RIGA TECHNICAL UNIVERSITY

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SIMULATION AND OPTIMIZATION OF LATVIAN REGIONAL ENERGY SYSTEMS FOR SUSTAINABLE DEVELOPMENT

Summary of thesis

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RIGA TECHNICAL UNIVERSITY
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Environmental Science Doctoral Program

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

This study is proposed for attaining the degree of Dr.Sc.Ing. in Environmental Engineering and will be defended the 18 July the 2011 at the faculty of Power and Electrical Engineering, 1 Kronvalda boulevard, room 21.

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CONFIRMATIONS STATEMENT

I, the undersigning, 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.

Ilze Dzene …………………………….

Date: ………………………

The dissertation is written in Latvian and contains: introduction, four chapters, conclusions, bibliography, two annexes, 85 figures, 13 tables and 130 pages. The bibliography contains 72 references.

TABLE OF CONTENT

BACKGROUND AND CURRENT SITUATION

Global warming is the rise of average temperature of the atmosphere and sea water. Ice and glacial melting, coast erosion and increase of seas water levels are direct consequences of this rise.

The scientific consensus links the rise of average temperatures to the increase concentrations of greenhouse gas emission in the atmosphere. One of the main anthropogenic greenhouse gas emission sources is the energy sector. In response to this problem, the European Union in the last decade has set important targets to reduce greenhouse gas emission in every sector of the economy. Important policies were developed in the energy sector, strongly promoting energy efficiency and renewable energy sources.

The other main driver for designing European energy policies is security of supply, which calls for diversifying energy sources, prevent possible power shortages and the need to produce safe energy at affordable costs.

Currently the main European policy driver is the 20-20-20 goal, where each Member States contributes to the goal of 20% increase in energy efficiency, 20% reduction of CO_2 emissions, and 20% renewable by 2020.

The development of the Latvian energy sector will have to address all these issues and be aligned with the European targets and policies. The renewable energy action plan is the main Latvian strategy document and roadmap. A draft Renewable Energy Law is now under development at the Ministry of Economics.

The Latvian Renewable Energy Action Plan lists a number of measures that Latvia shall undertake for reaching its 2020 target, where 40% of final energy consumption should be covered by renewable energy resources. In 2009 this share was 35.5%, which is the second highest in the European Union, after Sweden. However, the 40% target is ambitious and Latvia needs important and long term energy policies targeting all: the energy, environment, transport and agriculture sector. A key factor would be as well as regional and territorial planning, including detailed energy and integrated spatial planning.

Energy planning plays a role at different levels: at national, regional and local municipal level. However, regional energy planning is the most effective in promoting and stimulating renewable energy resources.

So far, Latvia's energy plans, which typically were integrated as part of general development plans, have been addressing national and local levels. At regional level there have been few attempts to for forecasting regional energy developments and trends. However, these documents were more wish lists, without concrete actions and targets based on detailed analyses. Consequently, they failed in gaining visibility and follow up. Moreover, they were a bad example for other Latvian regions.

OBJECTIVES

The main objective of this dissertation is the development of tools for "green" regions through the implementation of optimised regional energy plans. The background of these regional energy plans is enforcement of European Union's policy for the 2020 targets in Latvia.

The specific objectives of the dissertation are therefore set forth as:

1. Analysis of the impact of policy instruments to increase the share of renewable energy resources at a national and regional level.
2. Development of a system dynamic model for analysis and forecast of the primary energy demand and fuel mix.
3. Validation of the developed system dynamics model applied to the specific case of district heating systems.
4. Costs optimisation for the reduction of regional CO_2 emission to comply with set targets.
5. Development of a black box model linking CO_2 emission to regional installations. Empirical analysis based on data available from all combustion installations (100kW to 100MW) included in the National database of the Latvian Ministry of Environment and Regional Development.

RESEARCH METHODOLOGY

The research methodology is based on the theory of system dynamics. It includes problem formulation, identification of dynamic hypothesis, system modelling, model validation and analysis of results.

The optimisation study for regional optimisation of the energy sector has been developed based on 1000 combustion installations in the range of capacities from 100 kW to 100 MW. The study has been approbated in two regions. Data from the combustion installation in these regions have been collected for two years and analysed with mathematical statistical method like regression analysis.

SCIENTIFIC SIGNIFICANCE

The main scientific significance of this dissertation is the development of two models for the analysis on the share of renewable energy resources at the national and regional level:

1. A system dynamics analysis model for the evaluation of policy measures promoting the replacement of fossil fuel with renewable energy resources.
2. Optimization model for the evaluation the impact of CO_2 tax and the analysis of region's CO_2 emission benchmarks.

The models have been approbated with two Latvian regions, which are the former Limbaži and Ogre districts.

PRACTICAL SIGNIFICANCE

The practical significance of this dissertation, and in particular of the developed models, is evident at the following levels:

- National level – the government has now additional evidences that renewable energy sources are an economical viable alternative to fossil fuels and therefore governmental action plans and strategy documents should include political measures proposed in this dissertation.
- Municipal and regional level – regional and municipal energy plans can be now designed using both the system dynamic and the optimisation model developed in this dissertation.
- At the level of energy companies and investors –the optimization models are useful tools for the evaluation of the regional energy sector in the short term and in long term.
- Scientific level – the methodology developed in this dissertation can be used and further developed for the solution of similar problems, where emission reduction is a target.

