parameters (i.e. supercritical values) the efficiency in the summer mode will also be higher (Vasiliev, 1993; or Zeigarnik, 2006).

In order to characterise the efficiency of the power station in winter mode when the heat load becomes higher, the FUF (fuel utilisation factor), which is the ration of the amount of useful heat and electricity produced to the cost of heat in their production, should be used. FUF for CCGT CHP is approximately 86%, whereas for steam-powered CHP it is calculated as 85%. As can be seen, the difference for the winter mode is not great.

One of the criteria of the economic efficiency of power plants is fuel costs. The station, which provides higher efficiencies and FUF, will save more fuel in the production of an equal amount of heat and electricity. Due to the fact that CCGT CHP allows higher efficiencies in summer mode to be achieved, they provide less fuel costs than steam-powered CHP. When comparing the steam-powered CHP subcritical and supercritical parameters, it can be concluded that the CHP supercritical parameters, achieving higher levels of efficiency in summer mode, provide lower fuel costs than CHP subcritical parameters.

It is important to note that the economic benefits achieved through the use of more advanced energy technologies, apply only to the modes with low thermal loads. Therefore, the ratio of thermal and electric loads of consumers will largely determine the effectiveness of a decision on the combined generation of electricity and heat.

Another important factor when comparing the steam-powered CHP with different parameters and CCGT CHP is the fact that the specific thermal power per unit of electrical power for these technologies varies greatly.

It can be shown that steam-powered units generate much more heat than the steam-gas ones at equal values of electric power. It should be noted that within the steam power unit, higher technology parameters generate less heat than the steam-gas units with equal electrical power parameters. Hence, we can conclude that the transition to higher-powered unit parameters or combined-cycle units at the current level of consumption of thermal energy and a fixed level of electrical power is required to introduce an additional source of heat.

It was found that combined-cycle CHPs provide the greatest efficiency of production. Fuel economy when compared with CCGT-450T and T-110–130 is 16% per year.

Table 1 shows estimates of the basic parameters characterising the efficiency of CHPs depending on the mode of production activities for a variety of technologies. These findings are consistent with data from Bogachko et al. (2005), which has been evaluated for the condensing mode of operation of these blocks.

The difference in unit costs of electricity generation between the T-110–130 and T-250–240 in Bogachko et al. (2005) are 55 g/kWh, and between T-250–240 and combined cycle power plant 84 g/kWh. If we consider that the summer mode is not purely condensation, and heat load is about 20–30%, it is possible to judge the similarity of results.

In terms of production efficiency, the most optimal choice is the combined-cycle cogeneration unit type. It is especially worth noting that the maximum difference in effectiveness falls in summer mode when the heat generation as well as electric power

Table 1. CHP efficiency parameters depending on the mode of production for different technologies.

Parameter Summer		T-110–130	T-255–240	CCGT-450
FUF (fuel utilisation factor), %	Winter	83	83	84
	Transition (fall, spring)	76	78	80
	Summer	53	56	68
Specific consumption for the production of heat (kg/Gcal)	Winter	156	155	155
	Transition (fall, spring)	158	156	155
	Summer	159	157	155
Specific consumption for electricity generation (g/kWh)	Winter	174	172	173
	Transition (fall, spring)	201	192	184
	Summer	311	280	219

Source: own results.

is greatly reduced. From the point of view of investors, the economic efficiency of combined heat and power generation will be largely determined by the capital investment and payback period of implemented solutions.

The option of linking the station with steam power units pays off faster than the version of the composition with combined-cycle units (approximately 1.5 years). Moreover, the difference between the discounted payback period of the composition with subcritical steam power units (T-110–130) and supercritical units (T-255–240) is small (4 months).

6. Conclusions and policy implications

Our results on the one hand are determined by the capital investment, equipment life and maintenance costs, and on the other they are represented by the fuel efficiency of applied technologies. This is an important task since, by 2020, more than half of the energy equipment in Russia will have exceeded its economic life. Improving the efficiency of CHP in summer mode when the introduction of the technology supercritical parameters is offset by an increase in capital expenditure on construction units as well as of additional boilers (in comparison with the technology subcritical parameters). The big difference in payback period between combined cycle power units and steam power units also is caused by a significant difference in capital investment. Investments in the power plant composition with units T-110–130 are almost 27% less than in the power plant composition with CCGT-450 units. We should also stress the fact that there is a shorter life cycle in the case of CCGT, primarily because of the presence of the gas turbine. In terms of investment analysis, the organisation of combined heat and power on the basis of steam power plants is more suitable for a fixed heat load.

Overall, our results demonstrate that the main goals of reconstruction might include life extension, increasing production efficiency, as well as output. We extrapolate our findings by stating that these goals can be achieved through partial replacement of the most worn parts of the equipment (e.g. replacement of blades in the turbine), the combination of new and old equipment (such as add-in steam and gas cycle), and full replacement of equipment.

