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

Marika ROCHAS

ANALYSIS OF MECHANISMS FOR CO_2 EMISSION REDUCTION IN LATVIAN ENERGY INSTALLATIONS

Summary

Scientific supervisor
Dr. habil. sc. ing., professor
IVARS VEIDENBERGS

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Background and current situation

Climate change and global warming is not anymore a myth but a scientifically proved statement. In the last decade different severe changes in nature, like devastating storms and floods, heat waves, extinction of various species, and other extreme events have been observed. These variations in nature have initiated a serious debate on this topic all around the world.

In 1992, diplomats of many countries joined in fighting climate change with signing and ratifying the United Nations Framework Convention on Climate Change (Convention) and later in 1997 - the Kyoto Protocol was issued. Until now Kyoto Protocol, in power since 2005, is the only document clearly stating emission reduction targets at international level. The overall target is to reduce greenhouse gas (GHG) emissions at least by 5% in the period 2008-2012.

Latvia joined the Convention in 1995 and ratified the Kyoto Protocol in 2002. The individual target for Latvia is a reduction of GHG emission equal to 8% compared to the 1990 levels.

The 1st of May 2004 Latvia has became a member of the European Union and consequently has been adopting and participating to the common EU policy, including the environmental and energy sectors. So far EU has prepared and approved a number of directives regarding the promotion of energy efficiency in household and industrial sectors and aimed to increase the use of renewable energy sources.

Latvia has a relatively comfortable situation to meet its Kyoto reduction target in 2008-2012 as the economy has declined considerably in the beginning of 90ies and its high share of renewable energy sources in the power generation sector. On the other hand, this comfortable situation should not be improperly used, and Latvia has a high potential to increase energy efficiency in the power and industrial sector reducing its greenhouse gas emissions.

To reach and achieve this potential is necessary to implement a study about which economic instruments could efficiently bring GHG emissions reduction and promote energy efficiency measures.

Objectives

The main objectives of the thesis have been:

1. To analyse different scenarios for emission trading and to develop an appropriate allocation methodology for Latvian companies that participate in the EU Emission trading scheme in the period 2005-2007.

2. To analyse monitoring results and the influence of measurement uncertainty, based on one year monitoring results taken in a district heating company and to evaluate its possibilities to increase energy efficiency.
3. To analyse different CO_2 tax level and price of emission allowances with the objective to evaluate the advantages and disadvantages of these financial instruments and their capability to incentive companies to reduce GHG emissions by optimising tax and price levels from the point of view of energy efficiency and fuel switch measures.
4. To develop a benchmark methodology for energy installations to simplify the allocation of allowances for the next emission trading periods and to convince the companies to implement actions oriented to reduce GHG emissions.

Research methodology

The research has been based on mathematical analysis and modelling on collected monitoring data in an energy installation. In particular, regression analysis has been used to analyse CO_2 emission dependence from: fuel consumption, heat generation, combustion efficiency and other relevant parameters. The methodology used for the regression analysis has been verified by means of distribution law of the dependent variables, autocorrelation analysis and heteroscedasticity. An evaluation of the uncertainty of monitoring data has been carried out. The elaborated equations have been used for the optimisation of the impact of emission trading.

Scientific significance

Different evaluation methodologies for two CO_2 emission reduction mechanisms (emission trading and CO_2 tax) have been developed and approbated. In particular:

- Assessment and development of methodologies proposed in the European Union Emission Trading Scheme, for the allocation of allowances to concerned installation.
- Development of a methodology for data monitoring - based on one-year data collection carried out in a heat power generation plant. The developed methodology analyses the main parameters that influence CO_2 emissions reduction and the role of measurement uncertainty on the emission allocation principles.
- Development of a methodology for the evaluation of the effect of CO_2 tax rates on the implementation of energy efficiency

measures. The proposed methodology includes an optimisation analysis where the parameters of the objective function are emission allowances, tax levels and investments in energy efficiency measures.

- Development of an emission benchmark methodology, based on 2005 data for 35 district heating companies in Latvia. The analysis includes different fuel types, energy efficiency levels and heat energy produced.

Practical significance

This research study has different target groups, among all:

- Latvian state and in particular the Ministry of Environment and the Ministry of Economy - emission benchmark methodology for boiler houses could be used by the Ministry of Environment in the dialog with European Commission when harmonised emission benchmarks on European Union level will be discussed. The proposed methodology could be expanded to include calculation of emission benchmarks for cogeneration plants and targeted industries. Responsible authority can use the results of CO_2 tax analysis to develop new or amending existing legislation.
- Energy utilities and district heating companies - with the offered analysis of monitoring data and emission benchmark method -could estimate their GHG emissions and other parameters and compare them with other Latvian, EU and world companies.
- Investors - the methodologies will allow to evaluate and consider all the environmental aspects and conditions for assessing their investments.

Approbation

The results of the thesis have been reported and discussed in:

1. International workshop *"District Heating Policy in Transition Economies"* with a paper "Emission Trading Scheme. How it affects District Heating" in Prague, Czech Republic, 23-24 February 2004.
2. International workshop *"Emission trading - challenges for industries"* in Tallinn, Estonia, 13-14 May 2004.
3. Workshop *"Pollution"* for representatives of Latvian district heating companies with a paper on "The principles of emission allowance allocation for Latvian district heating companies" in Riga, Latvia, 22 July 2004.

4. With a paper "National allocation plan for 2005-2007" in workshop *"Emission trading scheme in Latvia"* in Riga, Latvia, 23 September 2004.
5. *45th RTU scientific conference* with a paper "Analysis of CO_2 tax implementation" in Riga, Latvia, 15-16 October 2004.
6. International conference *"Climate Technology Initiative"* in Leipzig, Germany, 16-20 October 2004.
7. International conference *"Energy Efficiency"* in Vienna, Austria, 21-22 October 2004.
8. *46th RTU scientific conference* with a paper "Use of emission benchmarks for allocation of allowances" in Riga, Latvia, 14 October 2005.
9. *64th scientific conference of University of Latvia* in Riga, Latvia, 31 January 2006.
10. International Symposium *"2nd International Symposium on Energy, Informatics and Cybernetics: EIC 2006"* in Orlando, USA, 16-19 July 2006.