APPROBATION

Methodologies, advancement of the work and results of this dissertation have been thoroughly documented and discussed:

1. Blumberga D., Dzene I., Rošā M., Simulation of the Development of Latvian Energy Sector. Regional Availability of Energy Resources//International scientific conference "Spatial Strategy for Sustainable Development: We Make Latvia's Future", 16 October 2009, Riga;

2. Dzene I., Bodescu F., Evaluation of Biomass Availability for Biogas Production at Regional Level//RTU 50th International Scientific Conference, Riga, 14 October 2009;
3. Dzene I., Rošā M., Blumberga D., Demand Side Management at Regional Level//The 5th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems, Dubrovnik, Croatia, 3 October 2009;
4. Dzene I., State of the Art of Biomass for Bioenergy Assessment - an EU-project for the Baltic Region: EUBIONET III//International workshop "Current and future woody biomass for energy – Monitoring Use and Understanding Technology", Riga, Latvia, 16 September 2009;
5. Dzene I., Energy Planning Examples from Latvian Municipalities//Workshop "Energy Certificates. Energy Efficiency in Municipal Development Plans. Financing Possibilities of Energy Efficiency Projects, Riga, Latvia, 28 May 2009;
6. Dzene I., Implementation of Energy Action Plan in Madona and Lubāna municipalities//Presentation at the Energy Cities Conference, Brussels, Belgium, 20 April 2009;
7. Dzene I., Evaluation of Possibilities for Using Renewable Energy Sources in Latvia by 2020//Poster and Oral Presentation in Young Scientists Lounge at the International Conference on Climate Solutions, Copenhagen, Denmark, November, 2008;
8. Dzene I., Regional Energy Planning//Institute for Environmental and Energy Science, Riga, Latvia, 16 June 2008;
9. Dzene I., Energy Plan for Limbaži region in Latvia//Evening Dinner Debate "Implementation of Decentralized Energy Actions in Rural Areas", Brussels, Belgium, 10 April 2008,;
10. Dzene I., Limbazi District Energy Plan. Presentation of proposed actions// Workshop "Financing of EU Structural Fund and Cohesion Fund for Energy Efficiency and Renewable Energy Projects. Limbazi District Energy Plan within the Scope of "Energy 4 Cohesion" Project, Goethe Institute, Riga, Latvia, 3 April 2008;
11. Epp Ch., Dzene I., Bioenergy Deployment in Rural Regions of Europe - Investment and Financing Opportunities addressed by the Energy 4

Cohesion Project//2nd International Bioenergy Investment & Finance Conference, Stuttgart, Germany, 7 March 2008;

Publications:

1. Romagnoli F., Dzene I., Barisa A., Blumberga D., Blumberga A., Davidsen P., Moxnes E., The Use of System Dynamics Approach for Assessing the Impacts of Policy Measures and Strategies on Wood Energy Market Development in Latvia//Proceedings of the 3rd International Symposium on Energy from Biomass and Waste, Venice, Italy, 8-11 November 2010. Pages 14-26;
2. Dzene I., Romagnoli F., Barisa A., Blumberga D., Blumberga A., Davidsen P., Moxnes E., Building-Up a System Dynamics Model for Transforming the Latvian Energy Market in Environmentally Sound Direction//Proceedings of the 3rd International Symposium on Energy from Biomass and Waste, Venice, Italy, 8-11 November 2010. Pages 1-13;
3. Sistēmiskas domāšanas integrēšana vides politikā. A.Blumbergas red. (Integration of Systemic Thinking in Environmental Policy, Edited by A.Blumberga), ISBN 978-9934-8196-0-5 – Riga: RTU Institute of Energy Systems and Environment, 2010. Pages 159-177;
4. Sistēmdinamika vides inženierzinātņu studentiem. A.Blumbergas red. (System Dynamics for Environmental Engineering Students. Edited by A.Blumberga), ISBN 978-9934-8196-1-2 – Riga: RTU Institute of Energy Systems and Environment, 2010. Pages 96-156;
5. System Dynamics for Environmental Engineering Students. Edited by A.Blumberga, ISBN 978-9934-8196-2-9 – Riga: RTU Institute of Energy Systems and Environment, 2011. – p.94-157;
6. Dzene I., Rošā M., Blumberga D., How to Select Appropriate Measures for Reductions of Negative Environmental Impacts? Testing a Screening Method on Regional Energy System//Energy (2010), doi:10.1016/j.energy.2010.05.001;
7. Blumberga D., Dzene I., Rošā M., Blumberga A., Modeling of Latvian Energy Sector. Regional availability of energy resources//Proceedings of International Scientific Conference “Spatial Strategy for Sustainable Development: We Make Latvia’s Future”, Riga, Latvia, 15-17 October 2009;
8. Dzene I., Bodescu F., Evaluation of Biomass Availability for Biogas Production at Regional Level//Proceedings of the Riga Technical

University international scientific conference "Environmental and Climate Technologies", 13th series., 3rd part., R.: RTU Publishing House, 2009, Pages 54-62;

9. Dzene I., Rošā M., Blumberga D., Demand Side Management at Regional Level//Book of Abstracts of the 5th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems, Dubrovnik, Croatia, 29 September – 3 October 2009, R: Faculty of Mechanical Engineering and Naval Architecture, Zagreb, 2009, Page 388;

10. Dzene I., Rochas C., Blumberga A., Blumberga D., Rošā M.. Sustainable Energy Planning, ISBN 978-9934-8058-2-0 – Riga, Latvia, 2009;

11. Al Saedi T., Blumberga D., Dzene I., Biogāze. Rokasgrāmata (Biogas. handbook)//Riga, Latvia, 2009;

12. Dzene I., Using Renewable Energy Sources in Latvia 2020 // List of Abstracts of Young Scientists Lounge of International Conference on Climate Solutions, Copenhagen, Denmark, November, 2008;

13. Rošā M., Blumberga D., Dzene I., Rochas C., Benchmark Methodology for Reduction of Greenhouse Gas Emissions // List of Abstracts of Young Scientists Lounge of International Conference on Climate Solutions, Copenhagen, Denmark, November, 2008;

14. Dzene I., Rošā M., Rochas C., Benchmark Methodology for Elimination of Greenhouse Gas Emissions // Proceedings of the Riga Technical University international scientific conference "Environmental and Climate Technologies", 13th series, 1st part, R.: RTU Publishing House, 2008, Pages 10-17;

15. Dzene I., Bioenergy use in Latvia // Forum. New Power Magazine for Renewable Resources and Energy Special Edition, 2008, Pages 24-26;

16. Dzene I., Veidenbergs I., Rošā M., Investigation of existing energy situation in Limbaži region // Proceedings of the Riga Technical University international scientific conference "Enerģētika un elektrotehnika" (Energy and Electrical Equipment) 4th series, 21st part, R: RTU Publishing House, 2007, Pages 177-182.

