RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Energy Systems and Environment

Liga ZOGLA
Doctoral Program in Environmental Science

METHODOLOGY FOR MODELLING ENERGY EFFICIENCY POLICY INSTRUMENTS IN INDUSTRIAL SECTOR

Summary of PhD thesis

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DISSERTATION PROPOSED FOR DR.SC.ING. DEGREE IN ENVIRONMENTAL ENGINEERING AT RIGA TECHNICAL UNIVERSITY

This study is proposed for attaining the degree of Dr.sc.ing. in Environmental Engineering and will be defended on January 22nd, 2015 at 2:00 p.m. at the faculty of Power and Electrical Engineering, Āzenes iela 12/1, Room 116.

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CONFIRMATION STATEMENT

I, the undersigned, hereby confirm that I have developed this dissertation, which is submitted for consideration at Riga Technical University, for attaining the degree of Dr.sc.ing. in Environmental Engineering. This study has not been submitted to any other university or institution for the purpose of attaining scientific degrees.

Liga Zogla …………………………….

Date: 22.01.2015.

The dissertation is written in Latvian and contains: an introduction, 5 chapters, conclusions, a bibliography, 3 appendices, 74 figures, 11 tables and 142 pages. The bibliography contains 154 references.

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Background and current situation

The industrial sector is considered to be one of the largest end consumers of energy and one of the major environmental polluters. In Latvia, the industrial sector with an average consumption of 32 PJ of energy per year is the third largest energy end-use sector, preceded by the household and transport sectors. The industrial sector is also the basis for economic growth of each country. The current industrial policy at the national level determines productivity growth in the manufacturing industry, which will undoubtedly contribute to an increase in energy consumption in the industrial sector as a whole. Consequently, it is important to ensure that not only an increase in production output is achieved, but also that the efficiency of production is improved, thus promoting the competitiveness of enterprises.

So far, energy efficiency requirements for the industrial sector in Latvia have been determined through the transposition and incorporation of the relevant European Union directives into the existing national laws and regulations. Apart from that, no specific targets for reducing energy consumption are being set. Nevertheless, production companies to date have implemented a variety of energy efficiency measures, primarily due to the gradually rising energy costs. Statistics show, however, that production companies in Latvia consume more energy per unit of output marketed than the EU-29 average. Therefore, in order to ensure the improvement of energy efficiency in the industrial sector, it is essential to find new solutions for the application of energy efficiency policy instruments in the industrial sector, with a view to eliminate the existing barriers to implementation of the energy efficiency measures in manufacturing enterprises and provide the required support for sustainable industrial development.

Objectives

In order to promote energy efficiency in the industrial sector, the objective of the doctoral thesis is to develop a methodology for modelling energy efficiency policy instruments in the industrial sector and to carry out approbation of this methodology on an example from a particular sector.

The following tasks have been set forth in order to achieve the objective of the thesis:

- to explore the framework of the existing regulatory requirements and energy consumption in the industrial sector, and, based on the results, define the target sector for further research;
- to study and identify the potential barriers to implementation of the energy efficiency measures in manufacturing enterprises;

- to study and determine the most appropriate energy efficiency policy instruments for the industrial sector;
- to conduct an in-depth study of the target sector, evaluating the energy efficiency changes and determining the energy savings potential;
- to create a model which can be used to predict the energy efficiency changes in the target sector and to evaluate the impact of the determined energy efficiency policy instruments on achieving the goals of the energy savings potential.

Research methodology

The methodology of the doctoral thesis consists of several stages, which are divided into separate research parts (see Figure 1).

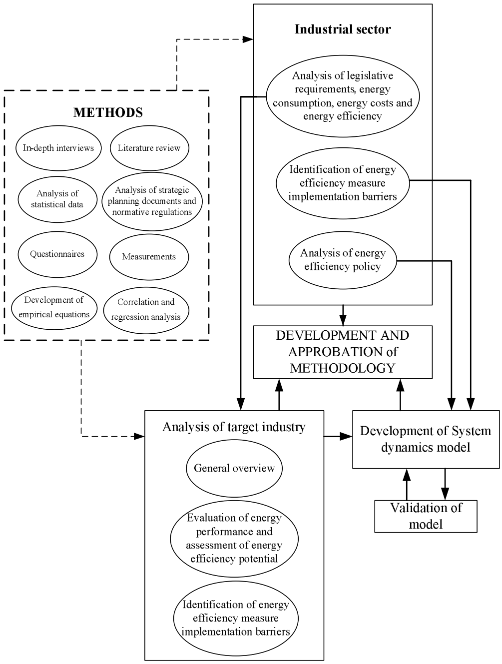

Fig. 1 Overall methodology of the thesis

Qualitative and quantitative research methods have been used to develop the doctoral thesis. An extensive analysis of literature, strategic documents, laws and regulations and statistical data has been conducted to assess the energy efficiency of the industrial sector, using mathematical statistics methods, such as correlation and regression analysis. On-site review of manufacturing enterprises has been performed, and the data characterising the necessary manufacturing processes have been collected and analysed in *MS Excel* and *STATGRAF* environments to evaluate the target sector. In addition to the mathematical processing of data and development of empirical equations, electricity monitoring has been conducted in one of the enterprises in the target sector. A system dynamics model has been developed in the *Powersim Studio 8* environment to forecast the energy efficiency changes and assess the impact of the energy policy instruments.

Two types of qualitative research methods have been used in the thesis: in-depth interviews and surveys aimed at identifying the barriers and motivational factors for the implementation of energy efficiency measures in manufacturing enterprises. In addition, meetings, telephone conversations and electronic correspondence with industry experts have been carried out.

Scientific significance

A methodology for the application of energy efficiency policy instruments in the industrial sector has been developed as a result of the doctoral thesis. To assess energy efficiency and determine its potential in the industrial sector, a new approach based on the application of the benchmarks describing the manufacturing processes has been created. It allows for evaluation of the energy efficiency changes consistently over time and setting specific, realistic targets for energy efficiency in the industrial sector.

A new simulation model has been developed that allows for the assessment of changes in energy efficiency and the impact of the energy efficiency policy instruments on the industrial sector, taking into account both economic and socio-economic factors.

Practical significance

The doctoral thesis has great practical significance. The thesis identifies those industries within the industrial sector in Latvia which require special attention to improve energy efficiency. The most appropriate energy efficiency policy instruments have been determined and proposals for the implementation of these instruments to promote energy efficiency in the industrial sector have been provided. Barriers to the implementation of energy efficiency measures in manufacturing enterprises have been identified and motivational factors for the introduction of such measures have been defined.

The results obtained in the thesis can be used for energy efficiency policy making in the industrial sector, and they are applicable to the following target groups linked to the promotion of energy efficiency in industry:

- policy makers: a methodology for the application of energy efficiency policy instruments in the industrial sector has been developed, based upon which it is possible to adapt the created model as a whole for the assessment of the industrial sector;
- industry associations: the associations' role and tasks have been identified, including the manner in which energy efficiency changes in manufacturing enterprises can be evaluated at the level of one industrial sector and in which the developed model can be used to forecast energy efficiency;
- manufacturing enterprises: one way to analyse energy consumption data at the enterprise level has been specified. The developed model can be used to forecast the energy consumption changes of one enterprise and to determine energy efficiency targets at the enterprise level.

Approbation

The results of the research have been discussed and presented in the following conferences:

1. ECEEE 2011 Summer Study: Energy Efficiency First: a Low Carbon Society with a presentation „Energy Management System in Industry. Experience in Latvia" – June 6-11, 2011, Belambra Presquile de Giens, France.
2. ECEEE 2012 Industrial Summer Study: 30 percent of Europe's energy use with a poster „Green investment scheme for Latvian industries" – September 11-14, 2012, Arnhem, The Netherlands.
3. 2012 International Energy Program Evaluation Conference with a poster „Methodology for Evaluation of Energy Efficiency Policy for Industries in EU Countries with Less Energy Intensive Industrial Sector" – June 12-14, 2012, Rome, Italy.
4. The 69th University of Latvia Scientific conference, section „Vides zinātne" with a presentation „Latvijas rūpniecības sektora ietekme uz klimatu" – February 2nd, 2011 Riga, Latvia.
5. The 9th International Conference of Young Scientists on Energy Issues (CYSENI 2012)" with a presentation „Advantages and Obstacles for the Development of Industrial Symbiosis in Latvia" – May 24-25, 2012, Kaunas, Lithuania.

6. The 17th European Roundtable on Sustainable Consumption and Production with a presentation „Efficient Use of Energy in Small Size Brewery" – October 14-16, 2014, Portoroz, Slovenia.
7. The 54th RTU International Scientific Conference, with a poster „The design of support program for energy efficiency improvement in Latvian industry" – October 12-14, 2013, Riga, Latvia.
8. The 55th RTU International Scientific Conference with a poster „Process benchmark for evaluation energy performance of breweries" – October 14-16, Riga, Latvia.

