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DEVELOPMENT AND STUDY OF SCENARIOS FOR ENERGY SECTOR IN LATVIA CONSIDERING THE ENVIRONMENTAL FACTOR

Summary of Thesis
of Scientific Degree of the Doctor Engineering Sciences (Dr.Sc.Ing.)

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Content

EXECUTIVE SUMMARY

Topicality of the goal

Since 1990 the energy consumption in Latvia reduced considerably; now it is stabilising and even demonstrating growth trends during the recent couple of years. The situation with emissions is similar, consequently, the further development of energy sector and related compliance with environment quality preservation requirements, as well as limitation and reduction of environment polluting emissions is a topical issue both on global as well as domestic scale.

With the purpose to resolve the said environmental issues, Latvia has passed a number of legal acts and has undertaken the commitment to comply with international requirements in the area of mitigating global climatic changes, by signing in 1992 Rio dc Janeiro "UN Framework Convention on Climate Change", ratified by Saeima of the Republic of Latvia in 1995, and in 1998 Kyoto protocol, ratified by Saeima on May 30, 2002. Thus, Latvia has committed itself individually or jointly, to ensure that its aggregate anthropogenic GHG emissions (CO2, CH4, N2O, HFC, PFC and SF6)[1] in years 2008-2012 are 8% below the level of 1990. Limitation of cross-border air pollution is a priority of Latvian environmental policy. Latvia has joined the UN ECE convention "on Long-Range Transboundary Air Pollution" and the protocols. In order to comply with the requirements, Latvia is monitoring the air pollution and is implementing the pollution prevention measures by reducing the emissions of the main air pollutants (SO2, NOx, CO, volatile organic compounds - VOC, heavy metals). Cabinet has set the admissible SO2, NOx, VOC, NH3 emission volumes starting with 2010 by its Regulation No.507 of 2003 "Regulations on maximum admissible emissions".

Environmental quality can be improved via specific measures which tend to be extremely costly, or via introduction of modem technologies in the energy sector itself, since it is one of the key polluters. In order to say "when" and "what" activities have to be implemented or technologies introduced in order to attain the most rapid economic development, a long-term development optimisation is necessary taking into account the environmental factor, because the development of energy sector is a long-term exercise. Finding the optimal long-term development strategy, determined by minimal total costs, simultaneously the measures to be taken and the technologies to be introduced are defined for each time period of the entire planning horizon taking into consideration the admissible emission levels. These measures and technologies assure a balanced and sustainable development, resulting in an optimal economic effect. Such optimisation would require the processing of large volumes of information, and the development of economic and mathematic tools.

Goals and tasks of the study

The objective of the study is to develop and to study the energy sector planning and development optimal strategies (potential development scenarios), considering the environmental factor, with the purpose to make them usable for constructive decision making in the area of energy sector and environmental issues.

In order to attain this objective, a task was set to build analysis tools for energy sector and environmental systems, that would be based on the Latvian energy sector structure, on potential future technologies and the possibilities to reduce emissions, as well as to draft the energy sector development scenarios, considering:

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[1] Carbon dioxide, methane, nitrous oxide, hydro fluorocarbons, per fluorocarbons, sulphur hex fluoride

- The environmental factor - limitation of NOx, SO2, VOC, GHG emissions;
- A more extensive use of renewable and local resources - a higher RES-E[2] share in gross national electricity consumption; a more extensive use of wood in district heating (DH);
- The possibility to reduce emissions by implementing energy saving measures;
- Reliability of electricity supply - import of electricity;
- The potential of regional market development - electricity and emissions market;
- Uncertainty of the emission reduction targets.

Research methods and tools

In order to develop and study the energy sector development scenarios, the below listed methods and approaches have been employed:

- Energy balance;
- Mathematical statistics methodology (regression analysis for energy consumption, energy resource and technology input data processing and evaluation);
- Useful energy consumption in relation to the macroeconomic indicator forecasts;
- Reference energy system (Latvian energy sector and environmental system target function and constraints);
- System analysis (energy sector and environmental system form a multifactor variable system);
- Simplex mathematic optimisation method for linear programming problem (the software is in GAMS programming language, and simplex algorithm has been used in search of optimal solution);
- Sensitivity analysis (base scenario has been developed; sets of scenarios have been created; scenarios have been compared);
- Stochastic analysis according to the Laplace Criterion (taking into account the future uncertainty of an event);
- Integration of the model database into the regional models (analysing the Baltic region energy and emissions trading effects, the models of several economies have been linked together).

Scientific novelty

The scientific innovation of the study is related to specific environmental strategy issues that might arise in further development of Latvian energy sector. In order to analyse the issues, a MARKAL model was used that has been adapted and modified for the Latvian situation. The model may be applied to resolve a wide range of issues, which is critical in order to define the policy of Latvia in the area of energy sector and environment, and may be applied for decision making on any level. The results obtained have been used in the Latvian environmental policies and energy sector development papers drafted by public institutions.

Practical application of the research results

Energy sector and environmental system analysis model MARKAL has been applied in a number of studies (in collaboration with different institutions), and individual results have been approbated when drafting various political documents.

- "The study of terms and conditions for national strategy and strategy drafting for the utilisation of biomass and other renewable energy in Latvian local government DH systems" (2004, in collaboration with "Vides projekti").