Publications

1. A.Blumberga, D.Blumberga, M.Blumberga, P.Cikmacs, I.Veidenbergs, Efficient lighting // Teaching aid, Riga, 2002, 124 pages.
2. M.Blumberga, D.Blumberga, Challenges and Chances for Climate Technology in Latvia. Country report // Conference "Climate Technology", Tutzing, Germany, 20-24 September 2003.
3. M.Blumberga, I.Veidenbergs, D.Blumberga, Evaluation of quantity of emission allowance operators in Latvia // Latvian Journal of Physics and Technical Sciences, issue 4, Riga, 2004, p.3-12.
4. C.Rochas, D.Blumberga, M.Blumberga, The performance of Feed-in Tariff to promote cogeneration in Latvia // Special number of "Energia pieniadzei srodowiska" - proceedings of the Conference "CHP market with the prospect of implementation of EU CHP Directive (on the promotion of cogeneration based on a useful heat demand in the internal energy market)". Warsaw, Poland. 16 March 2004.
5. M.Blumberga, I.Binovska, I.Veidenbergs, Analysis of CO_2 tax implementation // RTU Scientific articles "Power and electrical engineering", series 4, issue 12, Riga, 2004, p.24-31.
6. D.Blumberga, M.Blumberga, Energy Service. Energy Efficiency. 1st book // Riga, 2004, 127 pages.
7. M.Blumberga, Development and future of emission trading scheme in Latvia // Conference "Climate Technology Initiative", Leipzig, Germany, 16-20 October 2004.

8. M.Blumberga, D.Blumberga, C.Rochas, Analysis of Energy Efficiency Measures in Latvia. Potential of Emission Trading // Conference "Energy Efficiency", Vienna, Austria, 21-22 October 2004.
9. D.Blumberga, M.Blumberga, What it is possible to achieve with lighting training? Lessons learned in Latvia // The 6th International Conference on Energy-Efficient Lighting, Right Light 6, 9-11 May, 2005, Shanghai, China.
10. D.Blumberga, M.Blumberga, I.Veidenbergs, CO_2 taxes as economical tool for energy efficiency. Analysis of CO_2 tax impact on energy efficiency projects in Latvia // Latvian Journal of Physics and Technical Sciences, issue 3, 2005, p.3-12.
11. M.Blumberga, Use of emission benchmarks for allocation of allowances // RTU Scientific articles "Power and electrical engineering", series 4, issue 14, Riga, 2005, p.278-284.
12. M.Blumberga, Analysis of CO_2 emission sources // 64th scientific conference of LU. Geography. Geology. Environmental Science. Riga, LU, 2006, p.223.
13. M.Blumberga, I.Veidenbergs, D.Blumberga, I.Dadzane, Estimation of the fuel consumption uncertainty in energy installation // Latvian Journal of Physics and Technical Sciences, issue 3, 2006.
14. M.Blumberga, I.Veidenbergs, Emission benchmarks for energy installations in Latvia // The 10th World-Multi Conference on Systemics, Cybernetics and Informatics, Volume VII, 2006, p.242-246.
15. M.Blumberga, I.Veidenbergs, Calculation of emission benchmarks for district heating companies // RTU Scientific articles "Power and electrical engineering", Riga, 2006 (in publishing)

Structure of the thesis

The thesis consists of an introduction, 5 chapters and conclusions. It contains 128 pages, including 68 figures, 18 tables and 99 references. The literature review is not included in this summary.

1. Development of emission trading scheme in Latvia

The implementation of the European Union (EU) Emission trading scheme (ETS) is mandatory for all Member States, including Latvia, with deadline December 31st, 2004.

The first step regarding emission trading in Latvia, has been the commissioning of the first national allocation plan (NAP) for the period 2005-2007. The scientific results and methodologies used in the NAP have been summarised and analysed in the thesis. As the EU ETS was developed for the first time, feasibility studies and deep analysis have been and essential part of the NAP, addressed to the assessment of different methodologies for the calculation of emission allowances and allocation. Due to the short time that was given to Member States (MS) for the preparation of their NAPs, MS often chosed their own approach for emission allocation, however coordinating them with EU Greenhouse Gas Emission Monitoring and Reporting Guidelines (Monitoring and Reporting Guidelines). The thesis gives an insight how the Latvian approach was chosen and shares the experience on development of NAP as well as motivates the choice of the base year, early action and reserve for new installations.

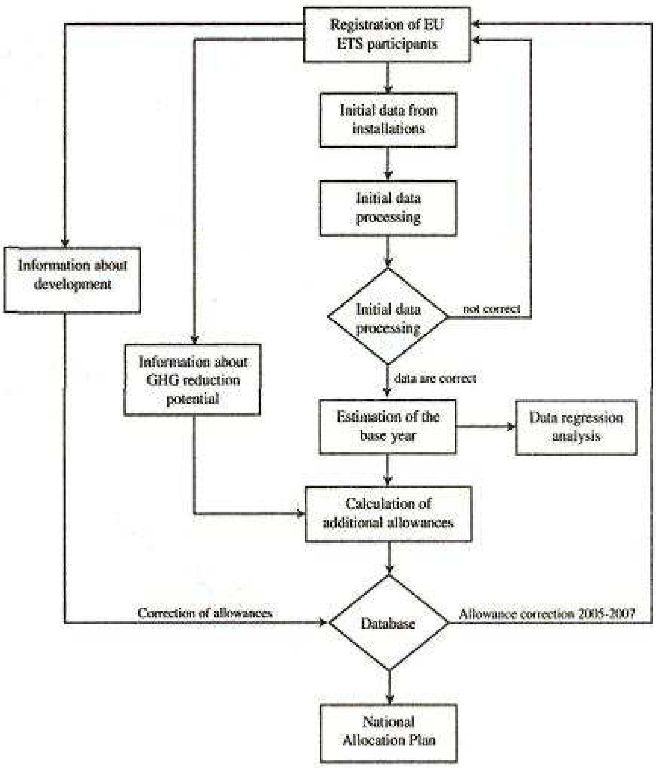

Fig.1.1. Algorithm for determination of the total amount of emission allowances

The algorithm used in Latvia for the determination of the total amount of emission allowances is given in Figure 1.1, and each step is described and analysed in detail in the thesis.