STRUCTURE OF THE THESIS

The work consists of the introduction, four sections and conclusions. It includes 130 pages, including 85 figures, 13 tables and a bibliography with 72 literature sources. The bibliography is not included in this summary.

1. OPTIONS FOR INCREASING THE SHARE OF RENEWABLE ENERGY SOURCES IN DISTRICT HEATING SYSTEMS

Different researches performed formerly in Latvia have shown that the existing Latvian energy policy and planned actions are not enough for reaching the 2020 targets for renewable energy resources and energy efficiency as set forth in the European Union’s climate package.

The District Heating sector is one of the largest primary energy consumers in Latvia. In district heating systems the dominating primary energy sources are natural gas and wood based fuels. Mutual breakdown of both these primary energy resources has changed a little over time. For example from 2004 to 2008 in district heating system the use of natural gas has been five times above the use of wood based fuels. Since 2004 oil products and in particular heavy fuel oil has been mainly replaced by natural gas and then partly by wood based fuels (see Figure 1.1.).

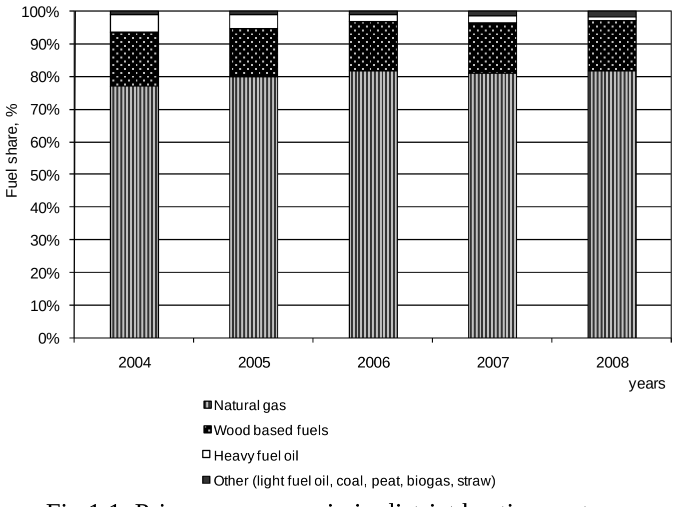

Fig.1.1. Primary energy mix in district heating system

Although Latvia has a high biomass potential, the share for wood based fuels in the district heating sector has experienced rather slow growth rates. In order to better understand and analyse this trend a system dynamics model was developed. Dynamic characteristics were based on historical statistical data and trends.

The objective of this study based on a system dynamic model is: (i) to precisely simulate the fuel mix structure of the Latvian district heating sector; (ii) to develop a set of alternative solutions for Latvia to reach the targets set for the share of renewable energy sources; and (iii) to determine whether it is possible a complete shift from natural gas to wood based fuels, both considering energy efficiency and Latvian economic growth. The developed dynamic model is both deterministic and forecasting. For example, it helps to understand the influence that policy measures and economic factors have on the fuel mix structure or the influence that policy measures have on heat energy tariffs.

An important factor, which has an influence on fuel mix, is the existing installed capacity by type of fuel. Therefore, the model is based on two main blocks, one for installations using wood based fuels and the other using natural gas.

These blocks are influenced by incoming and outgoing flows. The main flows influencing both blocks are: (i) investments in existing and new installations, both for refurbishment or new capacity and (ii) depreciation of current assets. Investments directed to installation are defined as incoming flows and they increase the block. Depreciations of assets are defined as outgoing flows and they decrease the value of the block (see Fig.1.2).

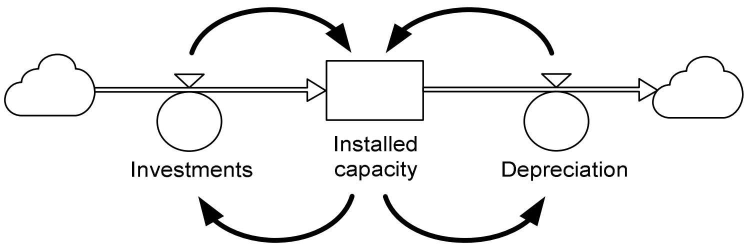

Fig.1.2. Elements of system dynamic model, blocks and flows

The resulting system dynamic model, for the dynamic analysis of these two blocks is shown in Figure 1.3. The combined installed capacity (natural gas installation plus wood based fuels installation) is assumed to be constant. In other words, an increase in wood based fuel installed capacity brings a decrease in natural gas installed capacity and vice versa.

The model allow to analyse in the selected simulation time period the costs of fuel mix, the unit costs for heat energy and the changes in the heat energy tariffs. Heat energy tariffs for installations using wood based fuels are influenced by: fuel price; capital costs of the installation; operational and maintenance costs; efficiency factor; reference serving time; calorific heat value and moisture content of wood fuel; annual interest rate and risk factor. The heat tariff from installations using wood based fuels is calculated as:

$$T_K = \frac{C_K^K \cdot \eta_K}{Q_{zK}^d} + C_K^O + \frac{C_K^I \cdot 10^3}{Q_{izl}} \cdot (i + \frac{1}{\tau_K^{ref}}) + R,$$

where

T_K –heat energy tariff, *LVL/MWh*;

${C_K}^K$ – wood based fuel price, *LVL/t*;

${C_K}^I$ –capital costs, *LVL/MW*;

${C_K}^O$ –operational and maintenance costs, *LVL/MWh*;

Q_{izl} – length of normalised heating season, *h/per annum*;

η_K – installation efficiency ratio;

${\tau_K}^{ref}$ – economical life time, *years*;

${Q_{zK}}^d$ – calorific heat value of wood based fuel, *MWh/t*;

i – annual interest rate, *%/per annum*;

R – risk factor.

