RIGA TECHNICAL UNIVERSITY

Guntars VEMPERS

EVALUATION OF POWER SYSTEM DEVELOPMENT PROJECTS AT THE CONDITIONS OF FREE MARKET ECONOMY

Summary of Doctoral Thesis

Riga 2012

RIGA TECHNICAL UNIVERSITY

Faculty of Power and Electrical Engineering
Institute of Power Engineering

Guntars VEMPERS
Doctoral student of the Power Engineering doctoral study programme EDN0

EVALUATION OF POWER SYSTEM DEVELOPMENT PROJECTS AT THE CONDITIONS OF FREE MARKET ECONOMY

Summary of Doctoral Thesis

Supervised by
Dr. habil. sc. ing., Professor
A.S.Sauhats

Riga 2012

Vempers G. Evaluation of power system development projects at the conditions of free market economy. Summary of Doctoral Thesis.-R.:RTU, 2011.- 33 pp.

This work has been supported by the European Social Fund within the project "Support for the implementation of doctoral studies at Riga Technical University".

ISBN …….

THIS DOCTORAL THESIS
HAS BEEN SUBMITTED FOR THE AWARD OF A DEGREE OF DOCTOR OF ENGINEERING SCIENCES (Power Engineering)
AT RIGA TECHNICAL UNIVERSITY

This Doctoral Thesis for the Degree of Doctor of Engineering Sciences (Power Engineering) is to be defended in public on September 10, 2012, at the Faculty of Power and Electrical Engineering, 1 Kronvalda Blvd., Assembly hall.

OFFICIAL REVIEWERS

Dr. habil. phys., Juris Ekmanis

Dr. sc. ing., Oļegs Linkevičs

Dr.sc.ing., Jūlija Matevosjana

DECLARATION

I hereby declare that I have worked out this Doctoral Thesis, which has been submitted for review at Riga Technical University for the award of a doctoral degree in the field of engineering (or other). This Doctoral Thesis has not been submitted to any other university for the award of a scientific degree.

Guntars Vempers ……………………………. (Signature)

Date: ………………………

The doctoral thesis has been written in the Latvian language and consists of an introduction, 6 chapters, bibliography, 7 appendices, 204 pages all in all. The bibliography consists of 67 items.

Introduction

The growing number of the world's population, the scarcity of power resources and striving for the benefits offered by modern civilisation have resulted in power systems of massive dimensions. To maintain and develop these power systems, considerable investments are needed in any country. All the elements of a power system function as a united system that is largely influenced by a number of quantitative and qualitative factors of changeable nature. Since many factors cannot be measured precisely, nor even described as probabilistic values, most decisions have to be taken in the conditions of uncertainty. The growth in energy consumption, the growing dimensions of power systems, their complexity and significance, the fluctuating prices of energy resources as well as the influence of accidental factors and uncertainty — all of the above have sharpened a number of serious issues related to the power industry: power supply efficiency and reliability as well as the environmental impact and sustainability of power supply.

The importance of a complex approach to power industry development issues determines the goal of the present doctoral thesis: to develop a methodology for feasibility studies of power facility projects on the basis of the game theory, with a special emphasis on using the methods of co-operative game theory. The conditions for the co-operation of market participants (producers, transmission and distribution system operators and consumers) have become particularly topical after the adoption of decisions on an international scale regarding the restructuring of power systems and the introduction of free-market mechanisms to the control of power system development and operation.

The present doctoral thesis formulates the task for a feasibility study; an algorithm for project substantiation is synthesized for a situation of several possible coalition founders. The rationality of supporting the actions of the initiator is proved. The task of power supply planning for independent consumers is formulated and solved, by means of forming a co-operative. A heat loads forecast for the city of Riga up to the year 2020 is substantiated. A development plan for Riga is synthesized, encompassing a prospective period till the year 2020. Also, a new methodology, suited to the market conditions, is substantiated for determining heat and electricity tariffs.

The developed methodology of project feasibility studies, which applies co-operative game theory for making decisions in the power industry in the conditions of uncertainty, can be used by all the participants of the energy market, so as to achieve the most efficient use of total resources.

List of Abbreviations

- JSC “Rīgas Siltums”	RS
- JSC “Latvenergo”	LE
- Centralised district heating system	CDHS
- Technical Regulations	TR
- Transfer pumping station	TPS
- District heating plant	DHP
- Thermal power plant	TPP
- JSC “Latvenergo” Riga TPP-1 production unit	TPP-1
- JSC “Latvenergo” Riga TPP-2 production unit	TPP-2
- Feasibility study	FS
- Cogeneration power unit	CPU
- Substation	s/s

Topicality of the Study

For hundreds of years, energy has been at the basis of the development of human society. From primitive campfires, stoves, windmills and horse power that were used for cooking, heating and transport, humanity has arrived at modern-day industry, transport systems and centralised district heating systems, which are unthinkable without modern, high-quality, reliable sources of energy. Electric energy, due to its characteristic features, has advantages in industrial, automatic production, transport and communication applications. The rising welfare level and life standard stimulates the need for energy services. Energy consumption is steadily growing; this tendency is expected to persist in foreseeable future and to promote further development of electric power systems.

The world’s growing population, the scarcity of energy resources and striving after the benefits offered by modern civilisation have resulted in power systems of grandiose dimensions. Power systems are arguably among the **most complicated** artificial technical systems created as a result of human activities. They consist of thousands of generators, transformers, hundreds of thousands of kilometres of power transmission lines and millions of consumers. The maintenance and development of a power system in any country requires **significant investments**. The consumers, independently from the generators, change their energy demand in accordance with their wishes. All the elements of the power system function as a **unified system.** The operation of the power system is strongly influenced by a number of natural factors: temperature, wind velocity, illumination level, etc. Changes in the operating conditions also make it necessary to change the operating mode of power facilities. Yet many factors do not yield themselves for precise measurement or even description as probabilistic values. This is why many decisions have to be made **in the conditions of uncertainty**.

The rise in energy consumption, the growing dimensions of power systems, their degree of complication and significance, the increase in the prices of energy carriers, the influence of occasional factors and uncertainty – all of the aforementioned has sharpened a number of serious energy-related problems.

- **Efficiency** and availability of power supply. Unfortunately, the standards of living for different layers of population differ even in developed countries that are well provided with energy. Still larger are the differences in living standards between industrially developed countries and developing countries. Provision with energy resources is very inhomogeneous at various places of the world. As a result of this, one fourth of the world's population still have no access to electric energy sources and, consequently, to most of the benefits offered by modern civilisation. The main reason for this is the **energy price**, which is inaccessible to the poorer layers of population. The growth in the energy prices hampers the development of industrial production and consequently limits the opportunities to solve many social and environmental problems.
- **Reliability** of power supply. Humanity has gradually got accustomed to conditions that are unthinkable without guaranteed energy supply and has adapted its way of living accordingly. Even in case of short-term power cuts, modern-day cities, industrial enterprises and transportation systems suffer damage and large-scale economic loss, emergency and catastrophe threats arise, possibly even with large casualties.
- **Environmental impact.** Energy production is practically impossible without influencing climate, the air and water basin, the natural sceneries and, as a result, the human living environment.
- **Sustainability**. This concept is linked to the limited amount of basic resources available to modern society. Although the amount of energy produced from renewable sources has increased considerably over the last decade, yet it is expected that almost 85 % of the increase in the energy production amount will be related to an increase in the consumption of fossil fuel.

The above problems are closely linked to each other. This mutual link has to be taken into account in the attempts to create rational power supply schemes. Even more, it can be argued that considering these problems in separation is most often pointless and results in misleading, incorrect results and conclusions. The importance of **complex consideration** of power industry development problems is generally acknowledged, yet in practice there are situations when solutions and projects that do not sufficiently cover all of the above-mentioned problems are proposed, substantiated and even implemented.

The acuity of the above problems has resulted in decisions on an international scale regarding the restructuring of power systems and the use of market conditions and mechanisms in the management of the development and operation of power systems. The power system is divided into a number of legally independent parts that compete with one another. Competition is the main factor that can ensure rational development of power systems. At competition conditions, it is inevitable that those companies that make correct, technically and economically substantiated decisions are more likely to survive.

Division of a system into a number of parts diminishes the dimensions of the objects to be managed. It seems that the models and algorithms for management and decision-making are simplified, yet at the same time, new problems emerge, which are first and foremost related to the interaction of the competitors' activities.

The need for change in power systems is first and foremost conditioned by changes in the operating conditions. It has to be noted that changes in the power industry, related not only to restructuring and market mechanisms, have been particularly swift over the recent decades in Latvia and other Baltic countries. Energy demand, prices and standards have undergone rapid changes. A wide range of new technologies for energy production and distribution has become available (steam-gas technologies, dissipated generators, alternative sources, SF_6 gas installations, new types of conductors, energy electronics devices). These changes, in their turn, have brought about the need to implement a large number of projects.

In the course of project implementation, uncertainty conditions arise in many cases. Consideration of these conditions in the decision-making process can be used to achieve significant improvement in the solutions of economic tasks. Game theory methods may be used. Regrettably, it is only in individual cases that such an approach is used in power engineering tasks. The present study can be regarded as directed towards diminishing the negative impact of uncertainty conditions when developing power system development projects.