2. Monitoring CO_2 emissions and measurement uncertainty

2.1. Monitoring CO_2 emissions

To ensure precise and reliable GHG emission control and reporting according to Monitoring and Reporting Guidelines, a number of important principles have to be taken into account during monitoring. In particular, the selection of the parameter to monitor and estimation of their uncertainty.

To assess the need and the efficiency of the monitoring system, data from one district heating company participating in EU ETS were monitored and analysed.

According to the Monitoring and Reporting Guidelines, GHG emission monitoring can be performed by:

- Using a calculation method;
- Making measurements.

Basically, the Monitoring and Reporting Guidelines allow companies to choose the easiest method. However, operators have to assure that the measurement equipments (meters) follow all standards and norms and are checked and calibrated. Each company participating in EU ETS has to prepare and implement its CO_2 monitoring system.

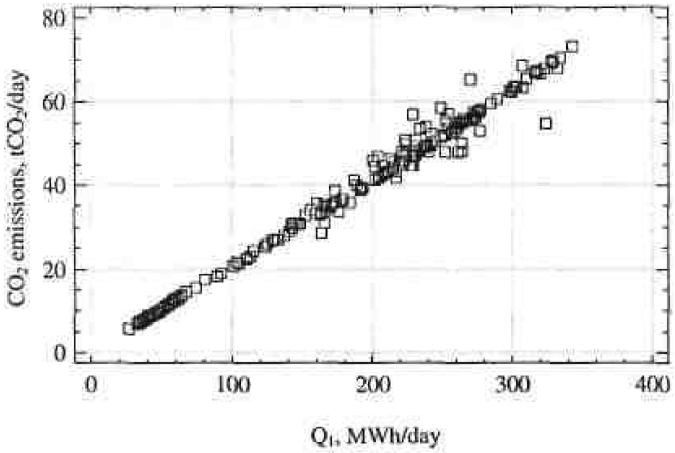

Fig.2.1. CO_2 emissions versus heat load

The processing and analysis of the Measurement data collected during monitoring are presented in the thesis. The data set is n=365 and they represent the daily average values. During the variation analysis it was concluded that data statistically important are: load (Q_1) (see Figure 2.1.), lowest calorific value and efficiency r\. These parameters are represented in the following regression equation:

$$CO_2 = -25,76 - 9,47 \cdot \eta^2 + 0,21 \cdot Q_1 + 1,03 \cdot Q_z^d, tCO_2 / day. \qquad (2.1)$$

Durbin-Watson statistic for equation (2.1) equals to DW =1.51 and significant correlation between the independent variables is not observed. Analysing the independent variables is possible to note that Q_1 depends from the consumers energy demand and Q_z^d corresponds to the average monthly lower heat calorific value for natural gas delivered by the joint stock company "Latvijas Gāze". The only factor that can be influenced is the efficiency η. Energy demand in the boiler house can be reached using one or more boilers and therefore the observed efficiency factor is either an indicator of the efficiency of one boiler, as for example in summer time, or an indicator of an average efficiency of two or more boilers, as in wintertime. Generally, it is necessary to have detailed information on energy efficiency of particular equipments, because an increase in energy efficiency is possible for specific equipment only.

Application of existing monitoring system is not sufficient to solve these problems and additional measurements were performed in the boiler house in the framework of this thesis. 3.2MW capacity boiler, used to supply the summer load was operating during the experiment.

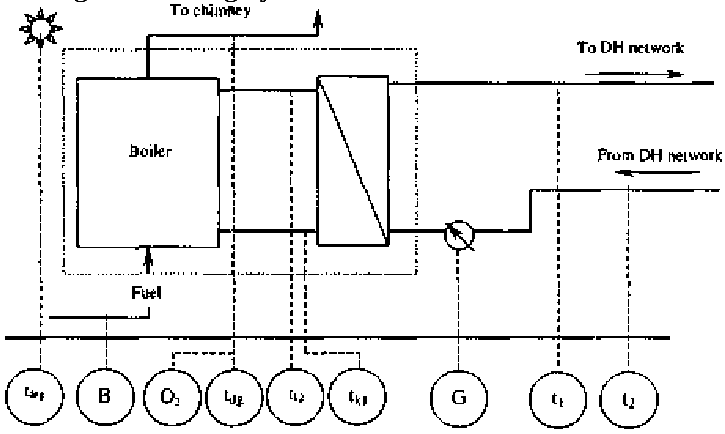

Fig.2.2. CO_2 emission monitoring experimental scheme

There were 35 hourly measurements taken in the period of time from July 11th to July 15th 2005 and 11 different parameters were identified and monitored (see Fig. 2.2.). Statistical data analysis and development of multifactor empiric model have been performed using STATGRAPHICSPlus computer program.

The following equation, which defines the changes of the efficiency, has been derived:

$$\eta = 1{,}048 - 0{,}0385 \cdot \alpha - 0{,}516 \cdot 10^{-3} \cdot t_g - 0{,}0247 \cdot 10^{-3} \cdot t_{k2} \qquad (2.2)$$

As a result of statistical data analysis R^2 value for the developed empiric model was 0.99. This means that the developed model (2.2) interprets 99% of efficiency factor variations of analysed regime.

During running of the regression analysis the verification on each stage has been implemented to check the accuracy of the performed step and to prove the ability to follow the next step. The result of the regression analysis - described in the empiric model linking efficiency factor in form of regression equation (2.2) - was evaluated. The performed analysis allowed concluding that:

- data regression analysis is proper method, because the dependent variables comply with normal distribution law;
- empiric model in form of regression equation (2.2) includes the main factors that determine efficiency factor. Its positive or negative values are logical and correspond to the physical explanation of the process;

- application of least-squares method for variable determination is proved. The variable values are not distorted because DW criterion is higher than limit value of 1.4;
- evaluation Of the coefficients of the regression equation is correct as there is no correlation observed between them;

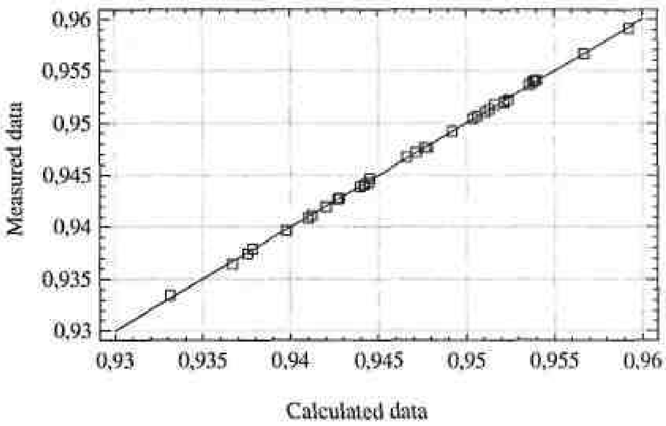

Fig.2.3. Empiric and calculated efficiency data comparison

- evaluation of the standard error is correctly estimated because residual distribution depending on dependent and independent variables is proportional.