Wood fuel price, capital costs, operational and maintenance costs, efficiency and calorific values are calculated as weighted average value among the wood fuel types used in Latvia: firewood, woodchips and wood pellets.

The system dynamics model (see Fig.1.3) integrates three kinds of policy measures for promoting energy efficiency and renewable energy sources:

1) P_S – policy measures, support mechanism, like subsidies for fuel switch in district heating from natural gas to wood based fuels. For example the replacement of natural gas boilers by woodchips fired boilers, prior to end of normal life time);

2) P_R – policy measures, risk compensation and guarantee schemes for wood based fuel; with the aim to stimulate the wider use of wood based fuels technologies;
3) P_η – policy measures, to support energy efficiency improvement measures in wood based fuels installations.

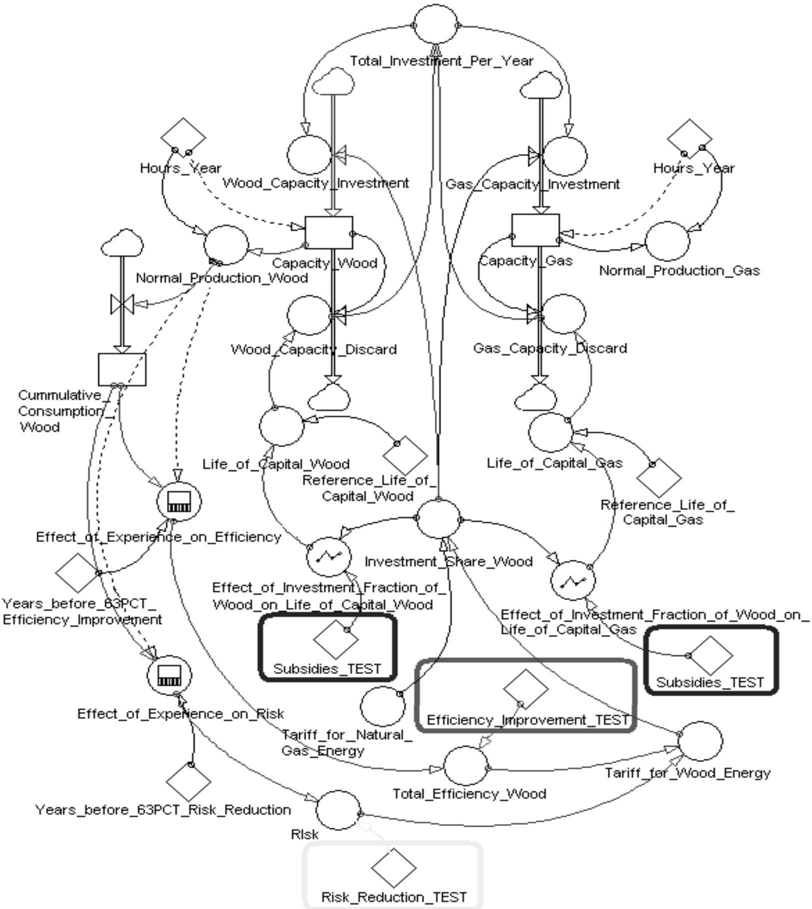

Fig.1.3. Main parts of the system dynamic model

These policy measures are combined to develop eight possible different scenarios, which are further simulated (see Table 1.1.).

A comprehensive description of the model and its mathematical formulation is given in the thesis and it's Appendix.

Table 1.1

Combinations of Policy measures for the development of different scenarios

Scenario	Policy instruments		
	P_S	P_R	P_η
1. Policy instruments are not used at all	0	0	0
2. support mechanism in form of subsidy	1	0	0
3. Information package	0	1	0
4. Energy efficiency (EE) package	0	0	1
5. Subsidy and information package	1	1	0
6. Subsidy and EE packages	1	0	1
7. Information and technology EE packages	0	1	1
8. All three policy measures together	1	1	1

The case when $P_S = 0$ means that subsidies are not granted; whereas $P_S = 1$ means that there are subsidies for the replacement of natural gas installations with wood based fuels installations. In this case often the replacement of natural gas installations may occur before the end of their economical life time (20 years).

The value $P_R = 0$ means that market players and the public is not made aware about good practices and experiences of using wood based fuels. In this case general motivation to fuels switching project and energy efficiency is lacking. The public is biased by fossil fuels lobbies and keeps considering that wood based fuels are polluting, damaging the environment and much more expensive. When $P_R = 1$ market players are enabled to a more objective analysis, thanks to marketing or support measures. Best practices are disseminated, promoting and enhancing the use of wood based fuels. Risk perception is thereby decreased.

With $P_\eta = 0$ there are not energy efficiency support measures for the improvement of existing wood fuel installations. With $P_\eta = 1$ a number of measures are enforced.

The simulation platform for system dynamic models allows activating policy measures (0 to 1), thereby running all eight different scenarios (see Fig.1.4).