Goal and Tasks of the Study

The goal of the study is the development of a methodology for working out feasibility studies, or technical and economic substantiations, of power facility projects. To achieve this goal, the following tasks are addressed:

- Analysis of approaches and methodologies for solving power facility project feasibility study tasks;

- Development of a methodology for working out feasibility studies of power facility projects;
- Formulation of project feasibility studies at competition conditions and synthesis of an algorithm for solving them;
- Substantiation of co-operative behaviour and its advantages; synthesis of a task solution algorithm;
- Substantiation of the advantages of the initiator of the co-operative behaviour; synthesis of a corresponding algorithm;
- Development of a feasibility study for the Riga city heat supply project;
- Development of a methodology for substantiating the selection of heat and electricity tariffs of combined heat and power plants.

Scientific Novelty and Contribution

1. The task of a feasibility study (a technical and economic substantiation) of projects to be implemented at competition conditions. A game theory approach has been used, based on Nash equilibrium conditions and coalition formation principles.
2. A project substantiation algorithm has been synthesised for the conditions when there are several possible coalition founders. The rationality of supporting the initiator's actions has been proved.
3. A task of power supply planning for independent consumers by forming a co-operative from these has been formulated and solved.
4. A forecast of the heat loads of the city of Riga up to the year 2020 has been substantiated.
5. A Riga city heat supply plan has been synthesised, considering prospective development up to the year 2020.
6. A new methodology for determining heat and electricity tariffs, adapted to the market conditions, has been substantiated.

Methods and Approaches Used

The doctoral thesis is based on using the methods of the game theory and, in particular, of the co-operative game theory, applying them to the feasibility studies of energy projects.

Approbation of the Study

The results of the study have been reported and discussed at the following conferences:

1) Power Tech, 2007 IEEE , Switzerland, Lausanne, July 1-5, 2007.
2) 3rd International Conference on Electrical and Control Technologies, ECT 2008, Lithuania, Kaunas, May 8-9, 2008.

3) 5th International Conference of the European Electricity Market, EEM 08, Portugal, Lisbon, May 28-30, 2008.
4) 16th Power Systems Computation Conference, PSCC2008, Scotland, Glasgow, July 14-18, 2008.
5) 4th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, May 7-8, 2009.
6) 6th International Conference on the European Energy Market, Belgium, Leuven, May 27-29, 2009.
7) IEEE Power Tech 2009 International Conference, Romania, Bucharest, June 28 – July 02, 2009.
8) 4th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, May 7-8, 2009.
9) 5th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, May 6-7, 2010.
10) 7th Conference on the European Energy Market, Spain, Madrid, June 23-25, 2010.

Publications

<u>Publications in internationally quotable scientific collections of articles:</u>

1) Sauhats A., Vempers G., Inde J., Neimane V. On Co-generation Strategies in the Cities of North-Eastern Europe // Power Tech, 2007 IEEE , Switzerland, Lausanne, July 1-5, 2007. – pp. 645-650.
2) Inde J., Neimane V., Sauhats A., Vempers G. Co-Generation Strategies and Development Possibilities in Cities of North-Eastern Europe // Oil Shale. – Vol. 24, 2007. – pp. 337-346.
3) Sauhats A., Neimane V., Vempers G., Tereskina I., Bočkarjova G. Optimisation of Power Supply Using Cooperative Game Theory // Thesis of the 3rd International Conference on Electrical and Control Technologies, ECT-2008, Lithuania, Kaunas, May 8 – 9, 2008. – pp. 162-167.
4) Sauhats A., Vempers G., Tereskina I., Bočkarjova G., Neimane V. Approach for Energy Supply System Planning Based on Cooperative Game Theory // Thesis of the 5th International Conference of the European Electricity Market, EEM 08, Portugal, Lisbon, May 28 – 30, 2008. – pp. 1-6.
5) Sauhats A., Neimane V., Inde J., Vempers G., Bočkarjova G. Using Cooperative Game Theory in Energy Supply Planning Tasks // Thesis of the 16th Power Systems Computation Conference, PSCC2008, United Kingdom, Glasgow, July 14-18, 2008. – pp. 1-8.

6) Neimane V., Sauhats A., Vempers G., Tereskina I. Allocating Production Cost of CHP Plant to Heat and Power // Thesis of the 4th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, May 7-8, 2009. – pp. 200-204.
7) Neimane V., Sauhats A., Vempers G., Tereskina I., Bočkarjova G. Allocation production cost at CHP Plant to Heat and Power based on Cooperative Game Theory // 6th International Conference on the European Energy Market, Belgium, Lēvene, 27.-29. May, 2009. - pp 182-187.
8) Neimane V., Sauhats A., Vempers G., Inde J., Tereskina I., Bočkarjova G. Allocating Production Cost at CHP Plant to Heat and Power Using Cooperative Game Theory // Thesis of the IEEE Bucharest Power Tech Conference, Romania, Bucharest, June 28 – July 2, 2009. – pp. 1-6.
9) Zima-Bockarjova M., Sauhats A., Vempers G., Tereskina I., Bočkarjova G. Examples of Energy Supply System Planning Based on Cooperative Game Theory // Proceedings of the 5th International Conference on Electrical and Control Technologies, Lithuania, Kaunas, May 6-7, 2010. – pp. 162-165.
10) Zima-Bockarjova M., Sauhats A., Vempers G., Tereskina I. On Application of the Cooperative Game Theory to Energy Supply System Planning // Thesis of the 7th Conference on the European Energy Market, EEM-10, Spain, Madrid, June 23-25, 2010. – pp. 1-6.

Local publications:

Inde J., Sauhats A., Tereskina I., Vempers G. Spēļu teorija energoapgādes plānošanas uzdevumā // "Enerģija un pasaule" No.2, April, 2008, pp. 76-79.

Practical Implementation

Below follows a list of projects supervised by the author of the paper and practically implemented at JSC "Siltumelektroprojekts", which serve as a source of ideas for the examples included in the promotion paper:

1) Business plan for the use and development of JSC "Rīgas Siltums" Left Bank district heating networks and heat sources for the period from 2006 to 2018. // JSC "Siltumelektroprojekts" // 2006.
2) Business plan for the use and development of JSC "Rīgas Siltums" Right Bank district heating networks and JSC "Latvenergo" heat sources for the period from 2006 to 2018. // JSC "Siltumelektroprojekts" // 2006.
3) Study of "District heating in Riga", Stratkraft Development. // JSC "Siltumelektroprojekts" // 2007.

4) Optimisation possibilities for the centralised district heating system in the city of Riga for the period from 2010 to 2020. // JSC “Siltumelektroprojekts” // 2010.
5) Formulation of the task for the reconstruction project for the production unit “ES-2” of the Central Thermal Power Plant in St. Petersburg (Russia). // JSC “Siltumelektroprojekts” // 2010.
6) Development of a complete sketch and technical design for the 110/10 kV indoor substation “Matīss” (Riga). // JSC “Siltumelektroprojekts” // 2009.

   The project was awarded the 1st prize of LEEA “The year’s best paper in the field of electrical construction, power supply to facilities, and designing of electrical installations in 2009” in the nomination “New construction projects”.
7) Sketch design of biofuel CHP plant in Jelgava, 73 Rūpniecības Street. // JSC “Siltumelektroprojekts” // 2009.
8) Construction of 110 kV and optical cable lines from substation “Grobiņa” to substation “Liepājas Metalurgs” and from substation “Liepāja” to substation “Liepājas Metalurgs”. Technical design. // JSC “Siltumelektroprojekts” // 2008.

   The project was awarded the 1st prize of LBA “The year’s best structure in Latvia in 2010” in the nomination “Electric installation works”.
9) Development of the technical design for the 20 kV outdoor electrical networks with a connection to the 110 kV substation for the business park in Ķekava municipality. // JSC “Siltumelektroprojekts” // 2007.
10) The implementation of all these projects has required mutual co-operation among the involved parties (the producers, the transmission network operator, the distribution network operator, the consumers etc.) in order to find out the optimum solution.

Structure of the study

The doctoral thesis consists of six chapters, including the introduction. The paper contains 30 figures, 55 tables (including table- figures) and 7 appendices.

Chapter 1 proves the topicality of the study and the validity of the selected study direction. The goal and the main tasks of the study are formulated. The scientific novelty and the contribution of the paper are described.

Chapter 2 substantiates the need for solving the planning tasks related to the development of the Latvian power system. The main causes for the rapid changes in the power systems are mentioned:

1) The capacity shortage characteristic in the Baltic countries.
2) The prices of energy carriers. Fluctuations of the prices for oil, gas and other types of fossil fuel in the increasing direction.