Publications

1. Ozoliņa, L., Rošā, M. The Consumer's Role in Energy Efficiency Promotion in Latvian Manufacturing Industry. *Management of Environmental Quality*, 2013, Vol.24, No.3, 330.-340.pp. (indexed in SCOPUS)
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3. Bartiaux F., Gram-Hanssen K., Fonseca P., Ozoliņa L., Haunstrup Christensen T. A practice–theory approach to homeowners' energy retrofits in four European areas. *Building research and Information,* 2014, Vol. 42, No.4, 525 – 538.pp. (indexed in SCOPUS)
4. Ozoliņa L., Rošā M., Blumberga D., Kalniņš S. Energy Management System in Industry. Experience in Latvia // Energy Efficiency First: a Low Carbon Society ECEEE 2011 Summer Study: Conference Proceedings, France, Belambra Presquile de Giens, June 6-11, 2011, 609. – 618. pp.
5. Ozoliņa L., Rošā M., Paturska A., Beloborodko A. Green investment scheme for Latvian industries // ECEEE 2012 Industrial Summer Study: Conference Proceedings, The Netherlands, Arnhem, September 11-14, 2012, 123. – 128. pp.
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7. Ozoliņa, L. Latvijas rūpniecības sektora ietekme uz klimatu. No: Geography, Geology. *Environmental sciences: The 69th University of Latvia Scientific conference: Abstract Book*, Latvia, Riga, February 2nd, 2011, 179. – 180.pp.
8. Beloborodko, A., Žogla, L., Rošā, M. Efficient Use of Energy in Small Size Brewery. No: *17th European Roundtable on Sustainable Consumption and*

Production: Book of Abstracts, Slovenia, Portoroz, October 14-16, 2014. 151. – 151.pp.

9. Beloborodko, A., Rošā, M., Ozoliņa, L. Advantages and Obstacles for the Development of Industrial Symbiosis in Latvia. No: *9th International Conference of Young Scientists on Energy Issues (CYSENI 2012): Conference Proceedings*, Lithuania, Kaunas, May 24-25, 2012, 279. – 288.pp.
10. Dobrāja, K., Ozoliņa, L., Rošā, M. Design of a Support Program for Energy Efficiency Improvement in Latvian Industry. No: *Environmental and Climate Technologies 2013: Conference Proceedings*, Latvia, Riga, October 14-16, 2013, 49. – 59.pp.
11. Eihvalde, D., Blumberga, D., Ozoliņa, L. Cleaner Production for Insulation Material Company and Economic Calculation. *Environmental and Climate Technologies: Abstract Book*, Latvia, Riga, October 14-16, 2013, 12 – 13.pp.
12. Žogla L., Žogla G., Beloborodko A., Rošā M., Process benchmark for evaluation energy performance of breweries. *Energy Procedia,* 2014 - Article in press. (indexed in SCOPUS)
13. Dzene I., Polikarpova I., Ozoliņa L., Rošā M., How ISO 50001 can assist in implementation of sustainable energy action plans? *Energy Procedia,* 2014 - Article in press. (indexed in SCOPUS)

Structure of the thesis

The *introduction* provides the reasons for the topicality of the selected topic, lists the research methods used in the development of the thesis and describes the scientific novelty of the research and its practical application. Chapter 1 entitled *Energy Consumption Framework in the Industrial Sector* deals with the analysis of the legislation related to energy efficiency in the industrial sector, as well as the data analysis in regard to the industrial sector energy consumption and energy costs, and evaluation of energy efficiency. Chapter 2 *Barriers to Implementation of Energy Efficiency Measures in Manufacturing Enterprises* is devoted to the analysis of literature and application of the qualitative research method to identify the barriers, which hinder the implementation of energy efficiency measures in Latvian manufacturing companies. Chapter 3 *Energy Efficiency Policy Assessment in the Industrial Sector* contains an analysis of various policy instruments aimed at improving energy efficiency in the industrial sector and provides an assessment of the existing policy instruments in Latvia. The chapter concludes with proposals for the application of the existing energy efficiency policy instruments in Latvia in order to increase energy efficiency in the industrial sector. Chapter 4 *Development and Approbation of the Methodology for Application of Policy Instruments in the*

Industrial Sector presents the developed methodology for the application of policy instruments for energy efficiency in the industrial sector, which has been approbated in the context of the brewing industry subsector. This chapter contains an in-depth assessment of the brewing industry subsector based on the literature and statistical data analysis, visits to brewing companies and measurements taken. The chapter concludes with the application of the benchmarks describing the processes, which has resulted in determining a variety of energy savings potential options in the brewing industry subsector. Chapter 5 *Development of a System Dynamics Model for Modelling of Energy Efficiency Policy Instruments* presents a developed system dynamics model based on the research carried out in the previous chapters of the doctoral thesis and conclusions drawn from the research. This chapter describes the created system dynamics model, the simulation of the model and scenario building, as well as the validation of the model and sensitivity analysis.

The doctoral thesis concludes with a summary of findings and conclusions, bibliography and annexes.

1. General Description of the Industrial Sector

The industrial sector as a whole is the third largest end consumer of energy in Latvia, with an average annual consumption of 30 PJ. The majority or 93% of the energy is used to ensure the production processes in the manufacturing industry [1]. Therefore, this thesis examines and analyses the manufacturing industry only.

In accordance with NACE Rev. 2 classification, the manufacturing sector is composed of 24 different subsectors. There are only four manufacturing subsectors in Latvia, where energy consumption is higher than 5%. The greatest share of energy consumption is seen in the manufacture of wood and wood products (46%), followed by the manufacture of non-metallic mineral products (22%), the manufacture of food products and beverages (12%) and the manufacture of metals (7%) [2]. Based on the information available in the database ODYSSEE, the Latvian manufacturing industry consumes more energy per unit of output marketed than the EU-28 and Norway average [3].

Considering the limited funding and availability of human resources in the state institutions of Latvia, energy efficiency policy instruments should be restricted to specific subsectors. In order to determine which subsectors of the manufacturing industry could be selected as the target industries for the application of energy efficiency policy instruments, three different indicators are used: energy intensity; capital intensity and employment intensity. Energy intensity is one of the most widely used indicators for assessing energy efficiency in the industrial sector. It describes changes in energy consumption, depending on the amount of the output marketed, and is determined using the following formula [4 – 7]:

$$I_{i,t} = \frac{E_{i,t}}{PV_{i,t}} \tag{1}$$

where:
$I_{i,t}$ – energy intensity in sector i in year t, GWh/thou. EUR (added value);
$E_{i,t}$ – energy consumption in sector i in year t, GWh;
$PV^{1}_{i,t}$ – added value of the products in sector i in year t, thou. EUR.

Capital intensity and employment intensity indicators are used because they describe the differences between the heavy (energy-intensive) industry and light (non-energy-intensive) industry. Capital intensity describes investment in tangible

[1] The amount of goods produced or services provided, including changes in inventories and own-produced fixed assets and intangible assets, net of goods and services purchased for re-sale.

goods, depending on the amount of the output marketed, and is determined using the following formula [8]:

$$KI_{i,t} = \frac{K_{i,t}}{PV_{i,t}} \tag{2}$$

where:
$KI_{i,t}$ – capital intensity in sector i in year t, thou. EUR/thou. EUR (PV – added value);
$K_{i,t}$ – gross investment in tangible goods in sector i in year t, thou. EUR.

Employment intensity describes the availability of human resources per amount of the output marketed. It is determined using the following formula [8]:

$$NI_{i,t} = \frac{D_{i,t}}{PV_{i,t}} \tag{3}$$

where:
$NI_{i,t}$ – employment intensity in sector i in year t, number of employees/thou. EUR (PV – added value);
$D_{i,t}$ – the number of employees in sector i in year t.

The obtained results, which describe changes in capital intensity depending on energy intensity, are shown in Figure 2. Energy-intensive industrial sectors are characterised by bigger financial investment in the production processes and the need to ensure greater energy consumption for production.

Closeness of the relationship between energy intensity and capital intensity has been determined using the correlation and regression analysis. The squared correlation coefficient is 0.31. This shows that the energy intensity accounts for 31% of the variability of capital intensity (63% of the variability of capital intensity is caused by other factors). At the same time, research mentions the existence of a relationship between employment intensity and energy intensity, as well as capital intensity and energy intensity. This allows for the use of these indicators to determine distribution in the industrial sector, yet they cannot be used in this case, as no statistically significant relationship is formed. Despite this, the analysis of the data clearly marks off four manufacturing subsectors (manufacture of non-metallic mineral products, manufacture of wood and wood products, manufacture of chemicals and manufacture of metals) which are fundamentally different from other manufacturing subsectors.

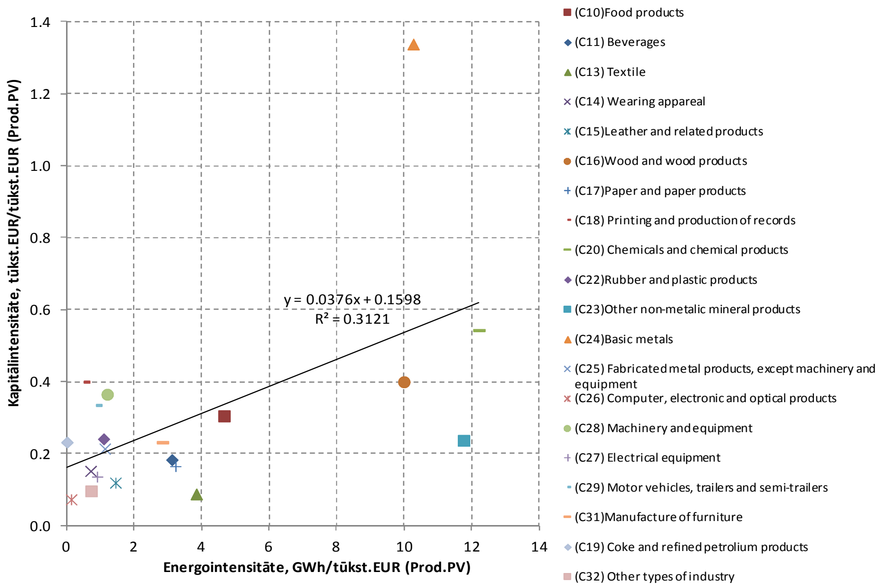

Fig. 2. Relationship between energy intensity and capital intensity in manufacturing industry subsectors

One of the key factors determining a company's willingness to implement energy efficiency measures is the share of energy costs in the company's overall budget. The larger the share of energy costs, the more the company is interested to introduce energy efficiency measures. To determine the energy costs for each individual manufacturing subsector, the energy consumption and fuel cost data from 2011 have been summarized. The results are shown in Figure 3. The total energy consumption in the sector is distributed as follows: electricity consumption accounts for 19%, natural gas – 25%, wood fuel – 37%, oil fuel – 11% and other types of energy resources – 8%.