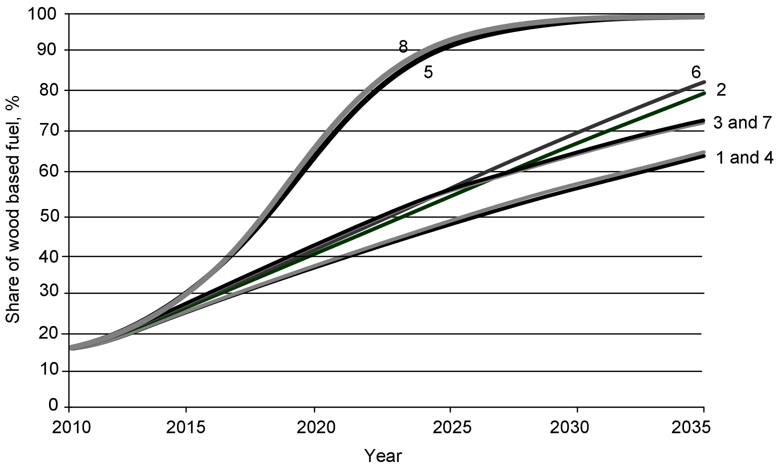

Fig.1.4. Share of wood based fuel in the primary energy mix for district heating systems under different policy scenarios

The relationship between policy measures and the resulting share of wood based fuels in the primary energy mix is not linear. The combination of different policy measures has different effects on the market. In particular on scenario 5 and scenario 8 enable a 100% switch to renewable energy sources in district heating systems with rapid growth rates. All other scenarios present more gradual growth rates and the share of wood based fuels by 2035 ends in the range of 65%-85%.

2. DEVELOPMENT OF A MODEL FORREGIONAL ENERGY PLANNING

An important part of this dissertation is the development of an optimisation model for regional energy planning. The model looks for an optimum benchmark for reducing emissions of green house gases in the atmosphere. Particular focus is on CO_2 emissions. The optimum benchmark corresponds to the maximum regional income generated by tax reduction expenditures or sale of emission quotas in the emission trading scheme.

Considering the results of previous studies, and as well as the Danish energy strategy towards 2050, the model tries as well as to understand the possibility to abandon the use of fossil fuels. Practical implementation of environmental issues is often possible only in case when optimum solutions are chosen. However, the implementation of measures to reach ambitious climate protection target need considerable investments, which may put high pressures on energy tariffs. Therefore, emission reduction targets should be evaluated very carefully and measures identified by optimised energy and action plans.

The optimisation model is set to maximize the regional income from CO_2 emission reduction activities. The solution of the optimisation problem gives information on how renewable energy policies and support mechanisms at regional level should be set up. The target function of the optimisation problem is expressed as

$$I_{ien} = \int_{i=1}^{n} (\xi_{nod.i} - \xi_{ef.i}) \cdot (\overline{E_i} - E_i) \rightarrow \max,$$

Where:
I_{ien} – regional income;
i = 1,...n – number of emission installations in the region;
$\xi_{nod.i}$ – corporate tax for polluting activity;
$\xi_{ef.i}$ – CO_2 emission reduction cost efficiency;
$\overline{E_i}$ – baseline emission volume for installation 1…n;
E_i – emission volume for installation 1…n after improvement actions (emission reduction measures).

The optimisation model consists of the following five modules:

- module for initial input data;
- module for input assumptions;
- technological module;
- climate module;
- economic calculation module.

The optimisation model algorithm is shown in Fig.2.1.

The module for initial data includes the installed capacity of each installation in the region and the type of fuel used. In Latvia these data are available from the State Statistical Database on polluting activities “2-Gaiss”. The module for input assumptions enables a number of reasonable simplifications:

- a single regional number of operation hours per annum for each installation;
- energy efficiency rates were defined depending on the type of fuel used;
- CO_2 emission factors defined depending on the type of fuel;
- the CO_2 saving cost efficiency assessment based on an empiric equation.

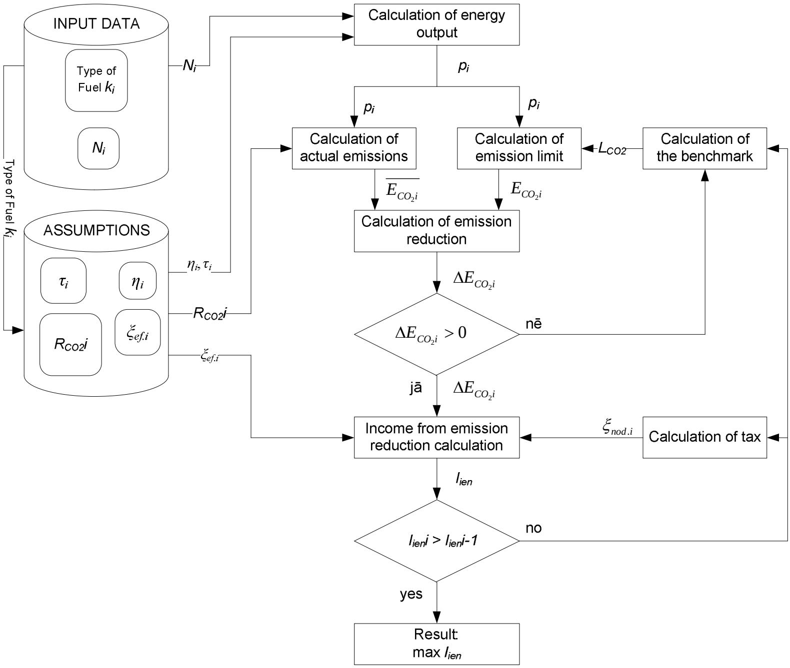

Fig.2.1. Optimisation model algorithm

The following specific assumptions were considered representative for Latvia:

- number of operational hours τ = 5000 h/year;
- CO_2 emission factor per energy produced for natural gas R_{CO2} = 0,229 tCO_2/MWh;
- CO_2 reduction cost efficiency $\xi_{ef.i}$ is expressed by the following empirical equation based on correlation analysis (see Fig 2.2.):

$$\xi_{ef.i} = 2 \cdot 10^{-8} \cdot (\Delta E_{CO2})^2 - 8 \cdot 10^{-5} \cdot \Delta E_{CO2} + 5.75$$

Technological calculations have been performed for all 1,000 devices by calculating the volume of energy produced and actual annual CO_2 emission from each device.