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[2] Renewable Energy Source - Electricity

- Evaluation of the activities in the area of reduction of national emissions in the energy sector for the period till 2010. Within the framework of activity programme "Reduction of national aggregate emissions" (2003, in collaboration with Environmental Ministry of the Republic of Latvia).
- Modelling and study of RES-E support schemes (2003, in collaboration with Ministry of Economy)
- Reliability and economic evaluation of Latvian electricity supply for the period till 2006 (2001, in collaboration with Ministry of Economy of the Republic of Latvia).
- In years 1998 and 2001, applying the model, energy consumption forecasts have been complied for the purposes of the Second and Third Latvian National Communication, within the framework of UN convention on climate change (in collaboration with Environmental Ministry of the Republic of Latvia).
- Trading of emission quotas between the Nordic and Baltic countries (in collaboration with Tallinn Technical University and Institutt for Energiteknikk).
- Evaluation of CO2 emission reduction potential by implementing energy efficiency measures in buildings via applying energy system optimisation model MARKAL (2000, in collaboration with Construction Department of Ministry of Economy).
- Latvian energy sector economic evaluation in the context of climate changes (2000, in collaboration with International Resources Group, Ltd, and Environmental Ministry of the Republic of Latvia).
- For the purposes of the study "Assessment of policies and measures in energy and forestry sectors), energy sector development scenarios were drafted (1998, in collaboration with Environmental Ministry of the Republic of Latvia).
- CO2emissions in Latvia (1998, in collaboration with Institutt for Energiteknikk).
- SOx emission forecast for Latvia till 2010 (1996, in collaboration with Environmental Ministry of the Republic of Latvia).

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The structure of the thesis

The thesis consists of introduction, four chapters and conclusions. For the sake of convenience, the description of the mathematical model is presented in the appendix. Chapter one presents an evaluation of different approaches and tools that may be used in decision making for optimal development of energy sector and environmental system. Chapter two contains an account on the present situation in the Latvian energy sector, together with the correlation with economic development. Chapter three, on the basis of the present energy sector structure technical and economic analysis and future prospects, describes the developed MARKAL model for Latvian energy sector and environmental system analysis. Chapter four presents development scenarios for solutions of problems (constraints).

1 Energy sector and environmental system analysis

Background

The study presents the description of the existing energy sector and environmental system models. Models can be grouped according to their purpose, structure and external assumptions, modelling methodology and other features. Economic development is in the core of economic models, while the energy system makes the core of energy sector models. Both model types deal with technology and technological progress, while energy system models give much more detailed description of the technology and technological progress.

Using energy sector and environmental system models, one can find answers to the below listed or similar questions:

- How do we develop the energy sector in order to ensure secure and cost-efficient energy supply?
- What emission volumes do we expect if a new environmental legislation comes into effect?
- What measures are to be taken in order to comply with environmental regulations? What effect will they have on the energy supply structure? And what will be the costs of emission reduction?
- To what degree do the strategies and their costs depend on assumptions (energy price, economic growth rate, energy demand etc.)

MARKAL model is commonly used worldwide for the purposes of energy sector and environmental systems studies. It has been created and is elaborated as a result of international collaboration: this is a major advantage if compared with models that have been developed by a single institution. MARKAL has been applied for by IEA and EIA (USA) in their most recent outlooks on global energy consumption scenarios for the future.

The model applied

Energy sector and environmental system model MARKAL has been selected as the most appropriate one for the purposes of the study. The model has been adapted for the Latvian energy sector and environmental system - for the analysis of energy supplies and consumption.

Specific energy and emission technologies that have been quantified with technical and economic specifications lie in the core of MARKAL. The technologies of today and of future serve as the input data for the model. Both the supply and the consumption sides are integrated in the model; a change on one side will cause a response on the opposite side. The model will select a combination of technologies, minimising the total discounted system cost. MARKAL will search for the solution by:

- Calculating the costs of each individual technology during its full life cycle, including environmental costs;
- Identifying and rating technologies according to their effect on total system costs;
- Checking whether all limitations have been observed;
- Specifying the best time for launching the activities, in order to comply with all limitations in the future;
- Monitoring, on a continuous basis, whether the selected technologies still remain the top ones.

The model uses reference energy system concept, which means linking together energy demand, resources, technologies and marketable commodities (energy carriers, emissions). The flow of energy carriers via the reference energy system has been presented in Figure 1.

A variety of energy supplies, processes and consumption technologies compete between themselves in the end consumer energy market, in order to meet the useful energy demand. MARKAL would select the optimal energy system structure for each given period, minimising costs and considering various limitations.

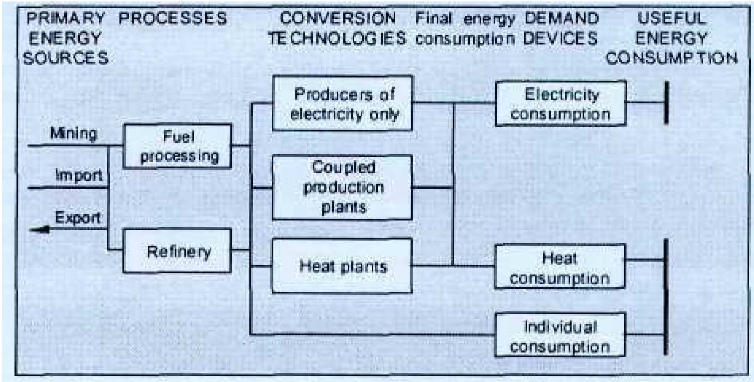

Figure 1: Energy flows in MARKAL

The main elements of MARKAL

MARKAL model structure has been formulated by variables, equalities and inequalities that arc defined by the input parameters. The entirety of this information is a mathematical presentation of reference energy system. An optimization problem formulation consists of three sets of entities: *decision variables* (unknowns), *objective function* (expressing the quantity to minimize or maximize), and *constraints* (equations or inequalities that must be satisfied).