To determine the share of energy costs, data on energy costs and turnover in 2011 have been used. The subsector of the manufacture of non-metallic mineral products has the biggest share with 13.2%, followed by the manufacture of wood products, chemicals and metals with 6%, the manufacture of textiles with 5.5% and the manufacture of food products with 4.6%.

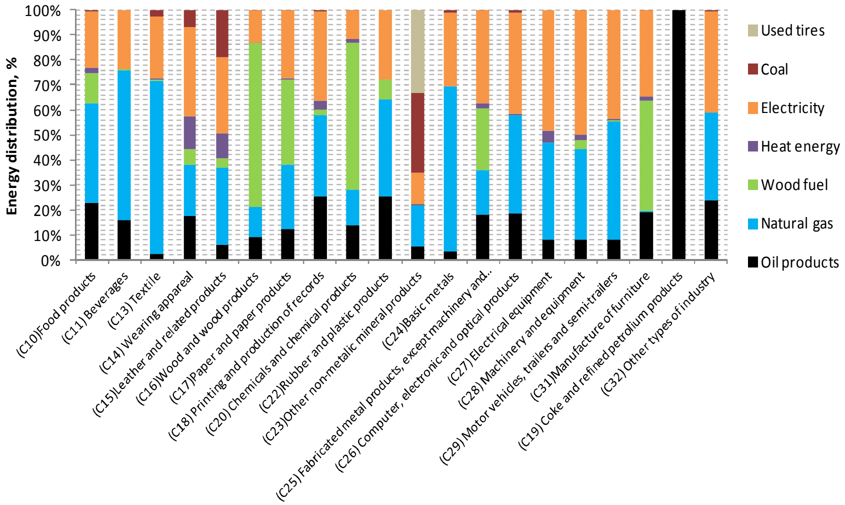

Fig. 3. Energy distribution in manufacturing industry subsectors

The main indicator which has been used until now to assess energy efficiency in the enterprises belonging to the manufacturing industry is specific energy consumption (SEC) which shows the amount of energy consumed to produce one unit of output. Unlike energy intensity, the SEC is primarily affected by the processes in the production unit and the use of resources. The SEC is determined using Formula 4. [4 – 7, 9].

$$SEC_{i,t} = \frac{\mathrm{E_{i,t}}}{\mathrm{Y_{i,t}}} \tag{4}$$

where:
$SEC_{i,t}$ –specific energy consumption in sector i in year t, MWh/output;
$Y_{i,t}$ –production output in sector i in year t.

To assess energy efficiency in the Latvian enterprises belonging to the manufacturing industry, the analysis of the data related to the brewing industry output and the amount of energy consumed has been carried out. Taking into account the information on the output and SEC provided in the permits for the performance of polluting activities, the closeness of the relationship between these values has been determined using correlation and regression analysis (see Figure 4).

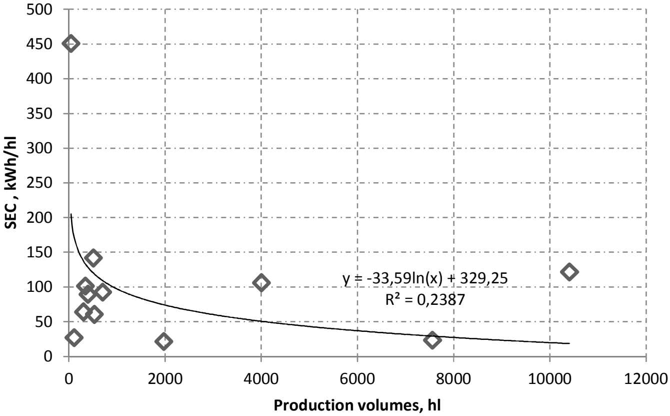

Fig. 4. Relationship between production output and specific energy consumption

As shown in the graph, the squared correlation coefficient is 0.23, which indicates that no statistically significant relationship between these values is formed. Theoretically, the mentioned relationship should develop. This non-compliance may be explained by the following: the information provided in the permits is incorrect; and data from both small and medium-sized enterprises (SMEs) and large enterprises have been used to determine the relationship. In order to assess the quality of the information, the data regarding the fuel consumption from the database *Gaiss-2* of the Latvian Environment, Geology and Meteorology Centre and from the permits for the performance of polluting activities have been compared. The results obtained indicate that the data from these sources cannot be used for the evaluation of energy efficiency in the brewing industry subsector. Consequently, it is likely that the data from these sources cannot be used to evaluate energy efficiency of manufacturing enterprises in other manufacturing industry subsectors as well.

Main conclusions:

In order to achieve a reduction in energy consumption in the manufacturing industrial sector, attention should primarily be paid to the following manufacturing subsectors according to NACE Rev. 2. classification:

- manufacture of non-metallic mineral products (23);
- manufacture of wood and wood products (16);
- manufacture of chemicals (20);
- manufacture of food products and beverages (10, 11);
- manufacture of textiles (13);

- manufacture of metals (mainly refers to Liepājas metalurgs AS) (24).

One of the solutions to achieve cost reductions in manufacturing enterprises is to implement support programmes aimed at promoting replacement of oil and natural gas with wood fuel. It is also important to encourage implementation of energy efficiency measures that reduce electricity consumption which is mainly used in production processes.

In moving forward, there is a need to improve the existing data submission and record-keeping system to make it possible to use for the evaluation of energy efficiency. In addition, it would also be essential to find new ways to assess the current status of energy efficiency in manufacturing enterprises.

2. Barriers to Implementation of Energy Efficiency Measures in Manufacturing Enterprises

In order to promote the reduction of energy consumption in manufacturing enterprises by means of different energy efficiency policy instruments, it is necessary to identify and determine the main barriers inhibiting the implementation of energy efficiency measures. There is a long track record of a variety of barriers to implementation of energy efficiency measures in manufacturing enterprises. A number of different ways to categorise the barriers by their impact are offered. The method proposed by S.Sorrell and E.Cagno is widely used for the categorisation of the identified barriers [10 – 13]:

- external barriers affecting the implementation of energy efficiency measures by enterprises, which are related to external factors, such as market changes (technology, energy tariffs, etc.), national policy and services rendered by technology suppliers/maintainers, equipment manufacturers and designers, as well as energy suppliers and capital providers;
- internal barriers that exist at the enterprise level: economic, organisational (the decision-making process), behavioural (individual beliefs), competence-related and knowledge-related, and technology-related and information-related.

When analysing various barriers, it is important not only to identify them, but also to understand what stages of implementation of energy efficiency measures they affect in order to apply the best and most effective policy tools.

So far, no study has been carried out in Latvia to assess the existing barriers, as well as the driving factors for the implementation of energy efficiency measures in enterprises. In the autumn of 2010, within the framework of this thesis, interviews were conducted in three milk processing establishments and two brewing companies that met the status of both SMEs and large enterprises. The interviews were held with companies that took part in the EU project ExBESS and had participated in the benchmark system [14].

During the research, the following main barriers have been identified in accordance with the distribution proposed by S.Sorrell and E.Cagno: lack of investment; risks associated with the introduction of the measures, particularly relating to interruption of the production processes and the development of additional costs; behavioural aspects: no desire to change, lack of interest in energy efficiency measures, other priorities are more important; as well as organisational aspects (complex decision-making process (large enterprises), energy efficiency is not a priority, as well as lack of time and lack of obvious benefits from the implementation of the measures). The company's management has a very substantial role to play in the implementation of energy efficiency measures in industrial enterprises, because management allocates the financial resources required for such measures. Consequently, the management's involvement and understanding of the importance of energy consumption in the company also has an impact on the company's development related to energy efficiency.

Main conclusions:

Since this is only the first study on the identification of barriers to the implementation of energy efficiency measures in manufacturing enterprises, there is a need to continue to identify the existing barriers, as well as the motivating factors in cooperation with industry associations. One of the first steps could be a survey and interviews with the participants of the current Climate Change Financial Instrument (CCFI) programme. In general, it can be concluded that the identification of barriers is an important aspect to be taken into account when developing and implementing energy efficiency policy instruments at the national level.

3. Energy Efficiency Policy Assessment in the Industrial Sector

Energy efficiency policy in the industrial sector is aimed at promoting and achieving a reduction of energy consumption in manufacturing enterprises. This, in turn, increases the competitiveness of such companies and contributes to economic growth. To achieve this, different types of information exchange between the state authorities and stakeholders with an interest in policy-making are used (see Figure 5) [15, 16].