Simulations have been run for four scenarios, which differ by CO_2 tax rates. The following tax rates were set in the module for economical calculation:

Scenario 1: CO_2 tax rate 7 LVL/tCO_2
Scenario 2: CO_2 tax rate 10 LVL/tCO_2
Scenario 3: CO_2 tax rate 15 LVL/tCO_2
Scenario 4: CO_2 tax rate 20 LVL/tCO_2

For each of these scenarios, the module for climate calculation was set with a range of benchmark values: L_{CO2} = 0.1 ÷ 0.225 tCO_2/MWh with incremental step of 0.025.

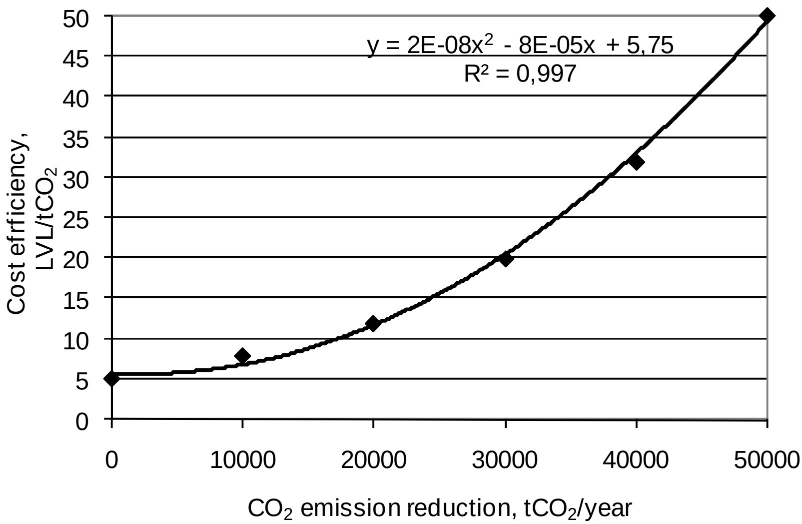

Fig.2.2. Relation between CO_2 emission reduction costs and CO_2 emission reduction

The scenarios have been analysed introducing two relative values, so that a comparison between regions of different sizes, number of installations, installed capacities, fuel mix can be compared.

The first relative value is the relative CO_2 emission reduction factor:

$$r_{CO2} = \frac{\Delta CO_2^{fakt}}{\Delta CO_2^{\max}},$$

Where:

r_{CO2} – relative CO_2 emission reduction factor;

ΔCO_2^{fakt} – actual CO_2 emission reduction, tCO_2/MWh;

$\Delta CO_2^{\max}$ – maximum CO_2 emission reduction, tCO_2/MWh.

The second relative value is the relative costs factor defined as:

$$i_{izd} = \frac{I_{izd}^{fakt}}{I_{izd}^{\max}},$$

Where:

i_{izd} – relative costs factor;

I_{izd}^{fakt} – actual costs, LVL/year;

$I_{izd}^{\max}$ – maximum possible costs, LVL/year.

In case of CO_2 emission reduction the costs may have different signs, because the total cost is the sum of the following components:

- capital investment for CO_2 emission reduction activities, which is positive („+” sign);
- income from emission sale with respect to CO_2 emission reduction, which is negative (“–” sign);
- prevented cost by reducing CO_2 tax expenditures due to decreasing volumes of CO_2 emissions, which is negative (“–” sign).

Relative values of the costs are calculated by dividing the cost components by the value of maximum costs for CO_2 reduction. The maximum is attained at small benchmark values. The results of modelling and simulating of all four scenarios (total costs at different tax rates depending on the benchmark value) are shown in Fig. 2.3.

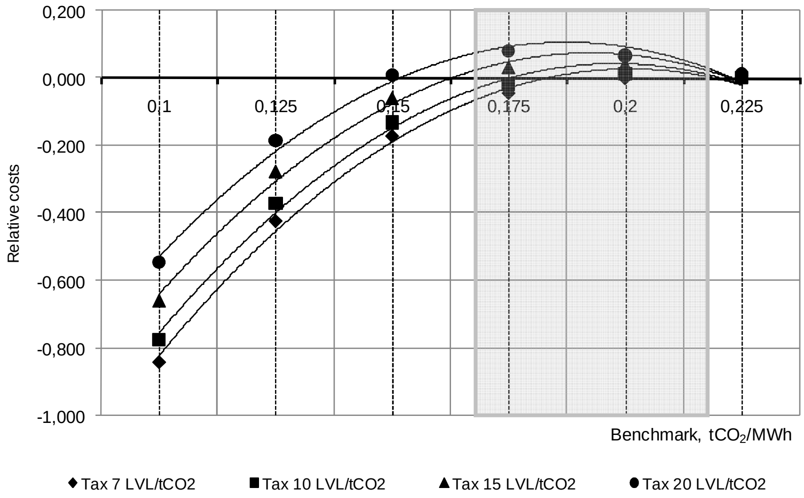

Fig.2.3. Theoretical optimisation model results

When the tax rate is increasing, the maximum value of total relative costs is also increasing, but optimum benchmark values are decreasing.

For a certain range of benchmark values, relative costs shows two possible solutions (at a certain tax level there are two benchmark values that gives the same relative costs). These solutions determine an area of solutions for which relative costs are always positive. In this area CO_2 reduction activities have positive or neutral economic effect.

Below the minimum benchmark value, which still give positive relative costs, reduction of CO_2 emissions need additional support. On the other hand, decreasing CO_2 tax rates directly decrease the range of benchmark values giving positive relative costs. For example, if the CO_2 tax rate is 20 LVL/tCO_2 then the benchmark range is from 0.15 to 0.225 tCO_2/MWh, but when the tax rate is decreased to 7 LVL/tCO_2, the range is down to 0.175 – 0.225 tCO_2/MWh.