Objective function of MARKAL minimize discounted sum over all time periods *t*, all regions *r*, all technologies *k*, all pollutants *p*, and all input fuels *f* of the various costs incurred, minus revenue from exported energy carriers, plus taxes on emissions. Mathematically, the expression to be minimized is as follows:

$$\sum_t \left[\left(\begin{aligned} & Invcost(k,t,r) * INV(k,t,r) + \\ & + Fixom(k,t,r) * CAP(k,t,r) + \\ & + Varom(k,t,r) * \sum_s ACT(k,t,r,s) + \\ & + Delivcost(f,k,t,r) * Input(f,k,t,r) * \sum_s ACT(k,t,r,s) + \\ & + Miningcost(c,r,l,t) * Mining(c,r,l,t) + \\ & + Tradecost(c,r,t) * TRADE(c,r,r',t) + \\ & + Importprice(c,r,l,t) * Import(c,r,l,t) - \\ & - Exportprice(c,r,l,t) * Export(c,r,l,t) + \\ & + Tax(p,t,r) * ENV(p,t,r) \end{aligned} \right) \Bigg/ (1+d)^{(t-1)*5} \right] \qquad 1\text{-}1$$

where:

lnvcost(k,t,r), Fixom(k,t,r), Varom(k,t,r) - unit costs of investment, fixed maintenance, and operation, of technology *k,* in region *r,* in time period *t*;
Delivcost(f,k,l,r) - the delivery cost per unit of fuel/to technology *k;*
lnput(f,k,t,r) - the amount of fuel *f* required to operate one unit of technology *k;*
Miningcost(c,r,l,t) - the cost of mining commodity *c* in the price level *l*;
Tradecost(c,r,t) - the trade transport or transaction cost for commodity *c* in region *r* and time period *t*;
lmportprice(c,r,l,t), Exportpricefc, r, l, t) - the (exogenous) import or export price of commodity *c*;
Tax(p,t,r) - the tax on pollutant *p*;
d - discount rate.

The decision variables represent individual choices made by the model:

lNV(k,t,r) - new capacity addition for technology *k*, at period *t*, in region *r*. Investment in new capacity is assumed to occur at beginning of period *t*, as a lump investment;

CAP(k.t.r) - installed capacity of technology *k*, at period *t*, in region r;

ACT(k,t,r,s) - activity level of technology *k*, time period *t*, in region *r*, during time-slice s;

TRADE(c,t,r,r') - quantity of commodity *c* sold by region *r* to region *r'* at time period *t*. This variable represents endogenous trade between regions;

IMPORT(c,t,r,l). *EXPORT(c,t,r,l)* - quantity of commodity *c*, price level *l*, imported or exported by region *r* at time period *t;*

MINING(c,t,r,l) - quantity of commodity *c* mined in region *r* at price level *l* at time period *t;*

ENV(p,t,r) - emission of pollutant p at period *t* in region *r*.

The constraints translate the rules governing the nature of the energy system and the operation of the individual technologies, for example, satisfaction of demands, capacity transfer, use of capacity, energy balance, electricity (and heat) peak reserve constraint, emission constraint, user-defined constraints. If even one limitation has been ignored, there is no solution for the problem.

2 Energy sector and environment in Latvia

National policy in the energy sector is focusing on promoting the competition, increasing the security of energy supply, promoting the use of renewable and local energy sources, and on environmental protection. The main objective is to promote the development of the energy sector according to a balanced and sustainable growth of the national economy.

In Latvian energy sector both the domestic (wood, peat, hydro) as well as imported (oil products, natural gas, coal) energy resources are used. The structure of primary energy supply (PES) has undergone a dramatic change (see Figure 2). Fuel oil and coal, commonly used at the beginning of 90-ies, have been replaced by gas and wood.

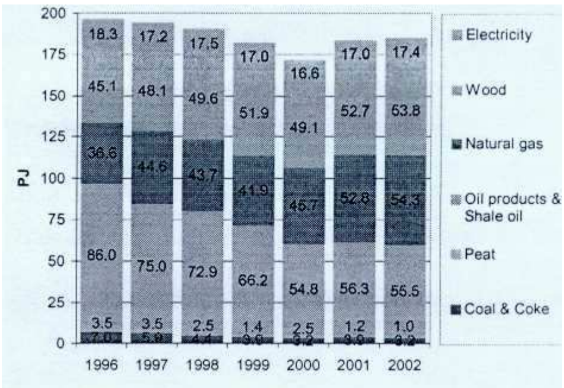

Figure 2: PES structure in 1996-2002, PJ

Power plants in Latvia meet about 65%[3] of gross national electricity consumption - hydroelectric power plants (HPP) about 43.4%, co-generation plants (CHP) about 19.3%, distributed power generation about 1.9%, whereas 35.4% is imported. Between 1996 and 2002, with the decreasing demand in DH, in the boiler houses and CHP plants the weight of consumption of natural gas has changed from 29% to 69%, oil products from 53% to 9%, wood from 10% to 21%.

In final energy consumption (FEC) is domineered by oil products (one-third), to be followed by wood, DH, electricity, natural gas, coal and peat. The main changes in the FEC are the decreasing share of DH and the increasing share of wood.

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[3] in average between 1990 and 2002

The key RES arc wood and hydro resources; wind energy and biogas is used as well. The RES share in the PES has increased from 16% (1996) to 34% (2002). RES is occupying a much more visible share in electricity generation. The contribution of decentralised RES-E is negligible - a mere 0.7% in 2002.