Close cooperation of the state institutions with various industry federations, associations and unions that represent the opinions of the companies belonging to a specific industrial sector is required for successful implementation of any policy. An essential condition for the successful implementation of the energy efficiency policy in the industrial sector is the availability of data and information for setting goals. Therefore, in order to launch any new energy efficiency policy in the industrial sector at the national level, it is necessary to carefully assess the current situation based on cooperation between state institutions and associations/enterprises. [15, 17, 18]

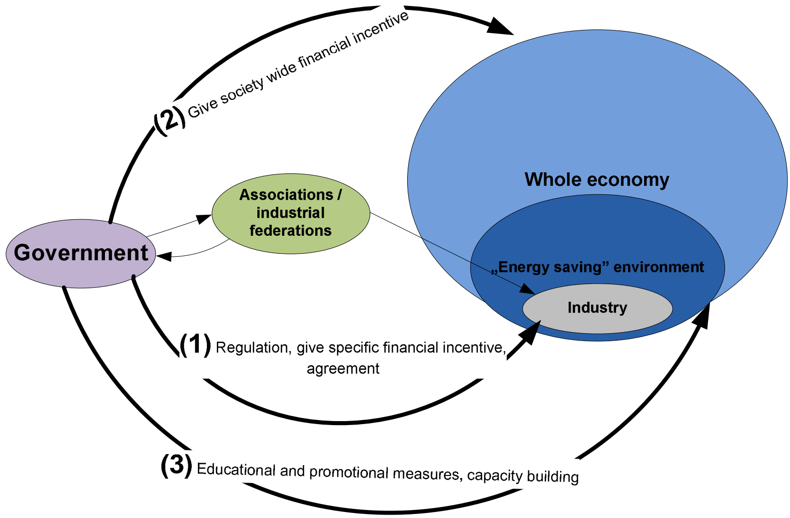

Fig. 5. Types of information exchange for implementation of energy efficiency policy instruments in the industrial sector [15]

Based on K.Tanaka's study of policy instruments in the industrial sector, policy instruments in the industrial sector can be divided as follows [15]:

- prospective policy: has a direct impact on the companies' action in reducing energy consumption. Such policy instruments in Latvia are laws and Cabinet's regulations; Energy management systems (EnMS) - ISO 50001 (a voluntary standard); and agreements: Cabinet's Regulations No. 555 – *Regulations Regarding the Procedures for Entering into and Supervision of an Agreement Regarding Energy Efficiency Improvement*;
- fiscal policy: financial obligations regarding energy and environmental compliance are imposed on manufacturing enterprises. The instruments

that can be applied in Latvia are energy and CO_2 taxes; EU ETS; and direct government support – CCFI project tenders for manufacturing companies;

- aid policy: helps to evaluate and analyse the current situation in the sector. The instruments corresponding to the situation in Latvia are the availability of information on the energy efficiency technological solutions; and industrial energy audits.

Energy efficiency policy for the industrial sector in Latvia has so far been based primarily on the fulfillment of EU requirements to achieve the goals set for energy efficiency at the EU level. One of the main disadvantages of the application of energy efficiency policy in the Latvian industrial sector could be the lack of data and information about the current situation in regard to energy efficiency and the potential for reducing energy consumption across industrial sectors as a whole and individually. Therefore, the existing energy efficiency policy goals set for the Latvian industrial sector are too general and modest. Consequently, it can be considered that the energy efficiency measures in the enterprises so far have been mainly carried out at the initiative of the production enterprises, rather than as a result of implementation of the national energy efficiency policy.

3.1 Analysis of Policy Instruments

This section contains an analysis of two instruments of the prospective policy in Latvia:

- Application of agreement programmes for the reduction of energy consumption in production companies so far has been the most widely used policy instrument in the world [19]. Since 15 July 2011, Cabinet's Regulations No. 555 – *Regulations Regarding the Procedures for Entering into and Supervision of an Agreement Regarding Energy Efficiency Improvement* have been in force in Latvia. These regulations provide for implementation of an agreement programme, which aims to achieve at least 10% energy savings in a sector, company or local government. The achievement of the energy savings target is justified by the energy efficiency action plan. Unfortunately, to date, no participant has applied for participation in this programme [20]. Taking into account the experience of other countries and comparing it with the existing Cabinet's Regulations No. 555, it can reasonably be considered that without significant changes to the current agreement programme, the developed Cabinet's Regulations No. 555 will not be supported by the specified target group, and the projected cumulative energy savings of 150 GWh will not be achieved by 2020.

- The energy management system (EnMS) is one of the energy efficiency measures to help enterprises to establish an organised system for the production process to ensure effective control of the company's operation and reduce energy consumption. Experience from the implementation of the EnMS shows that 10 % to 20% energy savings can be achieved within the first five years of implementation of the system. Moreover, this result can be reached with little financial investment. Therefore, legislation provides that Member States should encourage the introduction of the EnMS in both large enterprises and SMEs [20 – 23]. Since the introduction of the EnMS is not a mandatory requirement for enterprises in Latvia, only one company in Latvia became ISO 50001 certified by the end of 2013. Due to the relatively small experience in EnMS implementation, further information about the application of EnMS for manufacturing companies in Latvia is not available. Despite the fact that ISO 50001 has been implemented only in one Latvian company, several other companies have introduced some energy management principles [14]. Mainly, this is due to the continuously rising energy costs, which leads to the summarising and analysing of the energy consumption data by the companies. Data analysis and implemented energy efficiency measures are mostly initiated by the employees (chief power engineers) or management and are based on their own knowledge.

In addition, fiscal policy instruments are analysed. Subsidies for the implementation of various measures or energy audits are one of the most effective policy instruments.

A number of project tenders, mainly aimed at reduction of CO_2 emissions and energy consumption, have so far been implemented within the CCFI programme of the Ministry of Environmental Protection and Regional Development in Latvia. The call for the first project tender of this kind targeted to manufacturing enterprises and entitled *Complex Solutions to Reduce Greenhouse Gas Emissions in Production Facilities* was launched in July 2010. It was planned that the overall energy consumption would decrease by 33.9 GWh per year, of which 85% would be thermal energy consumption reduction and 15% – electricity consumption reduction [24]. Every year by 31 January, all project implementers are required to submit a monitoring report on the energy savings achieved as a result of the implementation of measures to the Latvian Environmental Investment Fund (LEIF). The analysis of individual monitoring reports showed that they had shortcomings and each report should be assessed separately. This was mainly due to the energy consumption measurement deficiencies, as in most enterprises energy consumption is not measured for the production processes individually. Consequently, in determining the energy savings, for example in case where new technological equipment is installed, it is difficult to objectively assess the savings achieved in the absence of a proper data recording system. By the end of 2013, calls for three more tenders *Complex Solutions for Greenhouse Gas Emissions Reduction* were launched within the CCFI programme. They were open to manufacturing enterprises, local authorities and medical institutions. The conditions for the project tender submission and approval were different from the first phase, while the monitoring system and supervision remained unchanged. Based on the evaluation of the CCFI programme for manufacturing enterprises, it can be concluded that it is not possible to assess whether the projected savings will be achieved from the manufacturing enterprises under this programme, because the inaccuracies in the data submitted by the companies are too large. To prevent this from happening, one of the solutions would be to review the existing methodology for project monitoring, as well as to establish stricter requirements for participants in the CCFI programme regarding the submission of monitoring reports.

Only one aid policy instrument is currently incorporated in Latvian legislation: industrial energy audits. The second prospective aid instrument to promote energy efficiency in the industrial sector is the benchmark method. Benchmarks are not currently used in Latvia for evaluation of the energy efficiency of manufacturing enterprises.

Cabinet's Regulations No. 138 – *Regulations Regarding the Industrial Energy Audit* aimed at conduction of industrial energy audits in enterprises have been developed in Latvia. The regulations contain only general requirements that should be taken into account when conducting an energy audit. Until March 2013, there were no companies in Latvia which could carry out the industrial energy audits in accordance with the requirements of Cabinet's Regulations No. 138, as companies are required to implement a quality management system according to ISO 9001:2008. Given this situation and the fact that large companies until 5 December 2015 must complete industrial energy audits, it is advisable to revise the requirement regarding ISO 9001 [25]. The benchmark method is often used as an aid instrument for the implementation of energy efficiency measures in manufacturing enterprises. Although the benchmark method has been widely used until now for the implementation of energy efficiency policy in the industrial sector in various countries, it cannot be applied and used equally in all manufacturing subsectors. To make a comparison of enterprises, it is very important to select appropriate indicators, system boundaries and adjustment factors [26, 27]. Even though the benchmark method is considered to be an effective way to determine the energy consumption potential and energy efficiency changes in different industries, there are still significant barriers to the application of this method [28]:

- lack of data at the level of enterprises, processes and equipment;
- no single methodology or guidelines for carrying out a comparison of enterprises.

Currently, the benchmark method is not used to assess the energy efficiency in Latvian manufacturing enterprises and determine the potential, although it can be used, for example, when summarising data from the Central Statistical Bureau (CSB), permits for the performance of polluting activities, as well as industrial energy audits and CCFI project tenders.

3.2. Proposals for the Application of Policy Instruments in the Industrial Sector in Latvia

Within the framework this thesis, it is proposed to develop and implement the Agreement Programme for Manufacturing Enterprises (APME). The main advantage of this programme is the energy efficiency commitments of manufacturing enterprises in the long term. Such a programme would help enterprises to plan energy efficiency improvement projects at the enterprise level over the long run.