Empirical and calculated data have been compared to validate the adequacy of the empirical model (see Fig. 2.3). Figure 2.3 shows a strong correlation between both sets of data. This implies that:

- the empiric model is applicable for calculation of efficiency factor, as well as for forecasting its changes;
- the equation is applicable for evaluation of the boiler operation regime.

Empirical equation (2.1) is a model for CO_2 emission calculation that has been derived during the thesis and correlates the parameters measured during monitoring, in particular: load Q_1, lower heat calorific value Q_z^d , and efficiency η.

The regression equation is valid in the following range:

- Efficiency η from 0.91 to 0.99;
- 24 hour heat energy output Q_1 from 30 to 350 MWh;
- Lower heat calorific value of natural gas Q_z^d from 33.54 to 33.67 MJ/m^3.

The changes of boiler efficiency have been studied during additional experiment. Regression equation (2.2) was obtained as the result of the experiment.

The regression equation in the observed energy source has the following validity range:

- Flue gas temperature t_g from 80 to 135°C;
- Air consumption ratio a from 1.16 to 1.26;
- Water output temperature of the boiler t_{k2} from 70 to 85°C.

2.2. CO_2 emission measurement uncertainty

According to the Monitoring and Reporting Guidelines an important element to consider during monitoring is the accuracy and precision of the collected data. Generally, the smaller is the uncertainty on the measured GHG emission data, the better it is. To achieve this requirement the participant of the EU ETS shall choose those control methods that include choice of measurement and calculation methods and choice of specific level (tier) for activity data, emission and oxidation factor definition. Choice of a specific level for equipment is defined based on its total CO_2 emission volume for one year period and using principle of volume size: the greater is the emission volume, the higher is the tier. This implies that equipment with greater emission volume is to be provided with higher tier of data acquisition and thus lower uncertainty level.

Data from the above observed boiler house have been used to define emission measurement uncertainty. As already above mentioned, the boiler house, participating in the EU ETS, has started its emission monitoring on January 1st, 2005. During the monitoring 24-hour natural gas and heat meter readings were registered and used in the further analysis. Monitoring methods of the 2nd or a higher tier are applicable for the company according to the claimed emission volume.

The main sources of uncertainty in the analysed installation calculated in this thesis were:

- measurements of natural gas consumption;
- changes of the lower heat calorific value;
- precision of the assessment of emission factor.

The following equation has been used to calculate the square of CO_2 emission standard uncertainty:

$$u_c^2(M) = \left(\frac{\partial M}{\partial B} u(B)\right)^2 + \left(\frac{\partial M}{\partial Q_z^d} u\left(Q_z^d\right)\right)^2 + \left(\frac{\partial M}{\partial R} u(R)\right)^2 \qquad (2.3)$$

where

$\frac{\partial M}{\partial B}; \frac{\partial M}{\partial Q_z^d}; \frac{\partial M}{\partial R}$ - sensitivity coefficient of a corresponding parameter d;

u(B); u(Q_z^d); u(R) - standard uncertainty of a corresponding parameter.

In the thesis $C0_2$ emission standard uncertainty was calculated for these levels of generated energy: 40, 200, 300 MWh/day. Evaluation of natural gas consumption, lower heat calorific value, and emission factor, as well as standard uncertainties, sensitivity coefficients, and the contribution indexes of values X_i in CO_2 emission uncertainty calculations are shown in Table 2.1.

Table 2.1. Parameters used in the uncertainty analysis and their characteristics

Value, X_i	Evaluation, x_i	Standard uncertainty, $u(x_i)$	Sensitivity coefficient, c_i	Standard uncertainty component, $u_i(y)$	Contribution index, %
Consumption of natural gas, m^3/h	185.1	1.74	0.045	0.078	98.7
Lower heat calorific value, TJ/milj.m^3	33.62	0.011	0.248	0.0027	0.1
Emission factor, tCO_2/TJ	56.1	0.058	0.149	0.0086	1.2
CO_2 emissions, tCO_2/day	8.43			0.0785	

As the data in Table 2.1 show, emission volume for the operational regime (40Wh/day) of the analysed company is 8.43+0.16 tCO_2.

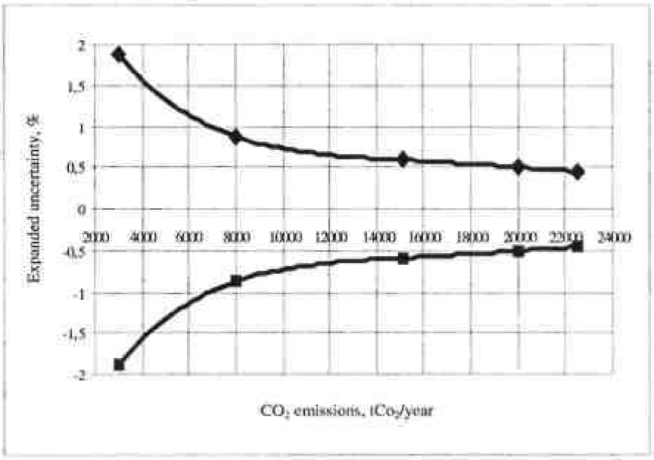

Fig.2.4. Expanded uncertainty versus yearly emission values of analysed company

The method examined in the thesi can also be applied for evaluation of the observed parameters in a period of month and year. Actual uncertainty can be determined by performing detailed daily (24 hours), monthly, and yearly company calculations of the boiler house operational regime using yearly monitoring data in similar way as previously described. However, it is a time- and labour-consuming process because the analysis and calculation of the performed regime is to be done in a course of year. A faster way to obtain uncertainty evaluation is to apply interpolation, using charts based on the calculation of the regimes. Relative value changes of calculated expanded uncertainty versus yearly emission values of the analysed company are graphically given in the Figure 2.4.