3) The community's attitude towards environment pollution. Emission charges have been introduced.
4) Energy consumption: Many production facilities have been shut down. The electricity and heat demand has diminished sharply. At the same time, a number of local regions have emerged where the energy demand has experienced a sharp rise.
5) Efficient technologies for energy production, distribution and use have become available.
6) Limitations have practically been lost regarding the use of investments for energy efficient and economically substantiated projects (credits from international investment companies have become available, as well as, in some cases, EU funds).
7) Legislation principles. Upon Latvia's accession to the European Union, it has become mandatory to observe many energy and environment protection laws and regulations (regarding support to alternative power sources, efficient combined heat and power plants, emission limitations, guaranteeing of safety and stability, energy quality provision conditions).
8) The community's attitude towards reliability (emergency risks).
9) The competition among independent energy producers that has come to exist in the power sector.
10) The conditions for the import and export of energy have changed sharply. One example to be mentioned is the shutdown of Ignalina Nuclear Power Plant, which used to produce up to 70 per cent of the whole amount of electricity generated in the Baltic states.
11) Further development of the electrical networks is expected, with the purpose of ensuring import/export trade with the Western countries.
12) Further reconstruction and development of the district heating networks is expected, diminishing the heat losses.

Due to the above reasons, it has become clear that the power industry needs rapid changes, for which to happen it is required that a great number of different projects are carried out.

A mathematical formulation of the power system development projects task and the designing optimisation task has been devised:

$$\{s_{i1}^{*} \ldots s_{id}^{*}\} = \arg\max \sum_{j=1}^{d} E\left[R\left(s_{ij}, S_{-ij}, X\right)\right] \quad (1)$$

where: s_{il} stands for project structure and parameters. d – the number of considered time periods, E – the symbol for mathematical hope, Sij – the controlled structures and parameters of the competing companies, X – determined or/and stochastic influencing factors.

In this way, during the solution of the optimisation task, the optimum parameters $s_{i1}^{*} \ldots s_{id}^{*}$ are searched for, which ensure the maximisation of the revenue R of the competing companies.

The presence of the indeterminate parameters makes it necessary to use the scenario approach and explains the difficulty arriving at the final solution regarding the choice of the project implementation variant. The classical game theory approaches (the Hurwitz, Minimax and other criteria) are reviewed. Their drawbacks and disadvantages are pointed out. A hypothesis about rational behaviour of the competing companies and their wish to maximise their revenues is assumed; a task solution method based on the Nash equilibrium and the Shapley distribution is proposed. Additionally, the advantages of the coalition organiser and his opportunity of gaining additional profit are reviewed.

In game theory, the Shapley value depicts one of the approaches to fair allocation of revenues, avoiding the drawbacks involved in the choice of the final decision with the most rational variant if there are several players. A fair allocation is ensured by selecting, in a uniform order, a random ordering and paying each of the players its expected marginal costs according to that ordering. Since the players can form $n!$ possible random orderings, then the probability of the set S being ranked directly before the *i*-th player is as follows: $|S|!(n-1-|S|)!/n!$. Therefore, the additional amount/ reward that the *i*-th player receives is as follows:

$$\phi_i = \sum_{i \notin S \subseteq N} \frac{|S|!(n-1-|S|)!}{n!} \left(R(S \cup \{i\}) - R(S)\right) \quad (2),$$

where n is the total number of players, $|S|$ is the size of the set S, the sum encompasses all the subsets of the set N that do not contain the i-th player.

In the simplest case when only two players participate in the game, the expression (2) is simplified and takes the following form:

$$\phi 1 = \phi 2 = \left(R(S \cup \{i\}) - R(S)\right)/2 \quad (3)$$

Other energy task solutions based on co-operative game methods that are used in world practice are reviewed. A conclusion is made that the use of such methods is now at an incipient stage. As a result, the algorithm shown on Figure No. 1 has been synthesised for the technical substantiation (exploring the feasibility) of projects.

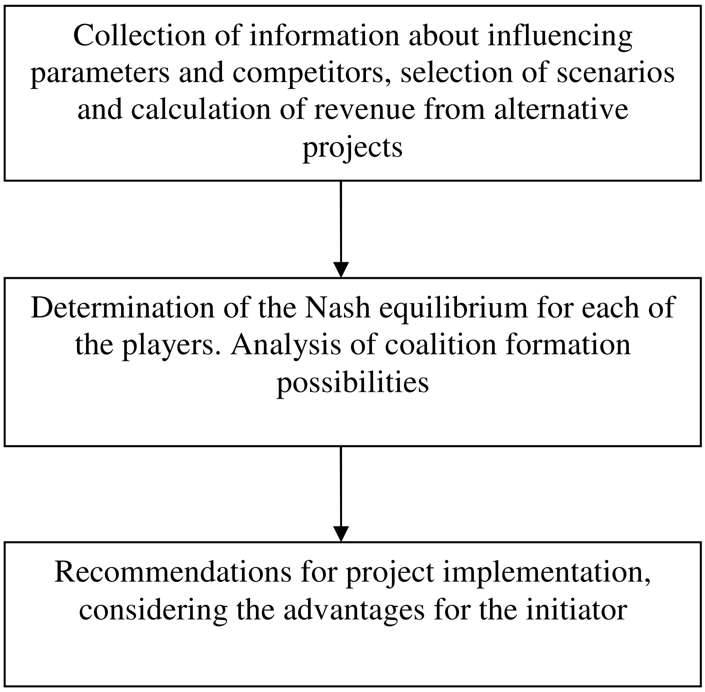


Figure No. 1: The algorithm for the technical and economical substantiation (feasibility study) of projects

Chapter 3 looks at new basic principles for power supply planning tasks, for the solution of which it is useful to employ the principles of co-operative game theory in order to obtain the optimum result:

1) The task of developing the power output diagram of a power plant. The power supply system in the centre of a large Northern European city is being reconstructed. The reconstruction is carried out by three mutually legally independent energy companies:

- The owner of the TPP;
- The distribution network;
- The transmission network.

District of a large city

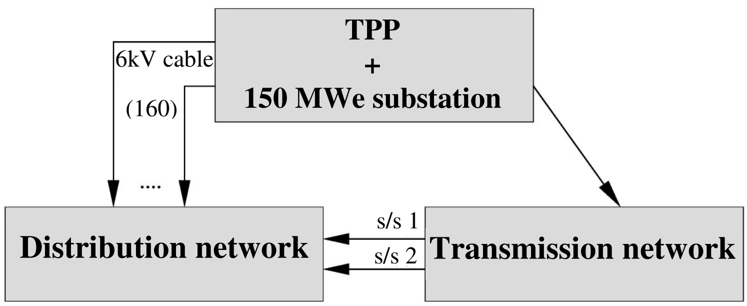


Figure No. 2: The structure of the interaction between the companies

The companies have to choose and come to an agreement about the substation diagram. The above-mentioned market participants make contradictory decisions; each of them encounters uncertainties caused by lack of appropriate information. The revenues of each of the companies depend not only on the strategy chosen by the company but also the strategies of two other companies. The best solution is possible if a coalition is formed from the above companies, since their co-ordinated operation results in maximum revenues. It has to be mentioned that in this case, the joining of a third player to the coalition does not result in additional revenues, which means that formation of a coalition from all the three companies is not rational.

2) Determining the energy costs of a combined heat and power plant when reconstructing a boiler house that ensures heat supply to a relatively small town in Latvia (30,000 inhabitants), into a combined heat and power plant (TPP). The obsolete boiler house is owned by the municipality. It is planned to involve an Investor (an independent company) in the TPP construction project.
Given the legislatively determined tariff for electricity produced by the TPP, by means of renewable type fuel, on condition that the current heat tariff is retained, the recoupment period of the TPP is 8 years. The relatively short project recoupment period has aroused serious interest among the potential investors. Still the municipality is interested in diminishing the heat tariffs to ensure that they are fair towards both the investor and the inhabitants of the city (the consumers), creating the conditions for combined heat and power production. If the TPP project is implemented by forming a coalition between the Municipality and the Investor, the heat tariff can be diminished by 33%. Besides, the investment recoupment period for the TPP remains within acceptable limits (10 years).

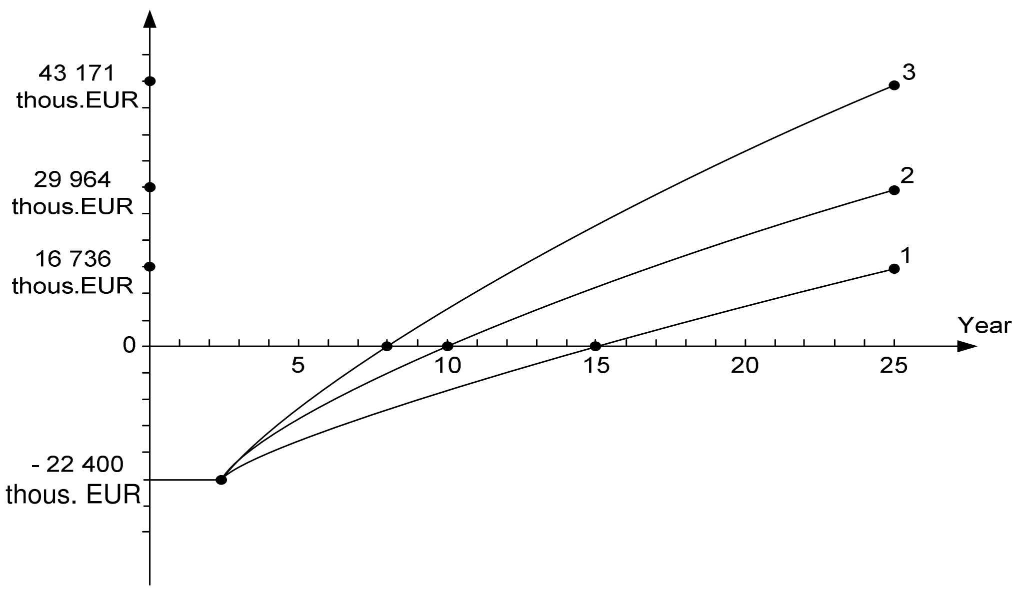


Figure No. 3: Payback period of the project: 1 – reconstruction of the boiler station; 2 – construction of the CHP plant and retaining of the existing heat tariff; 3 – optimum energy tariff for the consumer and for the investor of the CHP plant.