3. MODEL APPROBATION BASED ON TWO LATVIAN REGIONS

The optimisation model has been approbated using the data of two regions of Latvia – former Limbaži and Ogre districts. These regions were chosen for approbation of the model because they are representative regions. Limbaži region represents the so-called “wood fuel district” because natural gas is not available there and the main type of fuel used is wood. Ogres region represents the “natural gas district” where the most common fuel used is natural gas.

3.1. Model approbation on the example of Limbaži district

Since 1 July 2009 Limbaži district has been divided into three municipalities: Aloja municipality, Limbaži municipality and Salacgrīva municipality. The former Limbaži district is situated in the northern part of Latvia, on the Gulf of Riga and borders Riga district in the S, Cēsis district in the SE, Valmiera district in the E and Estonia in the N. Geographical position of the district has largely determined its existing fuel infrastructure. Because Limbaži district borders the sea there are several export ports located in the district (Skulte, Salacgrīva), to which export products, including fuel, are exported; thus ensuring regular flow of energy resources (mainly wood) through the region.

Various energy sources are used in Limbaži district. Heat energy is produced in both centralised systems and local heat sources as well as in individual heating systems. In Limbaži region, district heating systems exist in seven municipalities: Limbaži, Aloja, Salacgrīva, Umurga, Pociems (Katvari civil parish), Liepupe and Ozolmuiža (Brīvzemnieki civil parish).

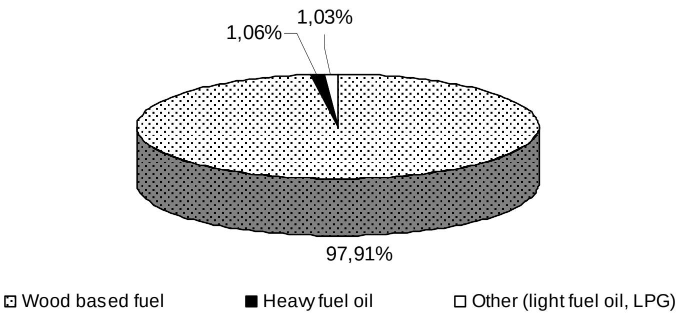

Fig.3.1. Fuel structure in Limbaži district in 2009

There are 42 installations with capacity ranging from 0.2 to 17MW installed in Limbaži district. Besides wood, heavy oil fuel, diesel and coal are also used. Installations using fossil fuel range from 0.2 to 5MW capacity. The general fuel mix structure of Limbaži district is shown in Fig.3.1.

It is important to note that the changes of CO_2 emission reduction cost efficiency in the reviewed power range are of practically linear character (see Fig.2.2). Cost efficiency is the main variable determining existence or absence of optimal cost or saving value (optimum) and its location.

Like in the theoretical calculation module, optimisation for Limbaži district installations is made with four scenarios applying four different tax rates. The results are shown in Fig. 3.2.

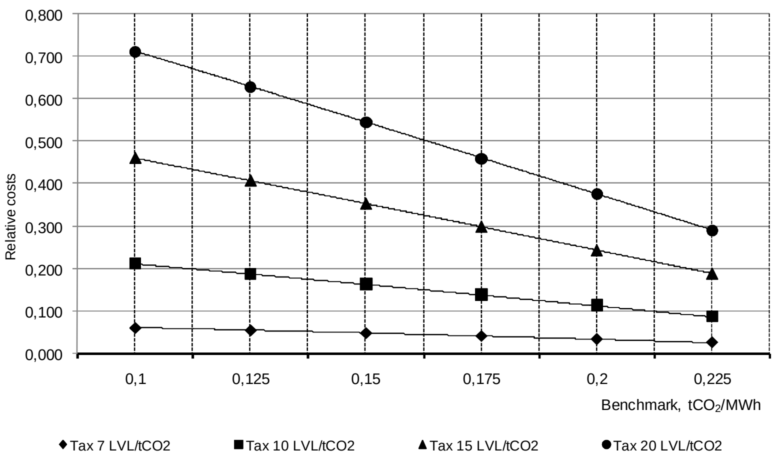

Fig.3.2. Limbaži district optimisation model results

These results for Limbaži district show that:

- there is a linear relationship between the benchmark and relative costs. Relative costs decrease with increasing benchmark values. This linear trend may be explained by the linear characteristic of cost efficiency changes;
- relative costs for heat sources of the district are positive in all reviewed scenarios. When the tax rate increases, the income of the district related to decrease of the CO_2 emissions increases also. Positive economic

effect is evident even in the case of the lowest reviewed tax rate (7 LVL/tCO_2). That is because the cost efficiency in case of Limbaži district is lower than the minimum reviewed tax rate;

- application of low CO_2 emission benchmarks to sources of Limbaži district is economically justified. The lowest value of benchmark reviewed in the analysis is 0.1 tCO_2/MWh.

3.2. Model approbation on the example of Ogre district

Since 1 July 2009 Ogre district has been divided into four municipalities: Ogres municipality, Ikšķile municipality, Ķegums municipality and Lielvārde municipality. The former Ogre district is located in the central part of Latvia and borders Riga district in the NW, Cēsis district in the N, Madona district in the E, Aizkraukle district in the S and Bauska district in the SW. The administrative centre of Ogre district is the town of Ogre.

Various energy sources are used in Ogre district. Heat energy is produced in both centralised systems and local heat sources as well as in individual heating systems. There are 57 sources with installed capacities ranging from 0.2 to 47MW in Ogre district. Natural gas is the most used fuel, because the region is well covered by natural gas network. The installed capacity for installations using fossil fuel in Ogre district ranges from 0.02 to 47MW. The fuel mix structure of Ogre district is shown in Fig.3.3.