For example, if from monitoring results that CO_2 emissions of the company are 10000 tCO_2/year, expanded uncertainty in this case is ± 0.75%. According to the uncertainty reporting requirements yearly emissions have to be presented as a value and its expanded uncertainty that compiles with 95% probability area: 10000±75 tCO_2/per year. This expression means that company's produced emission volume for a year period is within 9925 tCO_2/year to 10075 tCO_2/year limit. The mentioned fact has a practical importance in emission trading. If a company receives permission to emit 10000 tCO_2/year and exceeds this value for less than 75 tCO_2/year, the company should not buy additional allowances. Also, in case of emission reduction to 9925 tCO_2/year, the company should not sell allowances.

3. Analysis of CO_2 tax in Latvia

3.1. Analysis of the existing CO_2 tax rate

Natural resource tax law defines that starting from the 1^{st} of July 2005 a fee of 0.1 LVL for each emitted tCO_2 shall be paid by all combustion installations, except those using peat or renewable energy sources and those that are involved in the EU ETS. CO_2 tax will increase to 0.3 LVL/tCO_2 after July the 1^{st}, 2008.

The idea behind CO_2 tax is to reduce the use of less environmentally friendly energy sources and to increase energy efficiency and the share of renewable and local energy sources (wood, straw and peat) thus reducing air pollution. CO_2 tax rates differ in every country and vary from 0.1 LVL/tCO_2 in Latvia to 50 LVL/tCO_2 in Switzerland.

For evaluating the effect of CO_2 tax, a study was performed on a particular energy installation, applying different tax levels. The installed capacity of the installation was below 20 MW - i.e. the company pays CO_2 emission tax only if it does not participate in ETS.

Generally speaking, an increase in CO_2 tax rate would make companies be more interested in the implementation of energy efficiency measures. On the other hand, it is clear that any energy efficiency measure requires investments. Hence, an analysis to estimate the optimum tax level in function of the capital investment needed for implementing energy efficiency measure is an interesting aspect to stimulates companies to reduce their environmental impact.

However, CO_2 tax is not the only companies' costs to include in the analysis; important parameters are fuel and operational costs, which have also been considered for a more objective evaluation on how companies' expenses could stimulate investments into energy efficiency measures. Installation with low efficiency emits more CO_2 because of higher fuel consumption. Fuel costs amount for almost 50% of total heat energy costs and are a very significant line in a company's budget. In this case variable costs are associated with CO_2 emission tax and fuel consumption for energy generation depending on equipment energy efficiency. Investment for increasing energy efficiency versus different CO_2 tax rates are shown in Figure 3.1.

As Figure 3.1 shows, fuel costs and CO_2 emission costs per ton at different tax rates depend on efficiency factor of an energy source. When energy efficiency of the equipment increases, fuel consumption and emitted CO_2 volume decrease. For example, at tax rate of 0.1 LVL/tCO_2 company costs for generation of 35000 MWh/year will decrease for approximately 6000 LVL/year, when efficiency factor rises from 0.72 to 0.9. The most considerable cost decrease of 8000 LVL/year would be if tax rate is increased at 0.5 LVL/tCO_2. Thereby a question rises whether the rate defined in the Natural resource tax law corresponds to the essence of the tax itself- to stimulate companies' interest in performing appropriate measures to reduce CO_2 emissions.

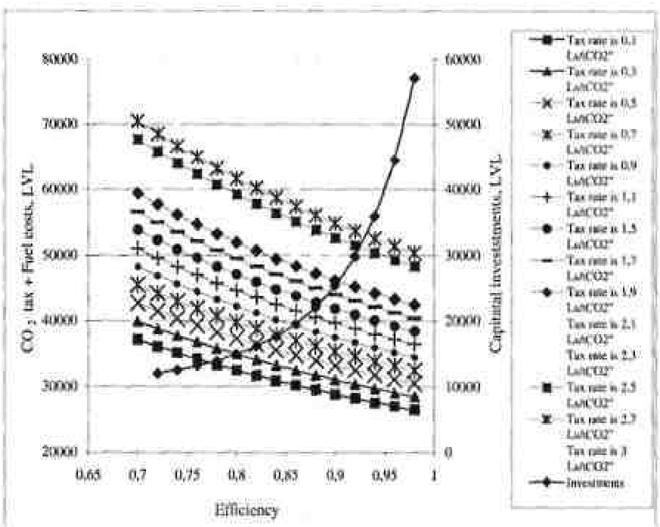

Fig.3.1. Investments for increasing energy efficiency versus different CO_2 tax rates

It is assumed in the analysis that at efficiency factor of 0.7, no energy efficiency measures are performed and there no investments and expenses related to equipment maintenance are necessary. Investment rate indicates that in order to reach higher efficiency factor of an energy source, the investments are much higher than tax reduction. As it is seen from Figure 3.1, investments increase by approximately 14000LVL when efficiency factor rose from 0.72 to 0.9. For these investments to be covered by CO_2 tax and reduction of total expenses related to fuel, tax rate is to vary between 2.5 and 3.0 LVL/tCO_2.

3.2. Optimisation of energy costs using economic instruments for CO_2 emission reduction

The objective of optimisation is to find the best set of parameters of an energy installation that would minimise the costs of energy generation along with the costs for implementing of $C0_2$ emission reduction measures.

In order to solve this problem the set of all significant variables and parameters has been identified.

Hence, company's energy costs for one-year period are evaluated as:

$$I_e = B \cdot Q_z^d \cdot R \cdot L_{CO_2} \cdot B + C_e \cdot W + T_f \cdot Q, Ls / year, \qquad (3.1)$$

where

L_{CO2} - CO_2 tax or price of allowances at the stock market, LVL/tCO_2;
C_k - fuel cost, LVL/t;
C_e - price of electricity, LVL/MWh$_e$;
W - consumption of electricity, MWh$_e$/year;
T_f - fixed part of the heat energy tariff, LVL/MWh.