3) Planning of power supply for new consumers. This section describes a typical example with connection of new consumers to the distribution network. Near an existing substation, it is planned to build the production facilities of four independent companies. According to a request from the companies, the distribution network company that ensures electric power supply has issued technical regulations entailing the setup of a diagram of electric networks ensuring that new clients can create connections independently from each other. It is important to note that in the considered case, the expenses are met by the consumers themselves. That is, each of the companies is interested in diminishing the expenses. On the initiative of company A, the issue of forming a coalition from companies A, B, C, and D was considered. As a result, based on the condition that all the four companies are to connect to the distribution network simultaneously, without diminishing the reliability of the connections, a much more rational diagram has been synthesised, considerably diminishing the planned investments. It can be concluded easily that it is rational to form a coalition. Additional gain is possible by taking up the initiative, which makes it possible to form the coalition in a way that is the most advantageous for the initiator. Considerable gain results not only for the initiator but also for the other participants of the coalition. In addition, it has to be noted that the formation of the coalition was also advantageous from the point of view of the company who owned the distribution network, since it results in the construction of a network with lower operating costs (due to a lower total length of cable lines).

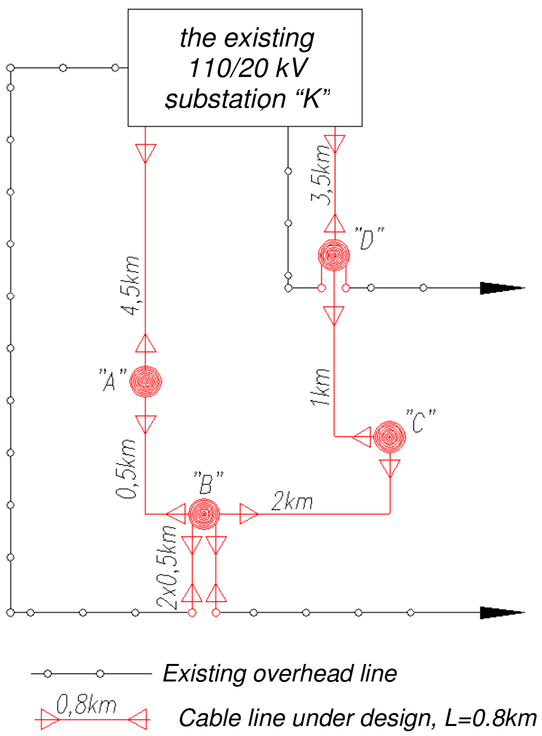


Figure No. 4: A diagram for the connection of independent companies A, B, C, and D

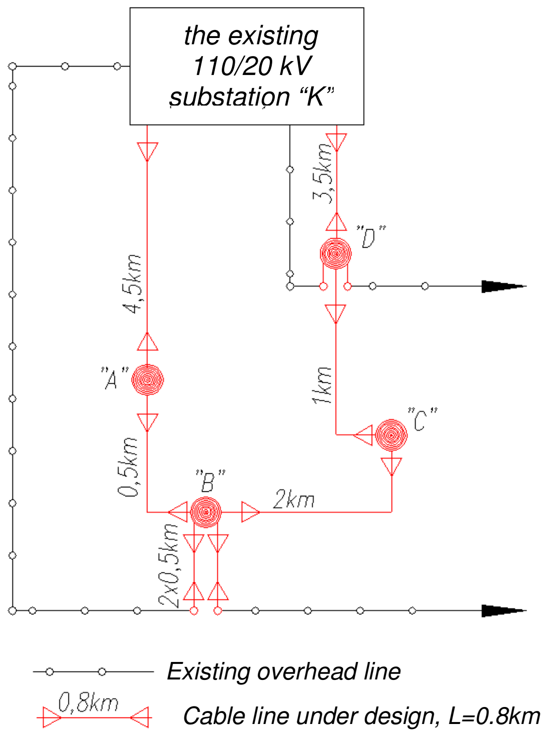


Figure No. 5: A diagram of the connection of a coalition formed by companies A, B, C, and D

4) Distribution of the heat and electricity tariff. Rational development of power supply systems requires an objective proportion between the heat and electricity prices. These methods are based on a calculation of the summary revenues RΣ, which are sufficient for normal operation of the TPP. RΣ is obtained from selling heat and electricity. The revenues gained from producing every type of energy are distributed on the basis of physical regularities, for example, in proportion to the produced energy. In this case, the differing values of heat and electricity are not taken into account.

A more frequently used method is the exergy method, according to which the energy value is changed by means of a coefficient β, which varies depending on the energy production technology used. The main drawback of this method is the impossibility of objectively evaluating the value of the coefficient β. Obviously, for different power systems the coefficient is different. For example, in case of ample water resources, which allow for cheaper production of electricity, a higher value of this coefficient should be chosen.

When electricity is sold via the network of the power grid, its price is determined by the market. However, in the case of small-sized TPPs, consumers have the possibility of receiving electricity from the TPP without the need to use the network of the power grid. In this case, the conditions dictated by the global market cease to be mandatory for these consumers. These access possibilities do not leave any advantages to those consumers whose consumption profile best corresponds to the combined heat and power production profile. Thus, the price determination process does not reflect the contribution of the heat consumers to the operation efficiency in terms of fuel economy and exhaust gas emissions when producing two types of energy.

This section reviews a method based on the co-operative game theory, by means of which the above-described limitations are overcome. The power supply task is formulated in the form of a game with the participation of a coalition with several players. Examples are provided on the basis of real-life data that have been used in planning power supply for the city of Riga.

5) Co-operative action with additional revenue for the initiator.

The first example is the heat supply and electric power supply alternatives for the new residential districts of the city of Riga. They analyse the existing tariff determination methods (the energy and exergy methods) for both types of energy, power and heat. These are then compared with the case when the co-operative game theory is applied. The methods yield considerably different results (see Figure No. 6). Using the game theory based method, we obtain electricity prices that are sufficiently close to the market prices, as well as relatively low heat prices. Such price relations stimulate ample use of cogeneration processes in energy production.

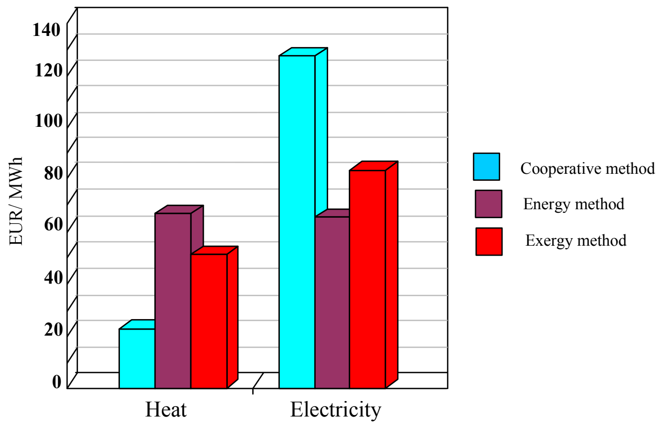


Figure No. 6: Energy tariffs calculated by various methods

The second example compares simplified production and selling processes for two (or possibly more) houses, each of which has a different owner, in ensuring their heat and power supply from own sources for own needs independently from each other or in the case of forming a co-operative.