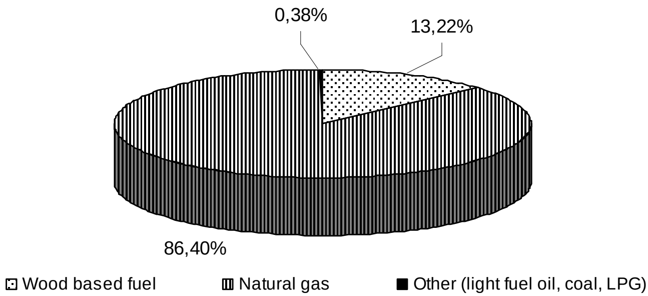

Fig.3.3. Fuel mix structure in Ogre district in 2009

The changes of CO_2 emission reduction cost efficiency in the reviewed power range are nonlinear. The results of optimisation of Ogre region energy system are shown in Fig. 3.4.

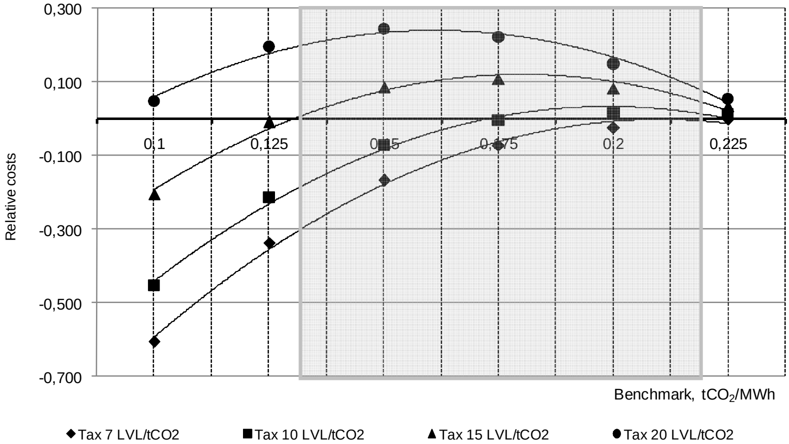

Fig.3.4. Ogre district optimisation model results

Heat sources of Ogre district differ from the heat sources of Limbaži district because they:

- use more fossil fuel – natural gas, diesel and coal;
- have higher installed capacities (up to 46.7 MW in the boiler house of Ogre PA "Mālkalne").

This means that CO_2 emission reduction activities in the district have greater volumes of emission reduction. If reduction of emissions grows, then the cost efficiency is increasing, too.

The activities performed in Ogre district in general may bring losses, be economically neutral or be profitable. This means that there exists a certain limiting value in case of which the district is not suffering losses in general, though is not getting income by reducing the CO_2 emissions. Such values have been identified in the thesis by benchmarking.

The comparison and analysis of economic calculations of the reviewed scenarios for Ogre district allows drawing the conclusions that:

- In case of the lowest tax rate (7 LVL/tCO_2) reduction of CO_2 emissions cannot give any profitability. Losses may be avoided only in case of high benchmarks (small reductions). The economically neutral situation is evident if the benchmark value is 0.21 tCO_2/MWh or higher;
- Increase of tax rate and reduction of emissions in the district sources may be profitable. For example, if the tax rate is 10 LVL/tCO_2, positive economic effect is evident in the range of benchmark values from 0.175

to 0.225 tCO_2/MWh. In case of tax rate of 20 LVL/tCO_2 income of the district is evident throughout the reviewed emission reduction range;

- Changes of district profitability depending on the selected benchmark value have nonlinear nature with the marked maximum (optimal value). The comparison of scenarios reviewed shows that increase of tax rates causes movement of maximum income values in the direction of lower benchmark values (greater emission reductions). For example, in case of tax rate of 10 LVL/tCO_2 the optimum corresponds to 0.2 tCO_2/MWh benchmark, but if the tax rate is 20 LVL/tCO_2, then the income optimum is 0.15 CO_2/MWh. It is evident that in case of higher tax rates greater volumes of the CO_2 emission reduction become economically justified;
- Application of the proposed optimisation methodology to economic assessment of CO_2 reduction by Ogre district enterprises indicates that the optimum reduction scenarios may be defined.

CONCLUSIONS

1. A system dynamic model for district heating system has been developed. With this model is possible to evaluate the impact that national and regional policy measures have on the energy mix in district heating companies. The model has been approbated for Latvian district heating systems; analysis as well as the specific case where by 2035 the sector could become independent fossil fuels and be fully switched to wood based fuels.
2. The results of the simulation carried out with the developed system dynamic model showed that there are two main policy measures to be included into national and regional renewable energy action plans: state subsidies for early state technologies and solutions and guarantee mechanism and schemes for investors.
3. Long-term influence on climate changes in the regional energy plans needs to be analysed. The proposed concept for CO_2 emission reduction is based on benchmark methods, which allows quick comparison with other regions and the possible effect of each activity at regional level.
4. The developed optimisation model, which minimise costs for CO_2 emission reduction activities, allows the assessment of CO_2 tax and decrease of the regional fuel CO_2 emission benchmark.
5. Results of optimisation show that when the CO_2 tax increases, the optimum is moving in the direction of lower benchmark values (greater CO_2 reductions). This means that the activities related to greater CO_2 reduction become economically profitable and the movement towards the development of “greener” region is taking off.

6. The optimisation model approbated on the example of two regions shows that results of optimisation depend on specific weight of renewable energy resources in the initial energy balance.
7. The analysis made for Limbaži district showed that there is not an optimum costs for CO_2 emission reduction activities, because the changes are linear. Linear trends derive by linear cost efficiency changes in district with an overall small installed capacity (less than 30 MW). Application of low CO_2 emission benchmarks to sources of Limbaži district is economically justified.
8. The analysis made for Ogres district showed that there is an optimal value for costs for CO_2 emission reduction activities. In particular there is a dependency on the chosen benchmark value. Nonlinear trends are evident in the districts with overall installed capacity over 30 MW.