To set the desirable energy sector development trends, the following has to taken into consideration:

- About 70% of energy resources are imported, which makes the national energy supplies insecure, and has an adverse effect on the national balance of payments
- Natural gas is the main fuel for the large industrial or DH boiler houses, and also CHP plants. However, the natural gas supplies come from only one region;
- Wood occupies a significant position in the PES, yet, it should be used in a much more efficient way;
- Right now peat and coal occupy a marginal role, yet, they have a huge potential for use in medium size and large conversion plants, thus diversifying the PES;
- Analysing the energy consumption during the recent couple of years, one can arrive to a conclusion that within the next 5 years we do not expect a significant increase. The increase in consumption will be offset by energy efficiency measures. A notable increase in consumption may not be expected unless large-scale industrial projects arc launched;
- Electricity import prices actually reflect only the current running costs. This is a constraint when decisions about building large power plants are being made;
- A phase-out of Ignalina nuclear power plant is planned. Narva oil shale power plants need substantial investment in renovation. The development prospects for the Russian energy sector do not give any reason to hope for cheap electricity import. Byelorussia does not have any excess capacities - it is even importing electricity from Lithuania. Nor does Latvia have a common grid with Baltic Sea region countries.
- Distributed power generation might contribute to increasing the security of supplies. In 1994 its share in gross national electricity supply was a mere 0.6%, whereas in 2002 it was already 4.9%.
- Electricity generation applying CHP technology is suitable for the thermal energy load, dictated by the Latvian climatic conditions.
- The use of RES for energy generation in most cases would be less cost efficient and still non-competitive in the market if compared with the conventional fossils, yet, the use RES increases the security of energy supply, diversifies the PES, solves social and economic problems, and reduces GHG emissions.

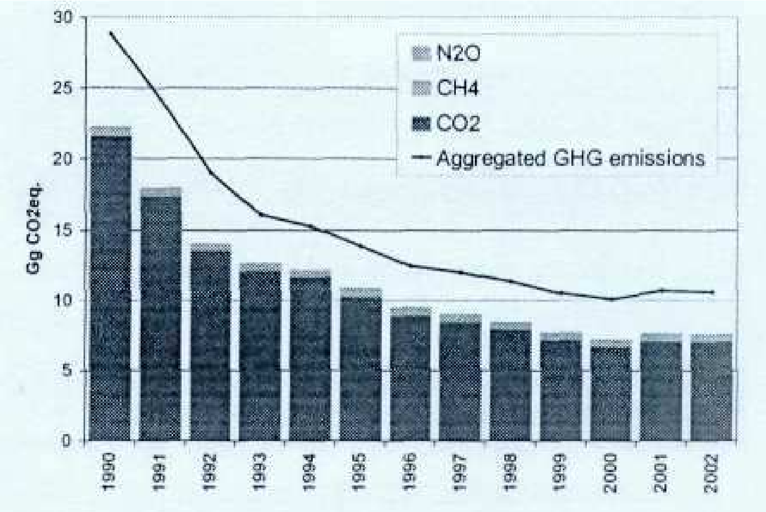

Figure 3: Aggregate GHG emissions in Latvia and GHG emissions in energy sector, CO2eq.Gg

The aggregate and energy sector GHG CO2-equivaIent emissions are presented in Figure 3. Since 1990 the decrease is by 63%, and by 66% from the energy sector. The emission breakdown from energy sector is as follows: CO2 (92%), followed by CH4 (6%) and N2O (2%). The aggregate amount of NOx and SO2 emissions mainly come from the energy sector (98%-99%), while in VOC emissions it contributes 66%.

Irrespective of the reduced emissions, in order to attain a sustainable growth, it is critical to restrict the use of fossil energy resources and develop a respective energy and emission limitation strategy. When selecting the development strategy, the issue what emission amount should be retained, or to what extent it should be reduced, is becoming increasingly topical.

3 MARKAL for Latvia and overall assumptions for the scenarios

The preparation of the model for the needs of analysing energy sector and environmental system is an important and time-consuming exercise, because the model has to present the energy sector with its elements on a sufficiently detailed level, employing a variety of technical and economic parameters for describing technologies and energy sources - technology investment and running costs, technology technical and environmental specifications, fuel price and delivery costs etc. The prices of primary energy carriers are an important element of energy consumption and supply.

The Latvian model comprises about 7500 variables; while solving the stochastic problem, the number increases considerably. The database of the Latvian model includes the areas where energy resources are used:

- Energy supply, transformation and processing into another type of energy electricity, DH, bio fuel manufacturing etc.;
- Final energy consumers - residential, services, industry, agricultural and transport sectors;
- Various energy sources, energy carriers and technologies.

In addition, the Latvian model has a number of other possibilities, allowing the modelling of:

- RES-E objective;
- Direct and indirect GHG emission limitations and taxes;
- Excise tax on energy resources etc.

Analysis are based on a base scenario, which contains a number of assumptions on macrocconomic development (Figure 4), changes in the number of population, the prices of energy resources, the government policy for energy sector and environmental protection, available technologies and their costs. It is assumed that the energy resource price curves are steadily growing, yet, it docs not mean they are interpreted as a stable price forecast: rather, they arc long-term curves round which the prices would fluctuate.

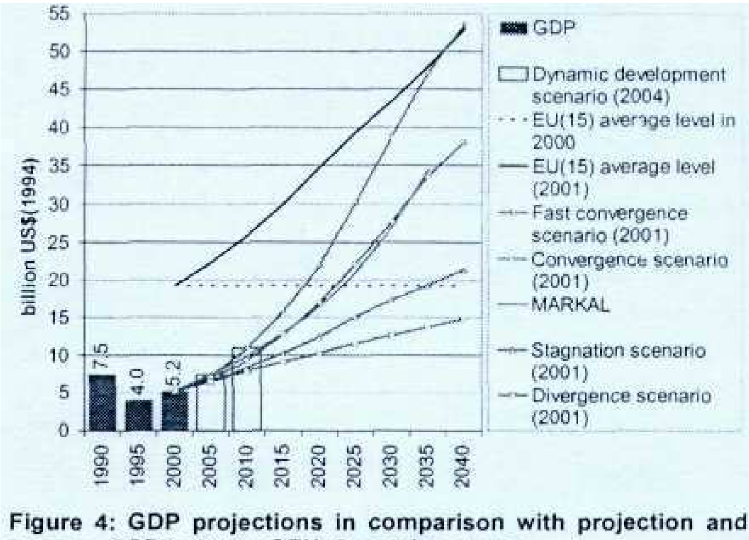

Figure 4: GDP projections in comparison with projection and average GDP in 2000 of EU15 member states

The Latvian MARKAL model simultaneously optimises the entire energy sector for nine 5-year periods. The first period centred to 1994 (the model base year) and covers the years between 1992 and 1996. The last period is centred to 2034. The first period is past, where the variables are calibrated according to their historical values (e.g. technology capacity and its utilisation, energy resource production, import and export). Calibrating the first period is one of the most important tasks when building MARKAL database, since it may have an effect on the model decisions for the future periods.