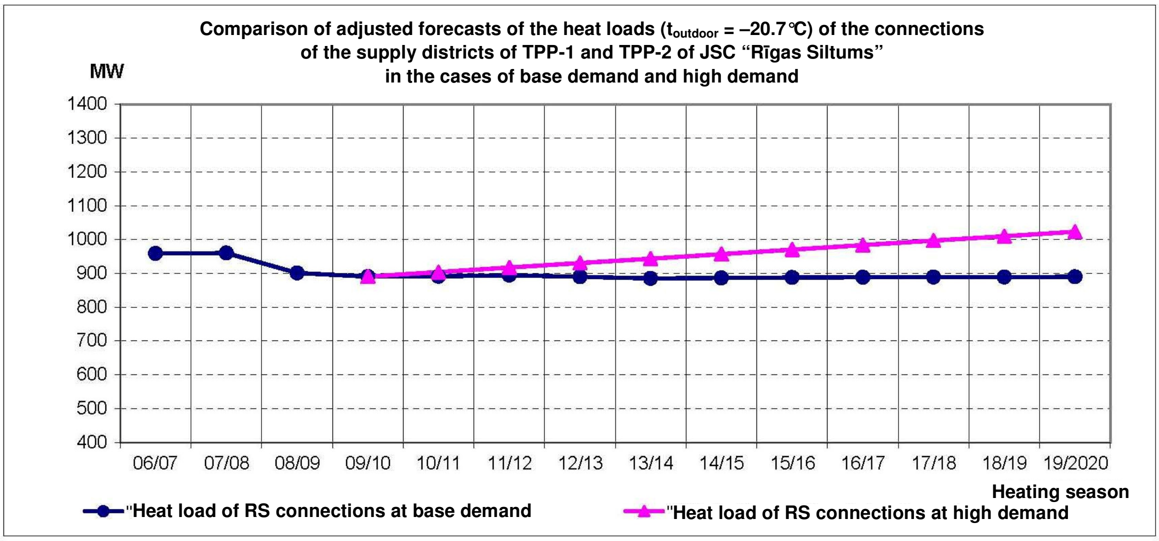
Chapter 4 provides a brief overview of the Riga city district heating system development plans up to the year 2020, in the development of which the author of the present paper participated from 2006 till 2011. The resulting experience and findings regarding the compilation of development plans have largely served as the basis for the present paper, particularly because over the last 20 years, no studies of this kind have been conducted, encompassing an analysis of the present situation along with a forecast of heat loads and consumption values, indicating the variants of possible measures for the development of Riga city CDHS to be implemented in nearer and more distant future, including economic substantiation. Therefore, the author had to collect world experience in the development of similar works and adapt it to the local conditions. For forecasting heat loads, a methodology has been developed, based on the forecast number of population, the forecast residential space, the forecast energy consumption by homes, the required heat load of the new customers, as well as statistical information about the heat loads of the previously connected customers, the overall economic development and a comparison of heat loads in comparable cities.

The CDHS of the city of Riga is operated by JSC "Rīgas Siltums", which produces, transmits and sells heat as well as ensures technical service for the internal heat supply systems of the heat consumer buildings. The major heat producers in Riga are the combined heat and power plants owned by JSC "Latvenergo": Riga TPP-1 and Riga TPP-2, from which JSC "Rīgas Siltums" purchases the bulk of the heat that it sells.

In the middle of the first decade of the new century, a favourable macroeconomic situation developed in Latvia for rapid development of the immovable property market, including the city of Riga. The total demanded heat load of the potential clients of JSC "Rīgas Siltums" in 2006 was 1166 MW_{th}. The existing total heat load of the Right Bank and Left Bank areas of the city of Riga at the design temperature was 927 MW_{th} + 321 MW_{th} = 1248 MW_{th}. The demanded load of the new clients and the load of the existing clients = 1135 MW_{th} + 1248 MW_{th} = 2383 MW_{th}. The heat sources also have to guard the load against losses in the DH networks. It has to be pointed out that in 2006 the total installed capacity of the heat sources of JSC "Rīgas Siltums" and JSC "Latvenergo" in these heat supply areas was 823.5 MW_{th} + 1499 MW_{th} = 2322.5 MW_{th}. From the above, it can be seen that in order to ensure the demanded loads, it was necessary to increase the capacities of the heat sources of the existing CDHS and reconstruct the existing DH networks as well as construct new ones, according to the geographic layout of the existing and new heat loads.

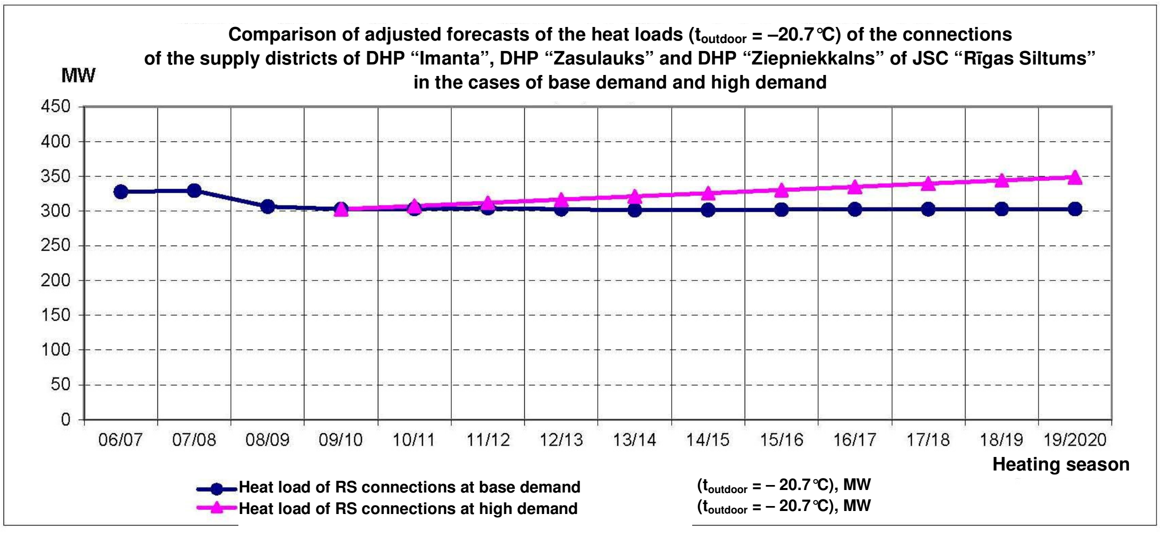
In 2010, the overall economic situation had changed considerably, therefore the earlier forecasts needed to be adjusted. The currently approved consumer heat load forecast is provided in Figure No. 7 for the Right Bank and in Figure No. 8 for the Left Bank.

Table Figure No. 7



Heating season	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/2020
Heat load of the connections of "Rīgas Siltums" in case of base demand ($t_{outdoor}$ = – 20.7°C), MW	958	960	901	890	891	894	889	884	886	887	888	889	889	889
Heat load of the connections of "Rīgas Siltums" in case of high demand ($t_{outdoor}$ = – 20.7°C), MW				890	903	917	930	943	956	970	983	996	1009	1023

Table Figure No. 8



Heating season	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/2020
Heat load of the connections of "Rīgas Siltums" in case of base demand ($t_{outdoor}$ = – 20.7°C), MW	328	330	307	303	303	304	303	301	302	302	303	303	303	303
Heat load of the connections of "Rīgas Siltums" in case of high demand ($t_{outdoor}$ = – 20.7°C), MW				303	308	312	317	321	326	331	335	340	344	349

In addition, weak spots in terms of power supply safety are analyzed and suggestions for its increase are formulated as well as the possibilities for increasing the power efficiency of the existing CDHS equipment are studied and economically substantiated. Economically substantiated suggestions for increasing the competitiveness of CHP plants operating in the electricity market conditions are provided.

It is practically impossible to implement the measures for developing the Riga CDHS, if there is no co-operation among the market participants (the heat producer, the transmission and distribution network operator and the heat consumers). In a situation when the heat producer is separated from the DH networks and the consumers, the reconstruction or modernization of the CDHS of practically any type directly affects all the three involved parties. Therefore, it is necessary to find such a solution that would ensure fair and equitable allocation of investments, additional operating costs and revenue among the following three players:

a) The heat producer;
b) The DH network operator;
c) The heat consumer.

In Chapter 5, a task of optimisation of Riga DH development is analyzed, in which the following is found out:

- The efficiency of power supply depends on a large number of parameters;
- The efficiency of power supply depends on possible structures of the networks. The structure of the networks can be chosen with a high degree of freedom;
- Part of the influencing parameters have a markedly uncertain character;
- The effectiveness of the adopted solutions depends on the action of the two main players participating in the power supply process: “Latvenergo” and “Rīgas Siltums”.

The structure of the algorithm for solving the optimisation task formulated in Chapter 4 is shown in Figure No. 9.

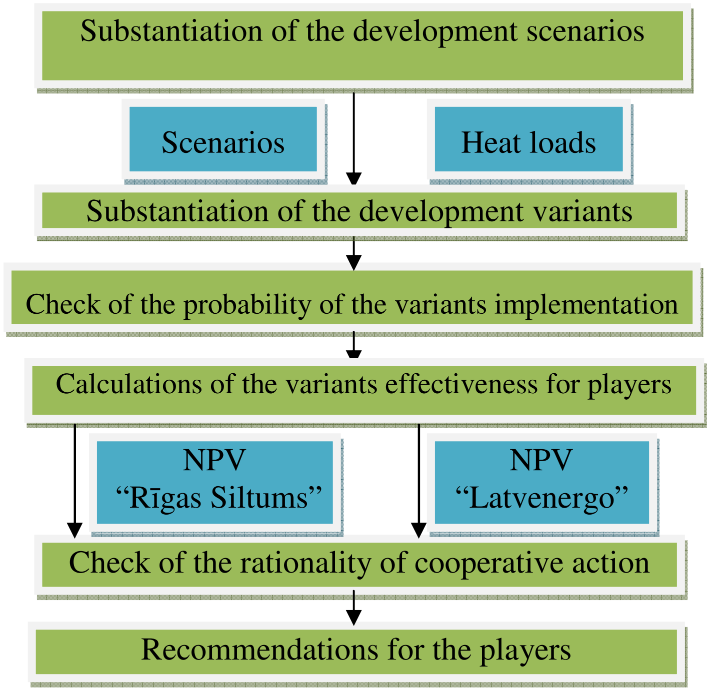


Figure No. 9: Structure of the algorithm for solving the task of Riga DH network optimisation.