In order to implement the APME, it would be necessary to make changes to the existing Cabinet's Regulations No. 555 – *Regulations Regarding the Procedures for Entering into and Supervision of an Agreement Regarding Energy Efficiency Improvement*. The requirements of the Cabinet's Regulations should be limited to the enterprises belonging to the manufacturing sector only. The development and implementation of the APME should be entrusted to a separate institution, such as a national energy agency or the Latvian Environmental Investment Fund, while supervision thereof should be performed by the Ministry of Economics. The application of industrial energy audits and the introduction of the EMS should be set as mandatory requirements for the APME participants. The preferred time schedule for the development and implementation of the APME is shown in Figure 6. Implementation of the programme can be divided into three stages:

Stage 1**:** The main task during the implementation of the APME is to identify the appropriate target group for the programme. It is important to determine which sectors of the manufacturing industry should be included, what type of enterprises should be covered (large enterprises, SMEs, micro enterprises) and what kind of energy savings should be achieved. The objective of this programme should be assessed in the light of the objectives of the developed National Industrial Policy and the requirements of the EU Directive 2012/27/EU. Based on the analysis carried out in the previous chapters, the APME could be applied to SMEs. Energy efficiency measures should be implemented in order to achieve reduction in both electricity and heat consumption.

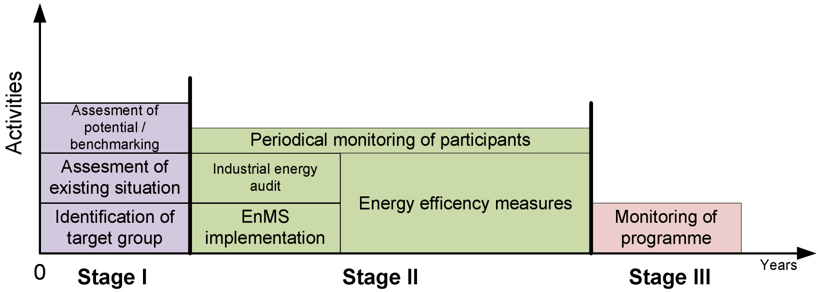

Fig. 6. Time schedule for the APME development and implementation

***Stage 2*:** The next step is the analysis of the current situation and the determination of the energy efficiency potential. To identify the potential of the existing situation, it is necessary to use the benchmark method. State 2 of the APME implementation is associated with the introduction of the programme in the enterprises for a period of at least five years. The first task is to ensure the involvement of the participants. During the first two years of the APME implementation, it should be ensured that all the APME participants have completed the industrial energy audits and launched the EMS. Tax incentives could be promoted for achieving the set energy savings to further motivate the enterprises. Submission of annual reports by the companies on energy consumption in the company would be mandatory. This is a way to achieve the supervision of the enterprises for reaching the set goals.
***Stage 3*:** This step is associated with the evaluation of the results of the programme. This stage involves interviews and surveys of the participants with a view to clarify the barriers for implementation of the programme, as well as data analysis of the energy savings. The obtained results would be used for further enhancement and improvement of the programme.

4. Development and Approbation of the Methodology for Application of Policy Instruments in the Industrial Sector

In order to increase energy efficiency in the industrial sector, successive steps should be taken for the application of policy instruments. The application of policy instruments has been conducted within this thesis according to the methodology developed by the author (see Figure 7).

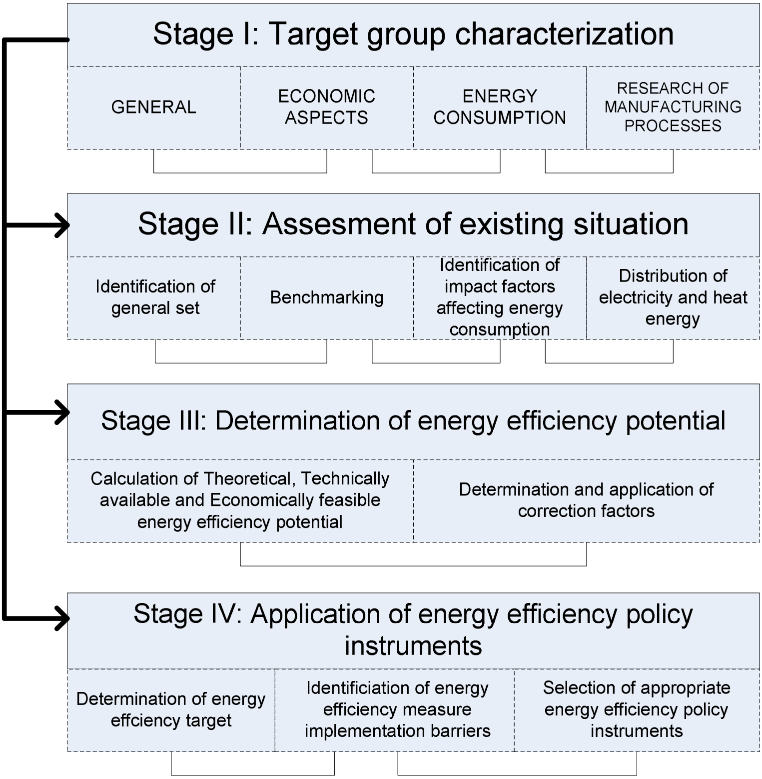

Fig. 7. Methodology for application of policy instruments in the industrial sector

The methodology for application of policy instruments in the industrial sector is divided into four successive steps:

1. *Characterisation of the target group.* First, target sectors are selected at the national level where there is a need to achieve reduction in energy consumption, and an assessment of these sectors is performed. In conducting the assessment, the enterprises are broken down by size, the share of energy costs and the specific energy consumption are determined and the current market situation and future prospects are identified. In addition, information on the manufacturing processes and their specific characteristics at the sector level is summarised.
2. *Assessment of the current situation.* First, a population which provides a good picture of the target sector is selected. The benchmark method is used to

assess the energy efficiency of the population. In addition, factors which influence changes in energy consumption are identified and a breakdown into heat and electricity consumption is made. Assessment of the current situation involves visits to the selected companies and taking energy consumption measurements.

3. *Determination of the energy efficiency potential*. Based on the assessment of the current situation, the potential of the target sector is determined. In addition, the sector-specific adjustment factors which can be used to determine energy efficiency potential are identified.
4. *Application of the energy efficiency policy instruments.* First, the energy efficiency goal of the target sector is defined, based on the analysis of the current situation and the determination of the energy efficiency potential, and the barriers for implementation of the energy efficiency measures are identified. Based on the barriers, the appropriate policy instruments are selected which will be used to eliminate the barriers for implementation of the energy efficiency measures in enterprises and meet the energy efficiency goal set for the sector.

4.1. Characterisation of the Target Group

In accordance with information from the *Lursoft* database, there were 22 breweries registered in 2012. Depending on the number of employees and the companies' turnover, brewing companies can be divided into the following groups [29]: 3 large enterprises (Aldaris AS, Cēsu alus AS and Cido grupa SIA); 3 medium-sized companies (Agrofirma Tērvete AS, Piebalgas alus SIA and Bauskas alus SIA); 7 small brewing companies; and 9 micro-breweries. Large companies accounted for 81.2% of the Latvian beer market share in 2012. SMEs had 11.4% of the market share, while micro-breweries had only 4.3%. Based on the energy consumption data for the brewing industry provided by the CSB, natural gas accounted for an average of 69% of energy consumption and electricity – for 26%. Taking into account the data on turnover in the sector and the cost of energy, the share of the energy cost in the turnover was an average of 4%.

The main raw materials for the production of beer are water, malt, hops and yeast. In terms of energy consumption, beer production processes can be divided as follows: brewing; beer fermentation/ aging; and beer bottling. The most heat consuming brewing process is the preparation of wort (40% of the total heat consumption in all processes), and the most electricity consuming process is conditioning or post-fermentation process (18.5% of the total electricity consumption in all processes) [30].

4.2. Assessment of the Current Situation

To assess the energy efficiency of breweries in Latvia, a questionnaire was made and sent out to 13 brewing companies. As a result, relevant data were obtained from four companies, which were visited and for which an in-depth analysis of the available information and data was carried out.

The specific energy consumption (SEC) data of the selected brewing companies were studied and comparisons were made with best practices in the EU and globally (see Figure 8). It was concluded that the SEC of the selected four breweries was almost twice as high as the average in other energy efficiency programmes implemented for brewing companies in the EU and around the world. This suggests that breweries in Latvia may have a comparatively high potential for energy efficiency.

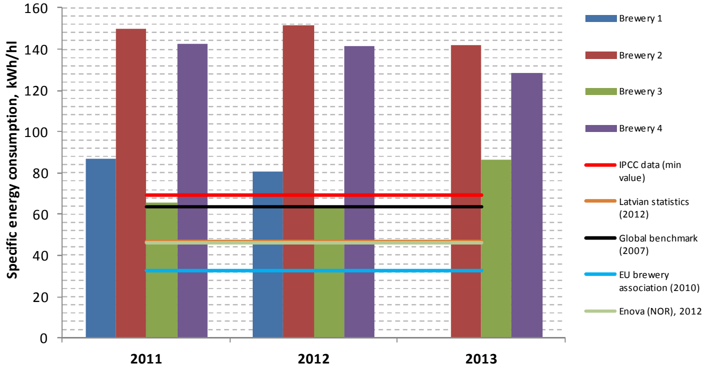

Fig. 8. Comparison of the SEC data across brewing companies

As described above, the SEC is affected by the energy consumption in the enterprise and the amount of output. Therefore, in order to understand what factors have an impact on the energy consumption changes in the company and whether they are the same in all cases, a detailed analysis of energy consumption data was conducted for each brewing company. The data available for all the companies were analysed taking into account Formulas 4.1, 4.2 and 4.3.

$$En = f\ (prod.) \qquad (5)$$

$$En = f\ (prod.; T) \qquad (6)$$

$$En = f\ (optimal) \qquad (7)$$

where:
En – total energy (electricity and heat) consumption;
Prod. – amount of output (beer and beverages);
T – monthly average outdoor air temperature, °C;
optimal – characterises the main factors that affect energy consumption changes in a brewery. The factors are determined separately for each brewery.