It is important to make the sectoral useful energy demand forecast, that would be in line with the national macroeconomic growth forecast. Energy demand forecast is made uncertain by the fact that the structural changes in national economy are still in progress; also, the ever increasing effect of high-tech on energy demand. For the purposes of the study the useful energy demand growth forecast is based on the long-term macroeconomic forecast for the years 2000-2035 with average GDP growth rate 5.6% for the years 1999-2014. The Table 1 demonstrates the aggregate useful energy demand growth rates for the sectors covered by MARKAL as well as other parameters.

Table 1: Macroeconomic forecast for base scenario

	1999	2004	2009	2014	2019	2024	2029	2034
Annual growth rate of GDP, %	3,7	5,7	5,2	5,8	5,5	5,1	4,7	4,3
Annual growth rate of useful energy demand, %	-5,9	1,4	1,5	1,7	1,7	1,5	1,5	1,5
Agriculture	-17,3	0,8	1,2	1,8	1,6	1,4	1,3	1,1
Services	-10,1	1,9	2,2	2,5	2,3	2,1	1,9	1,7
Residential	-3,8	0,3	0,4	0,5	0,6	0,8	1,0	1,2
Industry	-3,6	2,3	1,8	2,0	1,8	1,6	1,4	1,3
Transport	-0,5	1,8	2,6	2,6	2,7	2,1	1,9	1,9
Elasticity (% consumption growth / % GDP growth)	-1,59	0,25	0,28	0,30	0,30	0,30	0,31	0,34

The model uses the 1994 US$ as the currency[4].

4 Issue analysis

4.1 Reduction of emissions in the energy sector

The study deals with the situation in the energy sector, considering the requirements stipulated by air protection legislation regarding the sulphur contents in fuel and the permissible national emission volume. MARKAL structure has been adapted in a way that it is possible to calculate the emissions by type of fuel as well as by sector and the respective technology type, which is critical for calculating VOC and NOx.

The model covers the energy sector, this is why NOx and SO2 permissible limits are 6lGg and 101 Gg respectively, while VOS limit is 89.9 Gg, which is 66% of 136 Gg. The limits have to be complied with starting with 2010.

The study deals with four scenarios differing by growth rate and increase of electricity consumption. The useful energy demand between years 1999-2019 is assumed to increase in the spread 1-2.9%, while the electricity consumption increase- 1-6% annually.

Figure 5 demonstrates the scenarios (DM1, DM2, DM4 and DM6) for differing growth rates and respective emission volumes in the energy sector for the period 2000-2019.

In case of all scenarios, covering the said period, CO2, SO2 and VOC emission volumes do not exceed the limits. NOx level under DM2, DM4 and DM6 scenarios exceeds the limit 61 Gg per year respectively after years 2019, 2014 and 2009. This is mainly due to the rapid development of the transport sector. In the transport sector the reduction of NOx emissions is costly. This is why most of the NOx emission reduction is done in energy transformation sector.

Further on, DM2 scenario has been analysed in a greater detail, proceeding from electricity and useful energy consumption growth rate 2% and 1.6% per annum respectively (base scenario). The scenarios which include various emission reduction measures - use of fuel with lower sulphur contents, fuel and technology switching, emission abatement technologies etc. - have been compared with the base scenario, thus allowing to calculate the emission reduction costs. Table 2 demonstrates

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[4] 1 US$(I994)=0,7Ls(2000)

C02, S02, NOx and VOC emission reductions that have been obtained via comparing various emission reduction scenarios with the base scenario.