Within the Riga City CDHS Development Plan up to 2020, based on the heat demand forecast, the DH network hydraulic modes were calculated for a number of Left and Right Bank CDHS development variants, according to which the required measures were determined for implementing these variants, the forecast investments and operating costs as well as allocation of heat loads between the heat sources were calculated accordingly. Following that, the forecast production programmes for the heat sources were drawn up, determining the amounts of heat and electricity produced by these heat sources, the amounts of consumed fuel and CO_2 emissions as well as other expenses in the most characteristic modes and in total for every financial year within a 20-year period. After that, a financial evaluation of these development variants was conducted by determining the expected NPV (economical sensitivity calculations), depending on:

- The changes in the gains for every additionally supplied electricity unit, which is generated in the CHP mode;
- The possible EU co-financing scope;
- The decrease in the amount of capital investments.

In order to implement a number of measures for Riga CDHS development, co-operation among the market participants (the heat producer, the transmission and distribution network operator and the consumer) is necessary.

Measures to be implemented and possible solutions for CDHS development are shown on Figure No. 10.

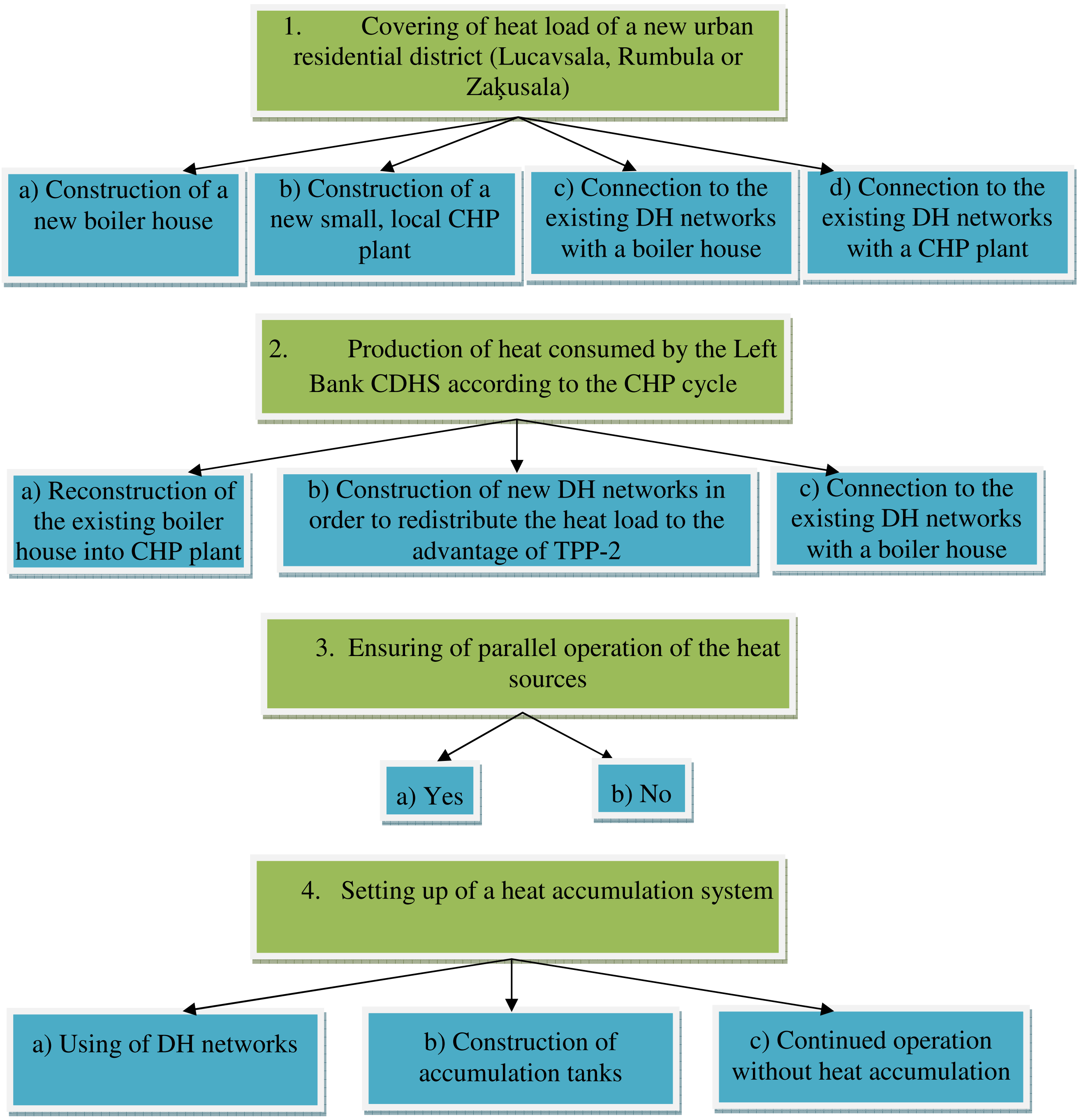


Figure No. 10: Measures to be implemented and possible solutions for CDHS development.

Measures to be implemented for covering of heat loads, involved parties and their gains and losses

	Measure to be implemented	Involved parties and measures to be taken by them	Gains and losses of the involved parties
1	2	3	4
1.	Covering of heat load of a new urban residential district (Lucavsala, Zaķusala, Rumbula or elsewhere)		
	a) Construction of a new boiler house	- The party ordering the construction of the boiler house, who initiates the construction and conducts the operation; - The heat consumers undertake to purchase heat from this source	Gain: - The consumer may benefit, if this new boiler house ensures a heat tariff lower than other sources, taking into account initial investments and operating costs; Losses: - The neighboring large CDHS sources have no possibility to increase the heat load.
	b) Construction of a new small, local CHP plant	- The party ordering the construction of the small CHP plant, who initiates the construction and conducts the operation; - The heat consumers, who purchase heat from this source; - The electricity consumers, who ensure the purchase from this producer	Gains: 1) The consumer may benefit, if this solution ensures heat tariffs lower than for other alternatives; 2) The additional electric capacities improve the safety of power supply and increase the competition on the electricity market, unless the mandatory purchase at increased tariffs is determined; Losses: - The neighboring large CDHS sources have no possibility to increase the heat load.
	c) Connection to the existing DH networks with a boiler house	- The owner of the DH networks have to construct a new main; - The boiler house have to ensure the required heat capacity; - The consumers have to conclude a heat purchase contract.	Gains: 1) The consumer may benefit, if the tariff of the existing boiler house together with energy losses in the networks will be lower than for other alternatives; 2) The existing DH networks and the existing boiler house will have the additional heat load, which may lower the fixed operating costs as related to the amount of supplied energy; Losses: 1) Inadequately large losses may emerge in long DH networks; 2) The loading of CHP sources is not increased.

1	2	3	4
	d) Connection to the existing DH networks with a CHP plant	- The owner of the DH networks have to construct a new main; - The heat source have to ensure the required heat power; - The consumers have to conclude a heat purchase contract.	Gains: 1) The consumer may benefit, if this solution ensures heat tariffs lower than for other alternatives; 2) The existing DH networks and heat sources will have the additional heat load, which will ensure lower fixed costs as related to one unit of supplied energy; 3) The additional heat load will allow generating more electricity according to the CHP cycle, especially in the summer period; Losses: - Inadequately large losses may emerge in long DH networks.
2.	Production of heat consumed by the Left Bank CDHS, according to the CHP cycle		
	a) Reconstruction of the existing boiler house(-s) into CHP plant(-s) (construction of Imanta TPP)	- The owner of the boiler house have to construct a CHP plant; - The sale of generated electricity have to be ensured, possibly, by means of the mandatory purchase	Gains: 1) For the consumers, possibly due to the income from electricity generation, it will be possible to lower the heat tariff; 2) The additional electric capacities will increase the power supply reliability; 3) The additional electric capacities will ensure a broader competition on the electricity market, unless the mandatory purchase is determined. Losses: - The large Right Bank CHP heat sources have no possibility to increase the heat load.
	b) Construction of new DH networks to cover this heat load by Riga TPP-2	- The DH network operator has to construct a connection line between the Right Bank and the Left Bank; - Riga TPP-2 has to ensure an appropriate installed heat capacity	Gains: 1) Considering the high efficiency of Riga TPP-2 and its larger relation between the produced electricity and heat, this heat source should have the lowest heat tariffs; however, the required investments in the DH networks as well as heat losses in the new pipelines have to be also taken into account; 2) In this way, Riga TPP-2 heat load in the heating period would be increased, which would allow producing the major portion of electricity in the cogeneration mode, thus increasing the summary heat and electricity fuel utilization coefficient. In the summer period, this heat load is likely to be covered by Riga TPP-1. Losses: - The DH network operator should place considerable investments in the main networks as well as take account of additional heat losses in them. The losses (in %) would particularly increase in the summer months, when the heat loads are comparatively lower.