In equation (3.1), which is used for observing company's operation costs in a certain period of time (e.g., in one year period), there are two values that are principally constant: fixed part of heat energy tariff T_f and defined generated energy volume Q. In the general case, when fuel quality and costs, electricity price and consumption volume, and fuel consumption are changing, equation (3.1) can be re-written in differential form as:

$$dl_e = Q_z^d \cdot R \cdot L_{CO_2} \cdot dB + B \cdot R \cdot L_{CO_2} \cdot dQ_z^d + BQ_z^d \cdot L_{CO_2} \cdot dR + BQ_z^d \cdot R \cdot dL_{CO_2}$$
$$+ C_k \cdot dB + B \cdot dC_k + C_e \cdot dW + W \cdot dC_e, Ls / year \qquad (3.2)$$

Now, in order to perform an optimisation analysis, it is important to identify the objective variable. The equation, which relates independent and dependent variables, is the objective function of the optimisation task. The minimum values of this function are the optimum criteria and parameters that secure the better operation under the selected boundary conditions.

The essence of the observed task can be defined as maximal reduction of generated energy costs as a result of implemented energy efficiency measures. This means that investments into energy efficiency measures and cost reduction are compared and the maximal difference between those values is searched. Mathematically it can be expressed as:

$$\Delta I_e(X_i) - \Phi_k(X_i) \to \max \qquad (3.3)$$

where

Φ_k - project investments, LVL/year;

X_i - independent variable parameters of the task;
ΔI_e - cost reduction, LVL/year.

Cost efficiency indicator is used for evaluation of investment influence. Using this variable the investments can be expressed as:

$$\Phi_k = \Delta M_x \cdot E_x, \text{ Ls/year,} \tag{3.4}$$

where

$E_x = \dfrac{\eta \cdot \Phi_k}{Q_1 \cdot R \cdot T}$ - efficiency, LVL/ tCO_2;

$\Delta M_x = CO_2^{'} - CO_2^{''}$ - CO_2 emission reduction, tCO_2/year,
where

$CO_2^{'}$ - CO_2 emissions before activity implementation, tCO_2/year;
$CO_2^{''}$ - CO_2 emissions after activity implementation, tCO_2/year.

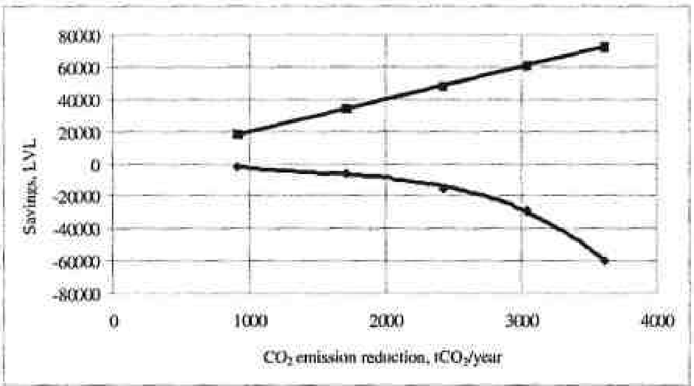

Fig.3.2. Income from CO_2 emission reduction and investments

Companies that participate in emission trading can express their benefits in economical terms. Generally, only the allowances (tCO_2) reduced as a result of energy efficiency activities can be considered as asset. Existing emission level can be paid off with the allocated allowances. In case of energy efficiency reduction, additional allowances have to be purchased. Allowance prices are market-determined. Even though the market is in the development stage, the price offered is currently approximately 20 LVL/tCO_2.

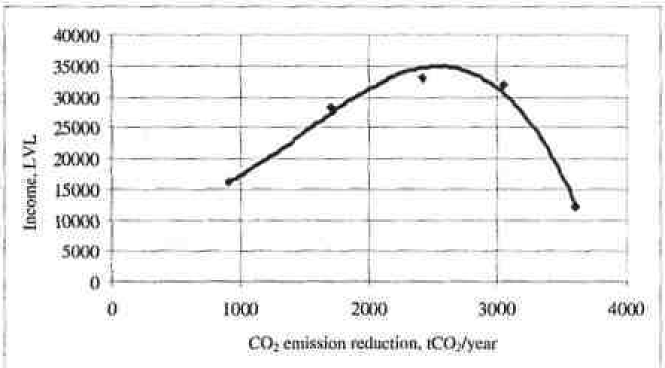

Fig.3.3. Income from selling CO_2 emission reduction in EU ETS

The example in Figure 3.2 shows the

reduction of energy costs derived from the income from emission trading. If the allowances can be sold at the price of 20 LVL/tCO_2, the income is described with the line above the X-axis. The lower line reflects the investment needed. Fluctuation of objective function is showed in Figure 3.3.

Figure 3.3 shows the resulting benefits. Benefit fluctuations are described by a curve with explicit optimum at emission reduction of 2500 tCO_2/year. It is clear that a company participating in emission trading with the correct emission allowance price would be able to cover project expenses with a profit margin.

The question about fluctuation of the objective function optimum as a result of allowance price fluctuation is still vital. This information would let to evaluate company risks that appear as a result of allowance prices fluctuation at the stock market. Figure 3.4 reflects fluctuations objective function optimum as a result of allowance price fluctuation. The lowest curve stands for allowance price of 15 LVL/tCO_2, the middle one - for 20 LVL/tCO_2, and the top one - for 25 LVL/tCO_2. When the price for allowance rises, the optimum of the objective function moves ahead, towards the highest CO_2 emission reduction.