Using multifactor regression analysis in the environment of the data processing programme STATGRAF, a number of regression equations that describe the energy consumption changes in the company are obtained for each brewery:

$$\text{Brewery 1;}\ En = 50.0381 + 0.00121908 \cdot I_{ies}\ ;\ R^2 = 0.710 \qquad (8)$$

$$\text{Brewery 2;}\ En = -9.62626 + 0.090715 \cdot prod. - 1.47329 \cdot T;\ R^2 = 0.810 \qquad (9)$$

$$\text{Brewery 3;}\ En = 116.288 + 1.19193 \cdot I_{ies} + 0.0136922 \cdot KEG + 0.0492631 \cdot ST - 4.10038 \cdot T\ ;\ R^2 = 0.839 \qquad (10)$$

$$\text{Brewery 4;}\ En = 198.598 + 0.071831 \cdot A_i + 0.171083 \cdot D_z - 9.10254 \cdot T\quad R^2 = 0.786 \qquad (11)$$

where:
I_{ies} – malt quantity, kg;
ST – bottled beer produced, hl;
KEG – KEG beer droduced, hl;
A_i – amount of beer brewed, hl;
D_z – amount of beverages brewed, hl.

In all cases, it can be seen that the closest relationship is formed between energy consumption and various parameters characterising the manufacturing processes. Based on the data analysis, it was found that a statistically significant relationship between energy consumption and output was not formed in all cases. Consequently, the SEC does not describe the company's energy efficiency changes in all cases.

To find out how different types of beer bottling affect the energy consumption changes in the brewing companies, electricity consumption monitoring was carried out for the beer bottling in brewery 1. The results are shown in Figure 9. The specific electricity consumption is determined taking into account the amount of beer filled and the electricity consumption at the time of bottling. The results show that the energy consumption in the company may be affected by a number of factors. Since electricity consumption for bottling accounts for a relatively large share of total electricity consumption and it can vary between brewing companies, the way in which the product is bottled should be taken into account.

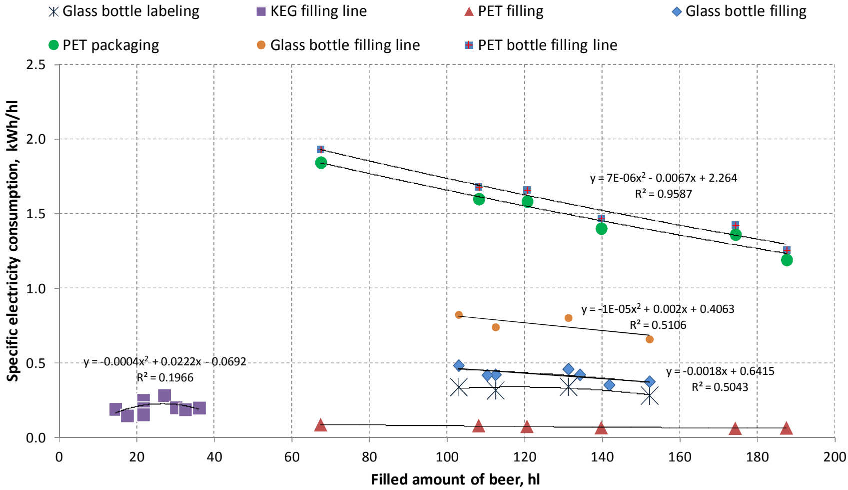

Fig. 9. Specific electricity consumption for various types of beer bottling

To determine the relationship between electricity and heat consumption in breweries, a data analysis was performed. It was found that electricity accounted for an average of 30% of energy consumption and heat – for 70%.

4.3. Determination of the Energy Efficiency Potential

This chapter contains calculation of three beer production benchmarks:

- Theoretical specific energy consumption (SEC_{teor}) – theoretical minimal energy consumption required for beer production;
- Technically available specific energy consumption (SEC_{teh}) – energy consumption required for beer production applying best available technical solutions (BAT);
- Economically feasible specific energy consumption (SEC_{eko}) – energy consumption for beer production applying standardized (the most widely used) energy efficiency measures.

In the calculation, the following brewing processes have been taken into consideration: mash preparation, filtration, wort boiling and wort cooling. For a list of characteristic parameters of the processes, see Table 1. In determining the size of the tank, it is assumed that the tank is a cylinder with the ratio of height and radius of 2:1 ($S = 4.39\ m^2$) and is the same in all cases, as minimum heat loss is obtained that way.

Table 1

Characteristic parameters of the brewing processes used

	Mash preparation	Filtration	Wort boiling	Wort cooling	Ferment ation	Conditioning
Volume, hl	20	20	20	20	20	20
Initial T_1, °C	35	75	95	90	-	-
Final T_2, °C	75	95	100	6	-	-
Beer T, °C	75	95	100	-	5	1
Ambient T, °C	23	24	26	-	9	7

The following equation is used to determine the amount of energy required for changing of the temperature of the substance (heating, cooling):

$$q_1 = \left| \frac{c \cdot m \cdot \Delta T}{p} \right| \text{, Wh} \qquad (12)$$

where:

c – specific heat capacity of the substance (water), kJ / (kg · K)
m – weight of the substance (wort), hl
T_1 – initial temperature of the substance (water), °C;
T_2 – end temperature of the substance (water), °C;
p – conversion coefficient from J to Wh, 3600 J/Wh.

Since heat loss is formed in different brewing processes due to heat transfer through the walls of the tanks, the following equation is used to determine the scale of the heat losses:

$$q_2 = \left(\frac{1}{\frac{1}{\alpha_{si}} + \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{se}}} \cdot S \cdot (T_{misa} - T_{vides}) \right) \cdot \tau \text{ , Wh} \quad (13)$$

where:
$1/\alpha_{si}$ – thermal resistance of internal surface of the tank, $(m^2K)/W$;
$1/\alpha_{se}$ – thermal resistance of external surface of the tank, $(m^2K)/W$;
δ – thickness of material layer in the tank wall, m;
λ – heat conductivity of a material layer in the tank wall, W/(mK);
n – amount of different layers in the tank wall;
S – area of tank walls, m^2;
T_{wort} – wort temperature, ^oC;
T_{in} – ambient temperature, ^oC;
τ – duration of the process, h.

Substantial heat loss occurs as a result of water evaporation during wort boiling. The following equation is used to determine the loss:

$$q_3 = \frac{m_{iztv} \cdot L}{p} \text{, Wh} \quad (14)$$

where:
m_{iztv} – evaporated amount of the total amount of wort, %
L – specific heat of vaporization of water, kJ/kg
p – conversion coefficient from J to Wh, 3600 J/Wh.

Based on literature review, the evaporated amount on average can be different for each brewery. Depending on the technology used, the amount can range from 4 to 15%. [31, 32].

In order to calculate specific heat consumption all previously shown values have to be considered. It is possible that some of the processes are used more than once during the production of a product. The formula that is used to calculate Q is given in Equation 15:

$$Q = \frac{\left(\sum_{i=1}^{x} q_{1,i} + \sum_{j=1}^{y} q_{2,j} + \sum_{k=1}^{z} q_{3,k} \right) \cdot 10^{-3}}{V} \text{, kWh/hl} \quad (15)$$

where:

Q –specific heat consumption, kWh/hl;
q_1 – energy consumption during heating or cooling of water, Wh;
q_2 - heat loss by heat conduction through tank walls, Wh;
q_3- heat loss due to the water evaporation, Wh;
x – number of processes involving heating or cooling water/wort/beer during beer production;
y – number of processes involving heat loss by heat conduction during beer production;
z – number of processes involving evaporation during beer production;
V – volume of produced beer, hl.

Based on previously described equations, the theoretical, technically available and economically feasible heat energy consumption was calculated for each process of beer production. Values shown in Table 2 are used for this calculation.

Table 2

Main factors influencing energy consumption in the brewing process

Characteristic parameters	Theoretical	Technically available	Economically feasible
Initial mash preparation T_1, °C	45	25	10
Heat insulation thickness, m	0.4	0.2	0.1
Heat insulation thermal conductivity coefficient, W/mK	0.01	0.025	0.04
Amount of evaporation, %	0.1	4	10

The following values were obtained as a result of the calculations: theoretical energy consumption: 16.25 kWh/hl, technical energy consumption: 21.15 kWh/hl and economic energy consumption: 26.99 kWh/hl.

Electricity consumption accounts for only 30% of the total energy consumption in breweries. Furthermore, the electricity consumption is largely affected by the parameters characterising the performance of the equipment and its layout. Therefore, no theoretical calculations of the consumption of electricity required for the processes are made within the thesis, but it is assumed that the theoretical electricity consumption is 7.5 kWh/hl regardless of the energy consumption type (theoretical, technical, or economic) [33, 34].

According to the calculation, the theoretical energy consumption for the brewing industry is 23.75 kWh/hl, technical energy consumption is 28.65 kWh/hl and economic energy consumption is 34.49 kWh/hl. The energy potential of the beer industry as a whole can be determined using the following equation:

$$En_{pot[teor;teh;eko]} = (SEC - SEc_{[teor;teh;eko]}) \cdot Prod \qquad (16)$$

where:

$En_{pot.}$ – energy efficiency potential, MWh

SEC – actual specific energy consumption, kWh/hl;

SEC_{teor} – theoretical specific energy consumption, kWh/hl;

SEC_{teh} – technically available specific energy consumption, kWh/hl;

SEC_{eko} – economically feasible specific energy consumption, kWh/hl;

Prod – production volumes, hl.