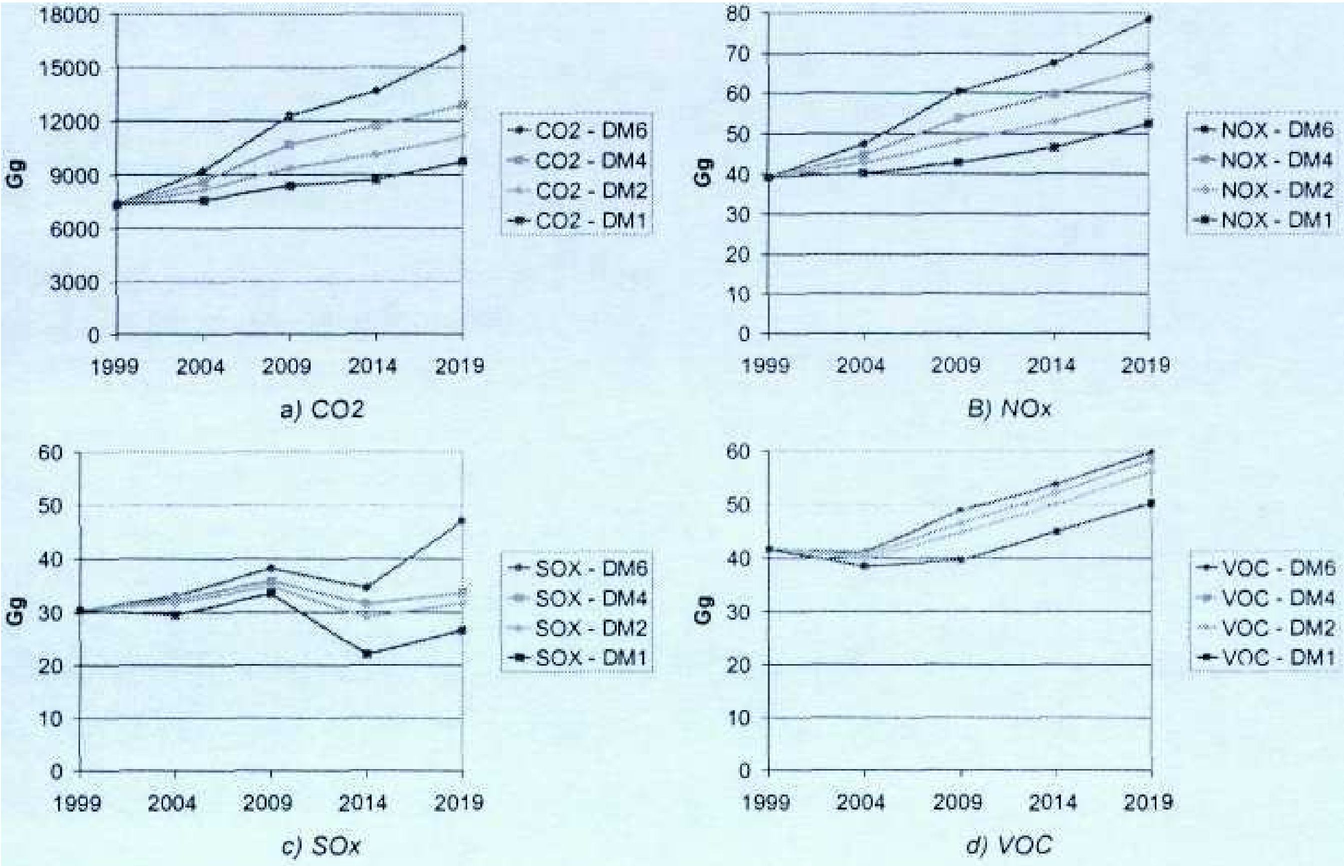

Figure 5: Emissions in energy sector, Gg

The scenario where fuel is with low sulphur contents SO2 emission reduction 259.2Gg in the period 1999-2019 would cost USS 1194 (1994) per reduced SO2 ton. The scenario where SO2 emissions are reduced by the same amount as in the previous scenario, the model, apart from fuel with low sulphur contents, can also provides other SO2 reducing alternatives. If we choose this strategy, SO2 emission reduction would cost USS 268 (1994) per reduced SO2 ton.

Table 2: Description of scenarios

Description	Emission bound	Emissions, Gg			
		CO2	SO2	NOx	VOC
Base scenario (annual useful energy demand growth rate 1.6% in period 1999–2019)	No	230357.3	789.0	1211.2	1162.5
		Cumulative emissions reductions against base scenario (1999-2019)			
Scenario with forced use of low sulphur fuel	No	3994.9	259.2	11.1	-23.2
Scenario SO2 bound equal with previous scenario SO2 emissions	SO2	9098.8	259.2	22.6	20.6
Scenario SO2 bound equal with 99% of base scenario SO2 emissions	SO2	162.0	6.4	0.7	0.2
Scenario NOx and VOC bounds equal with admissible emission volumes	NOx and VOC	873.0	11.8	58.6	0.8
Previous scenario with additional NOx bound in transport sector (60% of admissible emission volume)	NOx and VOC, NOx in transport	227.8	-5.4	63.4	1.3
Scenario NOx and VOC bounds equal with 99% of base scenario NOx and VOC emissions	NOx and VOC	2290.8	56.8	10.1	12.8

Flue gas desulphurisation is one of the most costly measures; it is exclusively an environment protection activity and docs not give any economic effect. If it is necessary to implement this activity it is worthwhile considering an alternative - to switch to other type of fuel.

By reducing the specific emissions, the benefits actually are higher, since the emissions of other substances reduce as well. For example, the reduction of NOx emissions would result in the change of the energy sector structure, consequently, VOC, CO2 and SO2 emissions are reduced.

4.2 CO2 emission reduction potential and cost estimates

The study, alongside with other emission reduction measures, provides an evaluation of three sets of energy efficiency measures in public buildings, multifamily houses and single family houses, and their effects on CO2 emissions in Latvia. The sets of measures vary according to costs and to potential energy savings. Relative potential energy savings, as a result of implementing the energy efficiency measures, arc 40%, 50% and 60%, respectively in all types of buildings.

The sets of energy efficiency measures include improvements of:

- The buildings construction;
- Internal heating and hot water system;
- Ventilation.

The study covers four sets of scenarios: without energy efficiency measures, where the energy efficiency measures in (he household and services sectors arc permitted to reach up to 10% of their aggregate potential; and three sets with respective energy efficiency measures.

In each individual set the scenario without CO2 tax is taken as a base. By increasing the CO2 tax, CO2 itself would reduce: this is because of the changes in the fuel and technology structure both on the supply and demand side natural gas and wood becomes more popular, and energy efficiency measures tend to use more of their potential.

Comparing the measures, one arrives to a conclusion that the set of measures with the lowest costs has to be implemented right away - at the present development scenario (base scenario). This is because the scenario with the least costly energy efficiency set of measures CO2 emissions and system costs are lower than in the base scenario, there the assumption is that the energy efficiency measures in the household and services sector may be up to 10% of the relative energy savings potential. In the case of apartment buildings, the measures No.2 and No.3 appear in the scenarios with CO2 tax USS 75 and 300 per ton respectively. In the case of private houses, measure No.2 appears in the USS 75 per ton scenario. In the services sector, measures No.2 and No.3 appear in the scenarios with CO2 tax USS 0 and 75 per ton respectively. With the increase of CO2 tax, the implementation of the measures tends to increase.