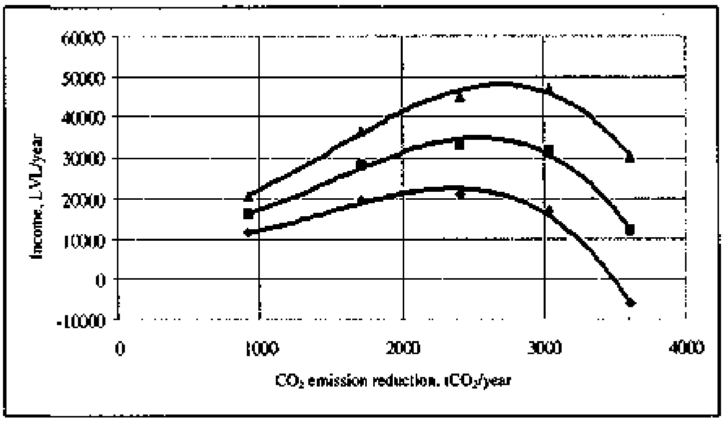

Fig.3.4. Income of the company in case of emission allowance price fluctuation

The results obtained in the framework of this PhD study, indicate that a company can either have losses or benefit applying economic tools of environment protection. Company losses are clearly observed when applying CO_2 tax; additional benefits are observed when participating in emission trading. The observed cases essentially differ in reduced tCO_2 cost. In the first case the cost is 0.1...0.3 LVL/tCO_2, in the second - 15...25 LVL/tCO_2. This implies that there is an existing limit value in case of which a company does neither take loss nor benefit when implementing a project. This value is the CO_2 tax value, because as it can be seen in the current situation in allowance trade system, allowance price is higher than the limit value.

4. Estimation of emission benchmarks for next ETS periods

Benchmark method has been declared as one of the best emission allowance calculation methods, as it allows comparing characteristics of similar companies in different countries with standards or BAT as well as promotes companies with higher emission levels to implement energy efficiency measures to reach the appropriate benchmark. The main disadvantage of the method is the need of precise statistical data. In the thesis emission benchmarks for district heating boiler houses participating in EU ETS were calculated. Following, the activity data of 35 boiler houses were used for the analysis:

- Fuel consumption, t/year or thous.mVyear in case of natural gas;
- Amount of heat energy produced, MWh/year;
- Efficiency.

The capacity of the investigated boiler houses varied between 2.8 MW to 144.9 MW. Only data from 2005 have been monitored and approved by authorised verifier and therefore can be considered more reliable, however data from 2000 have been included in the analysis too. For the estimation of the benchmarks the following parameters have been taken into account:

- activity data (tCO_2 / ...):
  - input energy (tons or m^3 fuel; MWh fuel);
  - installed capacity (MW);
  - output energy (MWh):
    - MWh electricity;
    - MWh heat;
    - MWh electricity and heat (cogeneration cycle);
- fuel-dependent or fuel-independent benchmarks.

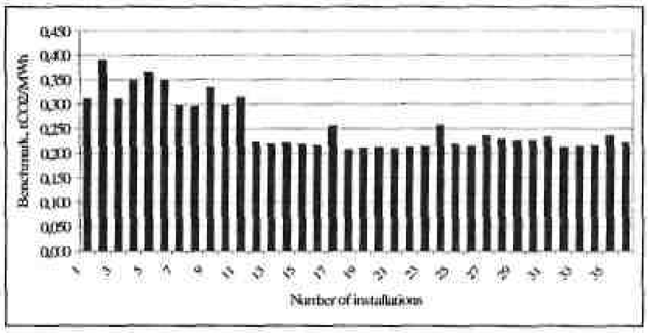

Fig.4.1. Different benchmarks of installations

The following analysis is addressed to boiler houses supplying heat energy to district heating systems. Therefore CHP plants and boiler houses for industrial process heat are excluded from the analysis. In the thesis benchmarks based on the output energy have been chosen and calculated for all the boiler houses, except wood-based fuel boiler houses. Detailed description of the obtained results is given in the thesis and summarised benchmarks of 2005 for different fuels are shown in Figure 4.1.

Based on the performed analysis, two main alternatives with sub-alternatives have been developed:

1. Fuel dependent emission benchmarks:

   1.1. Average benchmark for each fuel:

   - Heavy fuel oil - 0.345 tCO_2/MWh;
   - Diesel oil-0.314 tCO_2/MWh;
   - Natural gas - 0.223 tCO_2/MWh;
   - Wood - 0 tCO_2/MWh;

   1.2. Lowest existing benchmarks for each fuel:

   - Heavy fuel oil - 0.311 tCO_2/MWh;
   - Diesel oil - 0.295 tCO_2/MWh;
   - Natural gas - 0.208 tCO_2/MWh;
   - Wood - 0 tCO_2/MWh.

2. Fuel independent emission benchmarks:

   2.1. Average existing benchmark of all the fuels - 0.254 tCO_2/MWh.

   2.2. Lowest existing benchmark of all the fuels - 0.208 tCO_2/MWh.

To evaluate the alternatives above proposed, simple calculation and analysis have been performed and described in the thesis. Six different boiler houses were chosen and the results are summarized in Figure 4.2 and 4.3

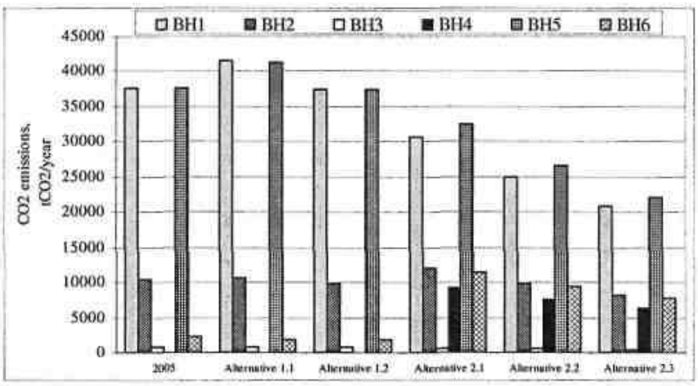

Fig.4.2. CO_2 emissions calculated based on existing methodology (2005) and proposed benchmark methodology (alternatives); BH1 (HFO); BH2 (natural gas); BH3 (diesel oil); BH4 (wood); BH5 (HFO+diesel oil+natural gas); BH6 (natural gas+wood)

Figure 4.2 shows calculated emission benchmarks for each boiler house using existing calculation method (2005) and benchmark alternatives described above. Figure 4.3 illustrates the difference between emissions calculated with existing methodology and proposed benchmark methodology.

The , positive values in Figure 4.3 mean that this specific boiler house, using chosen benchmark alternative, has less CO_2 emissions compared with existing 2005 emissions, and vice versus. For example in case of BH 4, fuel with wood resources only alternatives 2.1 to 2.3 are giving positive values as for alternatives 1.1 and 1.2 emissions are the same as in 2005. As Figure 4.3 shows, the worst data are for BH3 (fuelled with diesel oil); when using any proposed benchmark alternative it has only negative values which means that this boiler house will have to reduce their emissions.