In terms of policy implications, our results gain special importance in terms of economic transformation, reconstruction, and technical re-equipment of the energy sector in the Russian Federation, which is getting quite obsolete and needs a thorough restructuring. The Russian energy sector suffers from economic inefficiency and post-transformation legacy, which need to be dealt with, and calls for immediate economic measures to be taken by the stakeholders in order to make the sector up-to-date with the demands of the modern economy and the rapidly developing axis of energy production and transfer in European Union and its neighbouring countries. This is especially relevant with regard to the recent war in Ukraine and the issues in the energy payment and energy transfers that pertain between Ukraine and Russia. Recent developments and sanctions against Russia call for the new measures and energy effectiveness that might be achieved through the restructuralization of its energy strategy. However, the know-how related to the specific technologies (e.g. production of the nuclear power) might be developed in Russia and offered to the interested partners in the EU countries. Nuclear energy might represent one of the possible ways of solving the obsoleteness and ageing of Russian energy sector assets.

Acknowledgements

The reported study was partially supported by the Ministry of Education and Science of the Russian Federation, research project No. 26.1795.2014/K.

Funding

This work was supported by the Ministry of Education and Science of the Russian Federation [grant number No. 26.1795.2014/K]. This work was also supported by People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013 [REA grant agreement number 609642].

References

Andryushchenko, A. (2004). On dividing fuel consumption and setting tariffs at cogeneration stations. *Thermal Engineering, 8*, 677–678.

Augutis, J., Jokšas, B., Krikštolaitis, R., & Žutautaitė, I. (2014). Criticality assessment of energy infrastructure. *Technological and Economic Development of Economy, 20*, 312–331.

Bogachko, M., Il'in, E., Pechenkin S., & Timofeeva, Y. (2005). Choosing the optimal conditions for loading cogeneration units carrying a heat load during non-heating and transition seasons. *Thermal Engineering, 5*, 409–413.

Fujimitsu, M. (2001). History of power plants and progress in heat resistant steels. *ISIJ international, 6*, 612–625.

Kasperowicz, R. (2014). Economic growth and energy consumption in 12 European countries: A panel data approach. *Journal of International Studies, 7*, 112–122. doi:10.14254/2071-8330.2014/7-3/10

Konova, O., Komarov, I., & Lisin, E. (2012). The relevance of power generating capacities based on the combined cycle power plants of high power. *Czech Journal of Social Sciences, Business and Economics, 1*, 101–110.

Lisin, E., & Grigoryeva, A. (2012). Generators' strategic behaviour research based on the agent approach to the power market modeling. *Czech Journal of Social Sciences, Business and Economics, 1*, 75–81.

Lisin, E., & Strielkowski, W. (2014). Modelling new economic approaches for the wholesale energy markets in Russia and the EU. *Transformation in Business & Economics*, *13*, 2B (32B), 566–580.

Lisin, E., Strielkowski, W., Amelina, A., Konova, O., & Čábelková, I. (2014). Mathematical approach to wholesale power and capacity market regulation. *Applied Mathematical Sciences, 8*, 7765–7773.

Lykova, O., Lisin, E., & Kocherova, A. (2012). Analysis of the major preconditions of coal-hybrid power plants construction as a perspective direction of high efficiency heat-power engineering development. *Czech Journal of Social Sciences, Business and Economics, 1*, 92–101.

Maximov, B., & Molodyuk, V. (2008). *Theoretical and practical fundamentals of the electricity market*. Moscow: MEI Publishing House, 291 p.

Samarin, O., Lushin, K., & Paulauskaite, S. (2007). Energy savings efficiency in public buildings under market conditions in Russia. *Technological and Economic Development of Economy, 13*, 67–72.

Škare, M., & Družeta, R. P. (2014). Constructing official poverty lines for countries in transition-beyond the poverty line (2000–2010). *Amfiteatru Economic, 16*, 368–389.

Škare, M., & Sinković, D. (2012). Equipment investments and growth nexus–evidence from socialist and transition Croatia. *Technological and Economic Development of Economy, 18*, 504–528.

Sokolov, E., & Kovylyanskii, Y. (1990). Methodological bases of and trends in the development of district heating and cogeneration in the USSR. *Soviet Technology Reviews, 4*, 100–135.

Stoft, S. (2002). *Power system economics: Designing markets for electricity*. New Jersey: IEEE Press, 460 p.

Streimikiene, D., & Klevas, V. (2007). Promotion of renewable energy in Baltic States. *Renewable and Sustainable Energy Reviews, 11*, 672–687.

Vasiliev, Y. (1993). Scientific works of Sankt-Peterburg State Technical University on heat-power engineering and power-plant engineering. *Thermal Engineering, 3*, 2–4.

Zamula, I., & Kireitseva, A. (2013). Environmental liabilities arising from the transactions with atmospheric air as an accounting object. *Economics and Sociology, 6*, 190–200. doi:10.14254/2071-789X.2013/6-2/17

Zavadskas, E. K., Turskis, Z., & Tamosaitiene, J. (2011). Selection of construction enterprises management strategy based on the SWOT and multi-criteria analysis. *Archives of Civil and Mechanical Engineering, 11*, 1063–1082.

Zeigarnik, Y. (2006). Some problems with the development of combined generation of electricity and heat in Russia. *Energy, 13*, 2051–2058.