1	2	3	4
	c) Continue to produce heat by HOB (heat-only boiler)	- The consumers have to continue to buy the heat at the existing tariffs	Gains: - Any investments are connected with certain risks; in this case, the investments are the lowest and, hence, the risks are the lowest; Losses: - None of the possibilities offered by electricity generation according to the cogeneration mode are used.
3.	Ensuring of parallel operation of the heat sources		
	a) Yes	It is necessary to conduct the automation of DH network chambers, the modernization of dispatcher's workstations as well as the training of employees	- Joining of two separated systems into one common system entails the following advantages: 1) it is possible to purchase heat at the lowest available tariff; 2) to ensure maximum possible loading for the most efficient heat source; 3) to use a number of heat sources for mutual backup; and the following disadvantages: 1) As a result of joining, a larger and more complicated CDHS emerges, which has a higher probability of failures; 2) A single emergency may influence a larger number of consumers.
	b) No		The above-mentioned advantages and disadvantages are not present.
4.	Setting up of a heat accumulation system		
	a) Using of DH networks	- The DH networks operating with accumulated heat should maintain an increased temperature in the supply and return pipelines; - The consumers should ensure a correct operation of their heat transfer station at a more fluctuating DH water temperature	Gains: 1) Accumulation would allow making the heat load chart even, thus applying more loading to the CHP plants as well as allow them operating more evenly; 2) Heat accumulation provides the CHP plants with a heat load at higher market prices of electricity, ensures the shutdown of these heat sources at lower electricity prices, without disturbing the heat supply to the consumers; 3) Accumulation increases the safety of heat supply, since the accumulated heat ensures the reserving of heat sources; Disadvantages: - Accumulation results in considerable heat losses in the DH networks.
	b) Setting up of a heat accumulation system by constructing an accumulation tank near the heat source	- The owner of the heat source constructs a heat accumulation system	- As compared to the accumulation system of the above-mentioned DH networks, this tank system has the following advantages: 1) Lower energy losses; 2) The DH water temperature chart is not changed for the consumers; and the following disadvantages: 1) Comparatively high initial investments, the recoupment of which depends on the amplitude and frequency of fluctuation of electricity market prices.

As can be seen from Figure No10. and Table No. 1., in a situation when the heat producer is separated from the DH networks and the consumers, the reconstruction or modernization of the CDHS of practically any type directly affects all the three involved parties. Therefore, it is necessary to find such a solution that would ensure fair and equitable allocation of investments, additional operating costs and revenue among the following three players:

a) The heat producer;
b) The DH network operator;
c) The heat consumer.

In this paper, the following two most characteristic variants have been chosen as examples. Variant No. 4.1.: JSC "Rīgas Siltums", the DH network operator, ensures parallel operation of JSC "Latvenergo" heat sources, TPP-1 and TPP-2, on the right bank of Daugava in Riga, thus making it possible to apply more load to the most efficient source. Variant No. 9.1.: JSC "Rīgas Siltums", the DH network operator, conducts the joining of the CDHS situated on the right bank and the CDHS situated on the left bank of Daugava in Riga, thus enabling JSC "Latvenergo" heat sources, TPP-1 and TPP-2, to increase the heat load. For these variants, fair allocation of jointly gained NPV among the participants according to the Shapley value is shown.

Conclusion

The intension of the world community to increase the power supply effectiveness and reliability as well as to diminish the influence on the environment has caused a restructuring process of the power systems, the aim of which is to ensure market conditions and free competition in energy generation and sale.

As a result of the restructuring, the power supply ensuring monopoly is divided. A number of more or less independent companies are formed, the operation goal of which is to ensure as large revenue as possible, and which, in general, compete between each other. In order to protect the community interests, i.e. limit the revenue of energy companies, promote the use of ecologically clean and modern technologies, and ensure quality and reliability, a Regulator institution is established. This institution develops regulations and limitations for market operation. As a result of the restructuring and forming a regulated power market with participation of competing companies, the power system development planning task is changed essentially.

In the general case, taking into account the market conditions, the power supply planning task with the aim of maximising their own revenue will be solved by participating of all the companies operating within the system in question. Furthermore, the strategies chosen by the competing companies are not known before their implementation. It should be noted that even if the information about the strategies of the competing companies is known, the calculation of their revenue is a complicated task, which has to be solved by using the technical and economical software packages. The solution of such a task entails the following two main problems:

1) The interests of different companies disagree; hence, in general, it is impossible to simultaneously maximise the revenue of all the companies.
2) Since the revenue depends on consciously chosen actions of the competitors, it is impossible to predetermine any statistically approved probabilities corresponding to these actions.

Methods based on the game theory can contribute to making the right decision about the development of energy sources. In particular, the cooperative game theory taking into consideration a possibility to form a coalition should be used. The initiator of the integration process can gain additional revenue by choosing a successful way of coalition formation. In due course, this approach will result in a more efficient power supply system.

The above-mentioned examples show that even comparatively small projects, such as distribution network development projects, may bring the economic benefit (hundreds of thousands). In the larger projects (for example, the heat supply of Riga), the economic benefit may reach millions.

Further Study Directions

In the sphere of power generation, there are a number of planning tasks, for rational solving of which a formation of a coalition is required. Thus, the game approach can be used and the arising problem regarding allocation of expenses and revenue can be solved. Below follows a list, where these tasks are illustrated by examples.

- *Construction of a nuclear power plant for joint use by the three Baltic countries.*

After the shutdown of Ignalina nuclear power plant, Lithuania, Latvia and Estonia are becoming deficient. Each country, acting independently, can develop its generating capacities; however, the formation of a coalition could result in an alternative that is more advantageous for all the participants, i.e. construction of a power plant by joint efforts.

- *Construction of an underwater cable, connecting the Baltic countries and Sweden.*
- *Choosing of the location for a city substation.*

When choosing locations for constructing new city substations, there is often a conflict of interests between the transmission grid and the distribution grid, which are minimising their expenses and losses separately. Joint decisions are more economically efficient.

- *Allocation of payments for reserve capacities.*

The interconnected power systems have different structures and are provided with reserves in different ways. The joint use of reserves is advantageous for all parties; however, the task of allocation of payments for reserves is a burning issue.

- Allocation of expenses for the formation of global (common for several interconnected power systems) breakdown automation.
- *Allocation of payments for participation in the frequency regulation process.*

Only some high-capacity power plants usually participate in this process. This participation entails considerable expenses. Allocation of expenses among all energy producers can be solved by the considered methods.

Bibliography

1. A.G. Bakirtzis. Aumann-Shapley Transmission Congestion Pricing. In Power Engineering Review, IEEE, 21(3):67{69, 2001.
2. Aivars Kvesko. TEC-2. No pagātnes uz nākotni // "Enerģija un Pasaule" No.3 (62), June – July, 2010.
3. Arnis Kalniņš. Par atjaunojamās elektroenerģijas ražošanas izmaksām un tās konkurētspēju. // "Enerģija un Pasaule" No.4 (63), August – September, 2010.
4. JSC "Rīgas Siltums" Report Data on the Amount of Heat Produced and Supplied to Consumers, its Breakdown by Consumer Sectors and Service Zones for 2003/2004, 2004/2005 and 11 months of 2005/2006.
5. Technical Regulations 2005-2010 Issued by JSC "Rīgas Siltums".
6. JSC "Rīgas Siltums" Statistical Data on Heat Loads of Consumers.
7. JSC "Rīgas Siltums" Annual Reports 2004-2009.
8. The Present Condition and Economic Indicators of JSC "Rīgas Siltums" Power Facilities.
9. BALTSO Annual Report 2006. From Internet: www.baltso.eu
10. Data on Buildings and their Heat Supply in Helsinki: ÅF-Enprima Ltd, Report of Markku Saukkonen, Technical Consultant.
11. Data on Buildings and their Heat Supply in Stockholm: Officials Statistics Sweden Databases www.scb.se .
12. Directive 2001/77/EC of the European Parliament and the Council of September 27, 2001 on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market.
13. Dr.sc.ing. Anzelms Bačausks. Starpsistēmu elektrosaites – reģionālās kooperācijas pārvads // "Enerģija un Pasaule" No.2 (55), April – May, 2009.
14. Du Songhuai, Zhou Xinghua, Mo Lu, and Xue Hui. A Novel Nucleolus-based Loss Allocation Method in Bilateral Electricity Markets. IEEE Transactions on Power Systems, 21:28{33, 2006.

15. E. Faria, L.A. Barroso, R. Kelman, S. Granville, and M.V. Pereira. Allocation of Firm-Energy Rights among Hydro Plants: An Aumann-Shapley Approach. IEEE Transactions on Power Systems, 24(2):541{551, 2009.

16. Directive 2009/28/EK of the European Parliament and the Council of April 23, 2009 on the promotion of the use of renewable energy sources.

17. Elmārs Tomsons. Piedāvāto III un III+ paaudzes lielas jaudas enerģētisko kodolreaktoru realizācija. // "Enerģija un Pasaule" No.5 (64), October – November, 2010.

18. Basic principles of power development in the period from 2007 to 2016. Cabinet of Ministers, Ministry of Economy of the Republic of Latvia, July 27, 2006.

19. Ernst&Young. Managerial Accounting, Part 2, Great Britain, 1995, 203 pp.

20. E.Van Geert. Increased Uncertainty – a New Challenge for Power System Planners. IEE Colloquium on Tools and Techniques for Dealing with Uncertainty (Digest No.1998/200), 1998, pp.1831-1837.