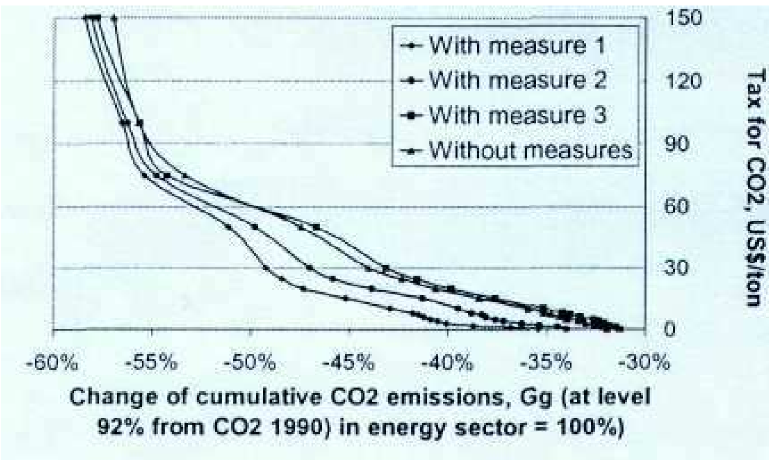

Figure 6: Cumulative CO2 emission depending on the tax

Cumulative CO2 emission (1994-2034) curves for the sets of scenarios depending on the tax are demonstrated in Figure 6. From the point of view of emission reduction, the scenario sets with measures No l and No2 arc more advantageous than the base scenario set.

4.3 RES-E objective

Directive 2001/77/EC "On the promotion of electricity produced from renewable energy sources in the internal electricity market" sets the national objective for each member country. Latvia has committed itself that in year 2010 the electricity generate from RES will cover 49.3% of total consumption.

The study analyses two factors that lie in the basis of the sets of scenarios - i.e. different growth rates (1, 2, 4, 6% electricity consumption growth per year) and the shares of RES-E, or, how much should RES-E contribute to the gross national electricity consumption starting with year 2010. Apart from these scenarios, also the scenarios with the CO2 tax and with the subsidies for RES-E power plants have been described.

If one compares the costs of the scenarios (with the same electricity consumption growth rates) with limitations, and the base scenarios without any limitations, we can get the extra cost for generating RES-E electricity. In average, the extra cost for the periods 1999-2019 and 1999-2034 are demonstrated in Figure 7. The extra costs tend to increase together with the increase of electricity consumption or RES-E target figure, moreover, the extra costs are lower for the entire modelling period.

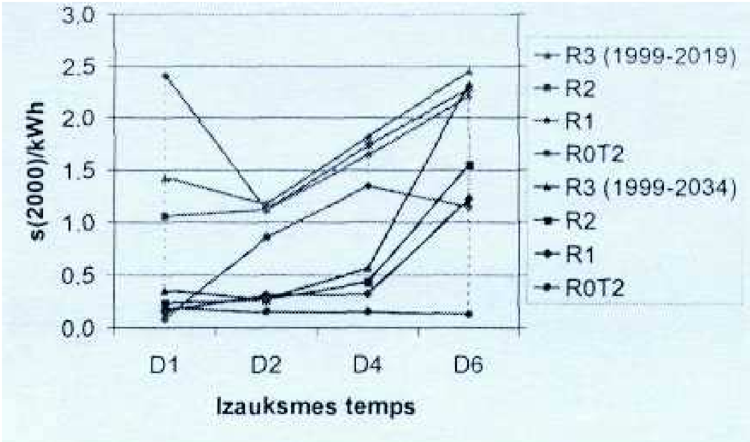

Figure 7: RES-E average extra costs for the periods 1999-2019 and 1999–2034and scenario groups (R0, R1, R2, R3 - respective RES-E objective – 0, 45, 49.3, 55%, T2 – subsidy to RES-E 2,8 US$/GJ, D1, D2, D4, D6 – respective electricity growth rates– 1, 2, 4, 6% per annum)

Energy sector average extra costs for the period 1999-2024 are presented in Table 3. These costs are 0.07% of GDP - to attain RES-E 49.3% and assuming that the demand in electricity increases 2% per annum.

With the increasing RES-E share, or by subsidising RES-E, the demand in electricity is expected to go down, because it will become a little more expensive, whereas the introduction of CO2 tax (US$ 20 per ton of CO2) will cause a considerable increase in demand for electricity, since its generation is less CO2 intensive.

Table 3: Energy sector average extra costs, % of GDP

	D1	D2	D4	D6
R3	0,07%	0,10%	0,27%	1,22%
R2	0,04%	0,07%	0,23%	0,89%
R1	0,03%	0,04%	0,15%	0,55%
T2R0	0,02%	0,04%	0,06%	0,06%

4.4 Promotion of utilisation of biomass for energy generation

Latvia has sufficient wood resources to be used for energy generation. Currently wood processing companies are undergoing consolidation, which allows to cut the costs of wood used in energy generation - by modernising the production equipment, by a more efficient employment of resources, and processing wood in form of chips, briquettes and pellets.

The study analyses several scenarios differing between themselves by the share of thermal energy generated by wood in DH. In the base scenario the use of wood increases:

- In PES (sec Figure 8 a) the most rapid increase is for natural gas and oil products (in the transport sector). The consumption of wood increases a little as well;

- The demand for wood increases in the transformation sector (boiler houses and CUP plants) by pushing out oil products: legislation comes into effect that actually bans the use of hard oil with sulphur contents over 1%. The share of natural gas remains approximately as is;
- As to FEC (see Figure 8 b) the share of natural gas, oil products (mainly in the transport sector) and electricity is increasing, whereas the share of wood and DH is decreasing. The demand for DH is to reduce from 19% in 1999 to 12% in 2024.