To determine the energy potential for the brewing industry, statistics from 2012 have been used: the amount of output is 1,405,200 hl; specific energy consumption – 46,85 kWh/hl. Thus, the theoretical energy potential in the brewing industry is 32.5 GWh or 49% of the total energy consumption in the industry. The technical potential is 25.6 GWh, while the economic potential is 17.4 GWh of the total energy consumption in the industry.

5. Development of a System Dynamics Model for Modelling of Energy Efficiency Policy Instruments in the Industrial Sector

The model is based on a structure which is built to reflect the demand for energy and the main factors for the implementation of energy efficiency measures in manufacturing enterprises. The model is created on the example of the brewing industry. Three main modules form the basis of the model:

- money accumulation and investment module;
- product manufacturing module;
- energy consumption and costs module.

All of these modules are interconnected through feedback links. The money accumulation and investment module is based on a number of inventories. The value of the inventories is determined by their outgoing and incoming flows. The specific production costs and the share of energy costs are taken into account to calculate the total production costs. The total production costs are determined using the following equation:

$$RI = (\bar{I}RI \cdot Prod.') + EI \quad (17)$$

where:
RI – production costs, EUR;
$\bar{I}$RI – specific production costs, EUR/hl;
Prod.' –amount of output, hl/year;
EI – energy costs, EUR/year.

When determining the revenue from the output marketed, the beer sales price and sales volume are taken into account. Revenue for the output marketed is calculated as follows:

$$I_{prod.} = C_{alus} \cdot Prod.'' \quad (18)$$

where:
$I_{prod.}$ – revenue from the output marketed, EUR/year;
C_{alus} – beer sales price, EUR/hl;
Prod.'' –output marketed, EUR/year.

The outgoing flow from the inventory '*amount of money for investment*' is calculated using the following equations:

$$PND_{EE} = ND_{invest.} \cdot EE_{likme} \quad , \quad (19)$$

$$PND_{citi} = ND_{invest.} \cdot (1 - EE_{likme}), \quad (20)$$

where:
PND_{EE} – amount of money for energy efficiency measures, EUR/year;
$ND_{invest.}$ – amount of money for investment, EUR;
EE_{likme} –rate of energy efficiency measures;
PND_{citi} – amount of money for other investments, EUR/year.

Taking into account the outgoing and incoming flows from the inventory '*amount of money available',* this value is calculated as follows:

$$PND = \int_{t=0}^{t=1} I_{prod.}(t) \cdot dt - (RI + P + PND_{invest.} + AN)(t) \cdot dt + PND(t_0) \quad (21)$$

where:

PND – amount of money available, EUR;
P – profit, EUR/year;
$PND_{invest.}$ – changes in the amount of money available for investment, EUR/year;
AN – costs related to the excise tax, EUR/year.

Depending on the amount of money available for energy efficiency measures, companies can implement energy efficiency measures determined by the specific energy efficiency investments, which are calculated using the following equation:

$$SEC^{EE}_{invest.,i} = \frac{\Delta SEC_i \cdot Prod._{at.} \cdot T \cdot AT_i}{Prod._{at.}} \ , \quad (22)$$

where:
Δ SEC – difference in changes in specific energy consumption, MWh/hl;
$Prod._{at.}$ – reference output, hl/year;
T – energy tariff, EUR/MWh;
AT – payback period, years;
i – type of transition of the value of changes in the SEC (specific energy consumption).

The product manufacturing module characterises changes in the manufacturing of products depending on the demand for the products. The demand for the products depends on the number of people who can potentially consume alcoholic beverages, and export volumes. The demand for the products is determined using the following equation:

$$D = (2{,}0635 \cdot iedz.sk. \ \cdot 10^{-6}) + (616407 \cdot eksp.^{0{,}0681}), \quad (23)$$

where:
D – demand for the product, hl/year.

The amount of the output marketed is defined as the minimum value of the available quantity of output and demand which provides that the amount marketed cannot be higher than the amount of products available. The amount of the output marketed is determined using the following equation:

$$Prod.'' = MIN \ (P_{prod.}; D) \ , \quad (24)$$

where:
$P_{prod.}$ – amount of products available, hl.

The output depends on the demand and production capacity and is defined using the following equation:

$$Prod' = MIN\left(D; \frac{R_k}{R_\tau}\right), \quad (25)$$

where:
R_k – production capacity, hl;
R_τ – time of manufacturing of the product, years.

The energy consumption and costs module is essential for application of energy efficiency policy instruments. The energy consumption changes depend on the output and reduction in energy consumption achieved through introducing energy efficiency measures. Equation 5.11 is based on a regression equation obtained from the data analysis of the current situation in brewery 2, which best describes the relationship between the output and energy consumption. The actual energy consumption is determined using the following equation:

$$En = (0{,}0779 \cdot Prod.' - \varepsilon) \cdot (1 - EE_{invest.}) \quad (26)$$

where:
En – energy consumption, MWh/year;
ε – equation error (6.9418);
$EE_{invest.}$ – effect of investment in energy efficiency measures.

Energy costs depend on the costs of electricity and heat generated from the heat and electricity consumption and tariffs. The energy costs are determined using the following equation:

$$En_{izm.} = \left(En \cdot T_{el} \cdot En_{el}^d\right) + \left(En \cdot T_{th} \cdot \left(1 - En_{el}^d\right)\right); \quad (27)$$

where:
$En_{izm.}$ – energy costs, EUR/year;
En_{el}^d – electricity share in the total energy consumption, 30%;
T_{el} – electricity tariff, EUR/MWh;
T_{th} – heat tariff, EUR/MWh.

In order to be able to evaluate the energy efficiency changes in the established model, the actual specific energy consumption SEC (kWh/hl), the SEC goal and the goal attainment difference are determined. The target SEC affects the motivation to reduce energy consumption. The greater the difference between the target SEC and the actual SEC, the greater the readiness to invest in energy efficiency measures. To assess changes in energy efficiency, the actual SEC is calculated using the following equation:

$$\mathrm{SEC}_f = \frac{En}{Prod.} \quad , \tag{28}$$

where:
SEC_f – actual specific energy consumption, MWh/hl.

The simulation of the model is based on two scenarios:

- baseline scenario: simulation of the current situation, where there are no goals for increasing the energy efficiency in enterprises;
- scenario of application of policy instruments: the established policy instruments are used to improve energy efficiency in enterprises (described in Chapter 3).

The time period selected for the simulation of the model is 25 years, which corresponds to the actual period from 2006 to 2031. The changes in the baseline scenario obtained as a result of the simulation of the model are shown in Figure 10. The graph demonstrates the changes in the SEC (MWh/hl) over time.

In the early years, the difference between the target SEC and the actual energy consumption is very substantial. This provides an incentive to increase investment in energy efficiency measures. Starting with the second year of simulation, the actual SEC reduces significantly, as the difference between the target SEC and the actual SEC is large and funds for the implementation of the energy efficiency measures are available.

Depending on the amount available for the implementation of the energy efficiency measures, the values of the actual SEC will gradually reduce and approach the target. It can be seen that the system as a whole seeks to achieve a balanced state. Since the model provides for a gradual increase in energy tariffs, the SEC target will also reduce. However, values of the actual SEC during the simulation of the model do not reach the set target, as the ‘floating target’ principle applies.

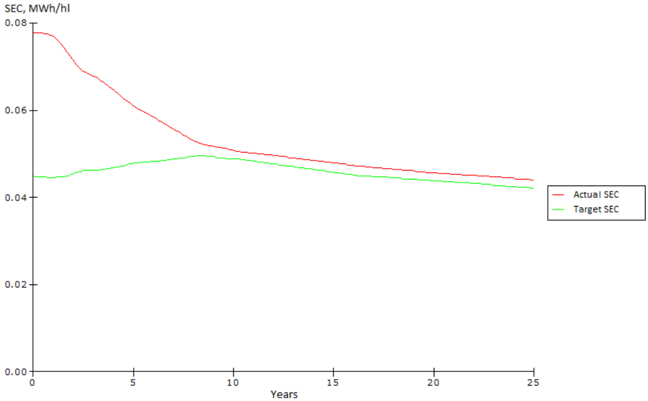

Fig. 10. Target and actual SEC

Based on the proposals formulated for the energy efficiency policy in the industrial sector, the following APME instruments are integrated in the model:

- industrial energy audit (EA policy);
- energy management system (EnMS policy) ;
- organization of training courses and seminars (Knowledge);
- co-financing for implementation of energy efficiency measures.

The policy instruments, such as the industrial energy audits, energy management and knowledge building, create a direct impact on the SEC target. Values of each instrument and the impact time are given in Table 3.

Table 3

Values and impact time of the energy efficiency policy instruments

Policy instrument	Simulation year		
	10	11	15
SEC target for knowledge, MWh/hl	0,042	0,041	0,040
SEC target for EA policy, MWh/hl	0,035	0,037	0,040
SEC target for EnMS policy, MWh/hl	0,035	0,035	0,035

It is assumed that in the case when the APME is created, time is required for the development and implementation of each policy instrument. Therefore, it is assumed that all policy instruments will start functioning in 2016. Furthermore, each instrument has a different impact on the target SEC. When the policy instruments become effective, the SEC target of the industry (M_n) is defined as follows:

$$M_n = MAX\ (EA_i^p, EnMS_i^p, Z_i^p, EI_i^d) \quad (28)$$

where:
EA_i^p – target value of industrial energy audits in year i, MWh/hl;
$EnMS_i^p$ – target value of the energy management system in year i, MWh/hl;
Z_i^p – target value of training courses and seminars in year i, MWh/hl;
EI_i^d – share of energy costs in year i, MWh/hl.