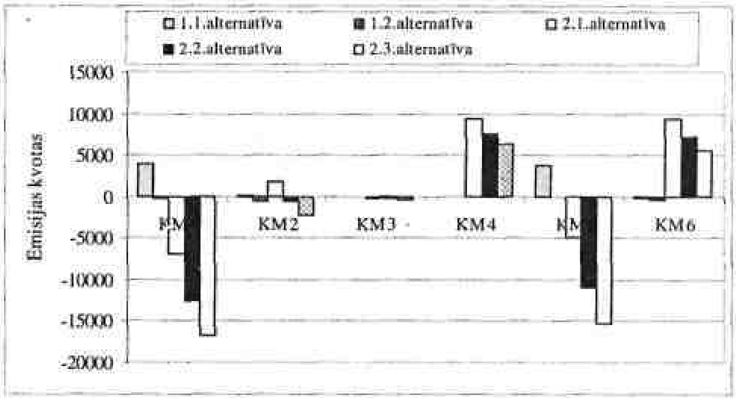

Fig.4.3. Difference between emissions in 2005 and benchmark alternatives

Evaluation of the benchmark alternatives have indicated that:

- The worst characteristics of boiler houses are in case of applying fuel dependent average benchmarks (alternative 1.2).
- If benchmark methodology will be chosen as basic methodology for calculation of emission allowances, applying any of fuel independent benchmarks (alternatives 2.1-2.3) will promote use of renewable energy.
- As the share of natural gas boiler house in energy balance is high, application of average existing fuel independent benchmark (excluding wood) - 0.254 tCO_2/MWh (alternative 2.1) would not encourage implementation of energy efficiency measures and reaching better characteristics (0.208 tCO_2/MWh).
- Though alternative 2.3 - when fuel independent benchmarks (including wood) - 0.173 tCO_2/MWh is applied, would give the most environmental benefits, it will have high financial and social impacts that have to be still analysed more in detail.
- Based on analysis performed fuel independent benchmark based on lowest existing characteristics (alternative 2.2 - 0.208 tCO_2/MWh) would be the most appropriate.

Conclusions

1. Analysis of four different schemes for allocation of emission allowance has been performed, including the assessment of their advantages and disadvantages. Based on these results, methodology for calculation and allocation of emission allowances for ETS participants have been developed. The proposed methodology includes:

    - algorithm for choosing the base year according climatic data and energy generation output;
    - analysis of possibilities to reduce CO_2 emissions in district heating companies and to allocate additional allowances as function of implemented environmental measurements.

    Furthermore, the methodology foresees the allocation of emission allowances for new installations (reserve) starting operation between 2005 and 2007.
    The methodology has been approved by the European Commission and used for development of Latvian National Allocation Plan 2005-2007.

2. Based on one-year CO_2 emission monitoring data, collected in a district heating installation, the methodology for performing statistical analysis on empirical data of boiler operation (based on the results to derive equations for CO_2 emission calculation) has been developed and verified. Physical interpretation of the describing processes of the equation has been implemented and the fluctuations of the parameters included in equation have been justified. The methodology can be used by companies to forecast their CO_2 emissions that depend from the amount of energy produced and energy efficiency measurements implemented.

3. Methodology for assessment of uncertainty of CO_2 emission monitoring of district heating companies using natural gas has been developed and practically verified, in particular the examination of the sources of the uncertainty, the analysis and estimation of type of uncertainty, the evaluation of the uncertainty budget of CO_2 emissions and the assessment of contribution of different parameters in the total uncertainty. To reduce the uncertainty of CO_2 emissions a special attention has to be paid to natural gas consumption, as the analysis of uncertainty budget show that measurements of natural gas consumption give the greatest uncertainty contribution (79-98%). Contribution of emission factor and lowest calorific value is in the range of 1.2-19.3% and 0.1-1.9% respectively. Based on the yearly emission values of the analysed company, graphical illustrations are presented for calculation of expanded uncertainty. It is proposed to withdraw from buying and selling allowances that fit in the interval of the expanded uncertainty.

4. Analysis of the influence of CO_2 taxes on a company CO_2 emission reduction measurement costs have been performed. Results show that existing CO_2 tax rate (0.1 LVL/tCO_2) is inefficient and does not promote companies to implement energy efficiency measurements or fuel switch projects. The analysis indicated that the situation could change if the tax rate is at least in the range between 2.5-3.0 LVL/tCO_2. At such rate the payback of energy efficiency measurements is positive.
5. Optimisation task for CO_2 emission reduction measurements have been formulated and solved. The objective of the optimisation task was to determine the parameters of an energy installation that would ensure the greatest cost reduction of energy produced with the smallest capital investments. Equation system of objective function has been defined. Regression equations derived from monitoring of the installation have been included. The optimisation model estimate the optimum between CO_2 emission reductions, investments needed, emission allowances with derivations in the price and CO_2 tax rates. The analysis of the objective function shows that in case of an increase of price of the allowances in the market, the optimum moves to higher CO_2 emission reduction. The minimum value of the price of emission allowance (rate of CO_2 tax) has been estimated, by which CO_2 emission reduction measurements can pay off. The optimisation methodology has been approbated for one energy installation, where energy efficiency measurements have been implemented.
6. Methodology for calculation of emission benchmarks for district heating companies has been proposed. Algorithm for classification of companies in homogenous groups and for calculation of emission benchmarks has been developed. For the calculation of emission benchmarks, data of 35 district heating companies participating in the next EU ETS period have been collected and used. Additionally monitoring data of 2005 have been exploited. Highest and lowest emission benchmarks for different fuels have been calculated accordingly:

   - Natural gas 0.258 tCO_2/MWh and 0.208 tCO_2/MWh;
   - Diesel oil 0.348 tCO_2/MWh and 0.295 tCO_2/MWh;
   - Heavy fuel oil 0.39 tCO_2/MWh and 0.311 tCO_2/MWh.

   Different alternatives of benchmarks have been proposed (highest, lowest, average, fuel dependent and fuel independent), applied and calculated in case of different district heating companies using diverse fuels. To promote companies to reduce CO_2 emissions, fuel independent emission benchmark has to be applied for all types of fuels. That would support as well as wider use of renewable energy sources.