21. G. Vempers, J. Inde et al. // AS „Rīgas Siltums" Kreisā krasta siltumtīklu un siltuma avotu izmantošanas un attīstības biznesa plāns laika posmam no 2006. līdz 2018. gadam. // 374 pp.

22. G. Vempers, J. Inde et al. // AS „Rīgas Siltums" Labā krasta siltumtīklu un AS „Latvenergo" siltuma avotu izmantošanas un attīstības biznesa plāns laika posmam no 2006. līdz 2018. gadam. // 437 pp.

23. G. Vempers, J. Inde et al. // Rīgas pilsētas centralizētās siltumapgādes sistēmas optimizācijas iespējas laika posmā no 2010.gada līdz 2020.gadam. // 524 pp.

24. Jānis Osītis. Pirmais pusgads bez Ignalinas AES // "Enerģija un Pasaule" No.4 (63), August – September, 2010.

25. J. Bialek. Tracing the Flow of Electricity. In Generation, Transmission and Distribution, IEE Proceedings, 143:313{320, July, 1996.

26. J.-C. Peng, H. Jiang, and Y.-H. Song. A Weakly Conditioned Imputation of an Impedance-branch Dissipation Power. In IEEE Transactions on Power Systems, 22:2124{2133, 2007.

27. J.F. Vernotte, P. Panciatici, B. Meyer (EDF)/ J.P. Antoine, J. Deuse and M. Stubbe (TRACTEBEL). High Fidelity Simulation Power System Dynamics. IEEE Computer Applications in Power (CAP), January, 1995.

28. Z. Krišāns, I. Oļeiņikova. Elektroenerģētisko uzņēmumu vadības pamati. Riga, Riga Technical University, 2007.

29. Leo Jansons. Globālo elektroenerģijas bāzes jaudu un energoapgādes drošības problēmu projekcijas Baltijas valstu ES integrācijas kontekstā. // "Enerģija un Pasaule" No.6 (65), December – January, 2010.

30. Leo Jansons. Baltijas valstis vienota Eiropas Savienības elektroenerģijas sektora un tirgus formācijas kontekstā: integrācijas leģitīmie aspekti un tehniskās problēmas (2003-2009) // “Enerģija un Pasaule” No.5 (64), October– November, 2010.

31. Lloyd S. Shapley. *A Value for n-person Games*. In Contributions to the Theory of Games, Volume II, by H.W. Kuhn and A.W. Tucker, editors. Annals of Mathematical Studies v. 28, pp. 307-317, Princeton University Press.

32. Republic of Latvia Central Statistical Bureau Database: http://www.csb.lv

33. Martin J. Osborne. Publicly Available Solutions for an Introduction to Game Theory, University of Toronto, 2004.

34. M. Balodis, O. Linkevičs, G. Klāvs. Energoapgādes variantu analīze un energoapgādes drošība Baltijas valstīs. “Latvenergo Vēstis”, 2004.

35. M. Bockarjova, M. Zima, and G. Andersson. On Allocation of the Transmission Network Losses Using Game Theory in Electricity Market. EEM 2008. 5th International Conference on European Electricity Market, pp. 1{6, 2008.

36. Regulations No. 112 of the Cabinet of Ministers of the Republic of Latvia “General Construction Regulations” (with Amendments), dated April 4, 1997.

37. Ordinance No. 835 of the Cabinet of Ministers of the Republic of Latvia “Basic Principles of Using Renewable Energy Sources in the period from 2006 to 2013”, dated October 31, 2006.

38. Regulations No. 262 of the Cabinet of Ministers of the Republic of Latvia “Regulations on Electricity Production, Using Renewable Energy Sources, and Pricing Procedure”, dated March 16, 2010.

39. M. Junqueira, L. C. da Costa, L. A. Barroso, G. C. Oliveira, L. M. Thome, and M. V. Pereira. An Aumann-Shapley Approach to Allocate Transmission Service Cost among Network Users in Electricity Markets. IEEE Transactions on Power Systems, 22:1532{1546, 2007.

40. V. Miranda, L.M. Proenca. Probabilistic Choice vs. Risk Analysis-conflicts and Synthesis in Power System Planning. IEEE Transactions on Power Systems, August 1998, Vol.13, pp. 1038-1043.

41. M. Zima-Bockarjova, J. Matevosyan, M. Zima, and L. Soder. Sharing of Profit from Coordinated Operation Planning and Bidding of Hydro and Wind Power. IEEE Transactions on Power Systems, Vol. 25, No.3, pp. 1663-1673, August 2010.

42. From Internet: http://www.achemagroup.com

43. From Internet: http://www.fortum.com/en/energy-production

44. From Internet: http://www.rs.lv

45. O. Linkevičs, A. Babikovs, S. Ķiene. Gotlink – elektriskais tilts uz Ziemeļeiropu. "Enerģija un pasaule", No.6, 2005.
46. O. Linkevičs, G. Klāvs, V. Gavars, M. Balodis, J. Andersons. Baltijas valstu energoresursu apgāde līdz 2025. gadam. "Enerģija un pasaule", No. 4, 2005.
47. O. Linkevičs. Kā izveidot fiziskus savienojumus ar Eiropas energosistēmām? "Enerģētika un Sabiedrība", No.22, 2003.
48. O. Linkevics, M. Balodis, A. Babikovs, J. Andersons, A. Sauhats, V. Chuvychin. Problems of the Grid Integration of Renewable Energy Sources in Latvia Prospective HVDC Interconnection of Latvia and Gotland. Wind Energy in the Baltic Sea Region, Gotland, 2005.
49. M.J. Osborne, and A. Rubinstein. A Course in Game Theory. MIT Press (Chapters 13, 14, 15), 1994.
50. P.A. Kattuman, R.J. Green and J.W. Bialek. A Tracing Method for Pricing Inter-Area Electricity Trades. Cambridge Working Papers in Economics, 2004.
51. P.A. Kattuman, R.J. Green, and J.W. Bialek. A Tracing Method for Pricing Inter-Area Electricity Trades. Cambridge Working Papers in Economics 0107, Faculty of Economics, University of Cambridge, June 2001.
52. Riga City Development Plan (Long-term Development Strategy of the City of Riga up to 2025, Riga City Development Programme for the period from 2006 to 2012, Riga City Territory Plan for the period from 2006 to 2018). Riga City Council, 2005.
53. Riga District Heating Development Concept for the period from 2006 to 2016. Resolution No. 1365 of Riga City Council, edited by Dr.sc.ing. M. Rubīna, August 1, 2006.
54. Shih-Chieh Hsieh. Fair Transmission Loss Allocation Based on Equivalent Current Injection and Shapley Value. In Power Engineering Society General Meeting, 2006. IEEE, 6 pp., 2006.
55. Shih-Chieh Hsieh and Hsin-Min Wang. Allocation of Transmission Losses Based on Cooperative Game Theory and Current Injection Models. In Industrial Technology, 2002. IEEE ICIT '02. 2002 IEEE International Conference, Vol. 2, pp. 850{853, 2002.
56. Thermoflow. Comprehensive Thermal Engineering Software. Thermoflow Inc., April, 2002.
57. L. Vasiļjeva Vides ekonomikas būtība, Part 1. Riga, Riga Technical University, 1998.
58. V. Neimane. On Development Planning of Electricity Distribution Networks, Ph.D. thesis, Royal Inst. of Technology, Stockholm, Sweden, 2001.
59. V. Neimane, A. Sauhats, G. Vempers, I. Tereskina, G. Bochkarjova. Approach for Power Supply System Planning Based on Cooperative Game Theory. The 5th International

Conference on the European Electricity Market – EEM 08, Lisbon, Portugal, May 28-30, 2008, ID#206.

60. V. Neimane, A. Sauhats, G. Vempers, J. Inde, I. Tereskina, G. Bockarjova. Allocating Production Cost of CHP Plant to Heat and Power, Using Cooperative Game Theory. IEEE Bucharest Power Tech Conference, 2009.

61. V. Neimane, A. Sauhats, G. Vempers, I. Tereskina, G. Bochkarjova. Approach for Energy Supply System Planning Based on Cooperative Game Theory. EEM – 08, Vol. 174, pp. 182-187.

62. V. Neimane, A. Sauhats, J. Inde, G. Vempers, G. Bockarjova. Using Cooperative Game Theory in Energy Supply Planning Tasks. The 16th Power Systems Computation Conference – PSCC2008, Glasgow, Scotland, July 14-18, 2008, ID#220.

63. X.J. Lin, C.W. Yu, and C.Y. Chung. Pricing of Reactive Support Ancillary Services. In Generation, Transmission and Distribution, IEE Proceedings, 152(5):616{622, 2005.

64. Неклепаев Б.Н. Электрическая часть электростанций и подстанций. М.: Энергоатомиздат, 1986. – 640 с.

65. Петренко Л.И. Электрические сети и системы. Киев.: Выща школа, 1981. – 320 с.

66. Славина Н.А., Косматов Э.М., Барыкин Е.Е. О методах распределения затрат на ТЭЦ // журнал «Электрические станции» № 11, 2001. – с. 14-17.

67. Справочник по проектированию электрических сетей. Под редакцией Д.Л. Файбисовича. М, 2006. – 320 с.