In turn, the availability of co-financing has no impact on the target, but helps to achieve it faster. Therefore, the availability of co-financing is defined as follows in the model:

$$I_{\bar{\imath}pat.}^{EE} = \left(\frac{PND_{invest.}^{EE}}{K_{max}}\right) + \beta \quad (29)$$

where:
$I_{\bar{\imath}pat.}^{EE}$ – specific investment in energy efficiency measures, EUR/hl;
$PND_{invest.}^{EE}$ – amount of money available for energy efficiency measures, EUR;
K_{max} – maximum capacity of the industry, hl;
β – amount of co-financing, EUR/hl.

The obtained results of the simulation in the case when all policy instruments are used can be seen in Figure 11. When all policy instruments become effective, the target SEC is set at a lower SEC value among the policy instruments, which corresponds to the EMS application of 0.035 MWh/hl. The system includes industrial energy audits for the assessment of the current situation. In parallel, a set of measures is also carried out to provide continuous training courses and seminars. The simulation results show that the estimated actual (0,035 MWh/hl) energy savings target in the brewing industry can be achieved or make progress ub reaching the target only provided that co-financing for the implementation of energy efficiency measures is received:

- if the amount of co-financing were 17.80 EUR/hl, the target SEC would be reached and even exceeded (0.032 MWh/hl) in the second year of the implementation of the APME (2017);
- if the amount of co-financing were 9.41 EUR/hl, the target SEC would be reached (0.035 MWh/hl) in the fifth year of the implementation of the APME (2021);

- if the amount of co-financing were 3.45 EUR/hl, the target SEC would not be reached in the period of the implementation of the APME. The actual SEC value in the 25th year of the simulation (2031) would be 0.03604 MWh/hl.

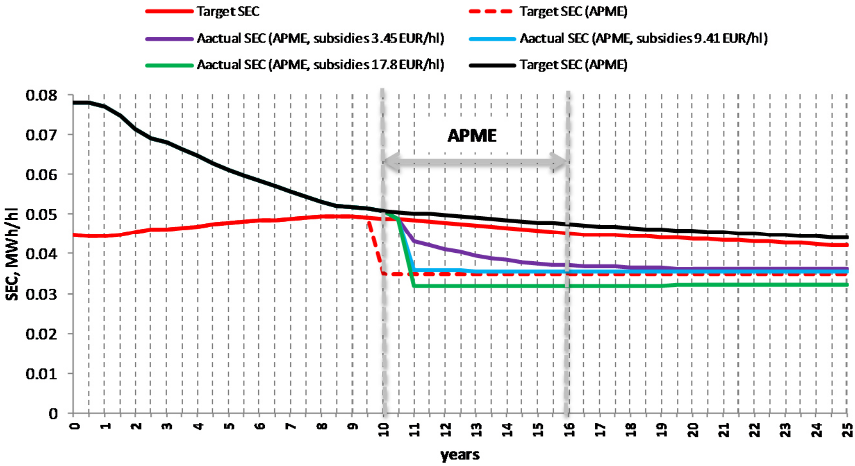

Fig. 11. Changes in the target and actual SEC when implementing the APME

To reach the target established within the APME for 2022 (0.035 MWh/hl), it would be necessary to introduce the EMS (including the industrial energy audits and training courses) and to provide co-financing for the implementation of energy efficiency measures in the amount of 9.30 EUR/hl.

To carry out a validation of the system dynamics model, historical energy consumption and output data have been used. The historical energy consumption data are available for the sector as a whole: the energy consumption data include the amount of energy consumed not only for the manufacture of beer, but also for the manufacture of other products (such as drinking water, soft drinks, etc.). The output data are available for the amount of beer produced (excluding the amounts of other products). To find out the energy share required for the production of other products, data from the permits for polluting activities of brewing companies have been used. The analysis of these data shows that beer production accounts for 73% of the total production volume in the industry. Beer production requires more energy in comparison with the production of other products; therefore, energy consumption in the brewing industry accounts for more than 73% of the total energy consumption in the industry. Precise data on the energy intensity related to the production of beer and other products are not available, so the historical specific energy consumption data are not identifiable as a fixed value, but a value area. The lower limit of the established historical SEC area is determined assuming that the production of beer and other products has the same energy intensity, while the upper limit is determined assuming that the entire energy consumption listed for the sector is consumed for the production of beer. During the in-depth analysis of the energy consumption data from the four breweries, it was determined that the available statistics on the total SEC of the industry are significantly lower than the data of the four brewing companies under analyses. This indicates shortcomings in the energy consumption statistics records; consequently, it is possible that the actual SEC value is higher than the indicated historical value area.

The comparison of the obtained model simulation results with historical data are shown in Figure 12.

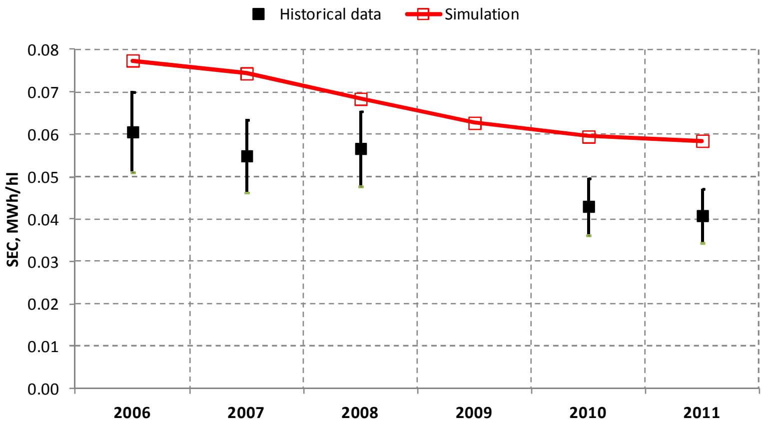

Fig. 12. SEC changes in the industry. Comparison between historical data and results of model simulation

In both cases, the same trend in the SEC changes can be seen. Starting from 2006, the SEC gradually decreased until 2011. When using system dynamics modelling, it is not always possible to get an accurate depiction of historical data, but it is possible to identify the trends in data changes. The created system dynamics model of the beer industry provides a good portrayal of the SEC changes in the beer industry.

Conclusions

1. In carrying out the analysis of energy consumption, energy costs and business operation data related to the manufacturing industrial sector, priority industrial sectors requiring support in the implementation of energy efficiency policy instruments were identified. The eligible industrial sectors (according to NACE 2 rev. classification) are: manufacture of non-metallic mineral products (23), manufacture of wood and wood products (16), manufacture of chemicals (20), manufacture of food and beverages (10), manufacture of textiles (13) and manufacture of metals (24).

2. In conducting semi-structured interviews in five manufacturing enterprises, the main barriers to the implementation of energy efficiency instruments in those enterprises were identified. The main barriers to the implementation of energy efficiency instruments were divided into economic (lack of investment and need for additional expenses to prevent risks), behavioural (importance of other priorities) and organisational (complex decision-making process) barriers. The energy efficiency measures supported by the Latvian government so far in manufacturing enterprises barely take account of the barriers to implementation of energy efficiency measures. When introducing future government support programmes aimed at improving energy efficiency in the industry, it is essential to take into account the potential impact of all barriers.

3. Based on the analysis of the existing legislation and literature, the most appropriate energy efficiency policy instrument for the industrial sector was identified, the implementation of which would help to achieve the energy efficiency of the industry in the long term. The most appropriate energy efficiency policy instrument in the context of Latvia is the voluntary agreement, which foresees performing industrial energy audits, implementing an energy management system and co-financing priority (most cost and energy effective) energy efficiency measures.

4. The in-depth analysis of the energy consumption data in four breweries shows that the specific energy consumption indicator (energy consumption/production output) used in the industrial sector so far may not always be applicable for the analysis of energy consumption changes in the sector and for comparison of energy efficiency levels across different companies. This is due to the fact that energy consumption in some

companies is not always statistically significantly linked to production output.

5. To assess the existing energy consumption and energy efficiency potential in the industrial sector and identify the impact of the energy efficiency policy instruments, a methodology has been developed. The methodology is based on the application of a new type of benchmark, which is determined not on the basis of the solutions in regard to the average or best available techniques in the industry, but on the energy consumption required theoretically in the specific industrial sector. Since the newly established benchmark is not associated with the energy consumption changes of other enterprises, it allows for a more objective assessment of the energy efficiency potential of an industrial enterprise and the sector. Approbation of the created methodology in the context of the brewing industry resulted in the establishment of the theoretical (maximum) energy savings potential for this sector: 32.5 GWh per year; the technically available potential energy savings potential: 25.6 GWh per year and economically feasible energy savings potential: 17.4 GWh per year.

6. Based on the developed methodology, a system dynamics simulation model for the application of energy efficiency policy instruments in the beer industry has been established and validated. The results of the model show that by implementing the agreement programme in the brewing industry, the economically feasible energy savings potential can be reached within 6 years if:
   - the energy management system is implemented with a target of economically feasible benchmark – 35 kWh/hl;
   - with the co-financing rate of 9.3 EUR/hl is introduced. The total amount of investments – EUR 13.0 million.

7. The developed methodology and the system dynamics model can be adapted to determine the impact of energy efficiency policy instruments in other industries and the industrial sector as a whole as well.

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Summary of PhD Thesis

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