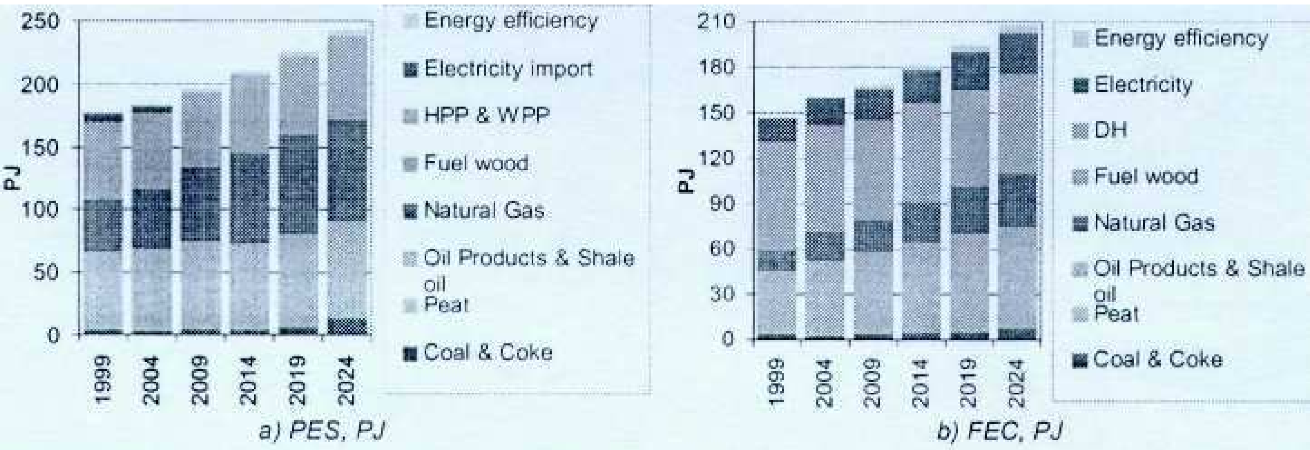

Figure 8: Base scenario results for period 1999–2024

generated from wood in DH. Since the demand in thermal energy is shrinking, fuel consumption reduces as well. Under the scenario where the share of heat from wood in DH is 15% (BIO_15), oil products have replaced wood in the transformation sector; under the scenario where the share of heat from wood in DH is 45% (B1O_45), wood is pushing out oil products and natural gas.

Table 4: Consumed DH

Scenario	1999	2004	2009	2014	2019	2024	1999	2004	2009	2014	2019	2024
	FEC, PJ											
BASE	146,4	159,9	168,3	181,1	194,2	207,2						
BIO_15	146,4	159,9	168,7	181,7	194,7	208,2						
BIO_45	146,4	159,9	167,3	179,6	194,1	206,9						
	incl. Consumed DH, PJ						incl. Heat from wood, PJ					
BASE	28,1	27,6	26,2	26,1	25,8	25,8	4,51	6,80	7,73	10,76	12,31	13,68
BIO_15	28,1	27,6	27,1	25,9	25,7	25,8	4,51	6,80	5,26	4,51	4,47	4,49
BIO_45	28,1	27,6	25,8	25,6	25,8	25,8	4,51	6,80	13,57	13,36	13,48	13,47
	DH in FEC, %						Heat from wood in DH, %					
BASE	19,2%	17,3%	15,5%	14,4%	13,3%	12,4%	12,4%	19,3%	24,4%	35,6%	41,1%	45,7%
BIO_15	19,2%	17,3%	16,1%	14,3%	13,2%	12,4%	12,4%	19,3%	15,0%	15,0%	15,0%	15,0%
BIO_45	19,2%	17,3%	15,4%	14,3%	13,3%	12,5%	12,4%	19,3%	45,0%	45,0%	45,0%	45,0%

The scenario where the share of heat from wood in DH is 15% results in the highest emission (CO_2, SO_x, NO_x and VOC), since wood has been replaced by oil products. The emissions are lower in the scenarios where wood is used more.

The scenario where the share of heat from wood in DH is 45%, is by 232 million US$ (1994) more costly than the base scenario in the period 1999-2024; yet, it gives 3514 Gg CO_2 emission reduction. CO_2 emission reduction average cost per ton is US$(1994) 66, provided that the system cost increase is related to CO_2 reduction.

4.5 Emissions trading

Emissions trading is the ability of one party to transfer, swap, buy, sell its right to produce emissions to another party, with the purpose to attain a common goal - to reduce emissions at the lowest cost possible. Emissions' trading enables the emission sources (e.g. generators) to cut down the emissions beyond the permissible level (base scenario) and to sell this cut to someone else, who have limited possibilities to reduce their emissions, or they are more costly.

The Appendix B countries need to reduce their GHG emissions by 5.2% between the years 2008 and 2012. The price per CO2-cquivalcnt emission reduction is expected to be starting form US$ 3 and up to a few hundreds.

Emission quotas and electricity trading between the Nordic and the Baltic countries

The analysis of the emission quotas and electricity trading between the Nordic and the Baltic countries has been done by merging four individual MARKAL model databases: three individual databases from the Baltic countries and one common Nordic database. In the base scenario there arc no limits to GHG emissions. The other scenario is based on the Kyoto protocol, and with extra 5% cut on emissions in the decades after 2010 (the reinforced Kyoto protocol).

According the scenario with electricity and emission trading, Norway is the largest electricity net exporter, because it still is able to develop non-expensive hydroelectricity and gas power plants. Moreover, gas power plants are a little cheaper in Norway than in other Nordic countries, because Norway is closer to the resources. This also allows CO2 deposition in aquifers under the North Sea. In Sweden, nuclear energy is replaced by biomass, wind and gas energy; energy is also imported. Energy is used in a much more efficient way, via implementing measures on the end user level. Table 5 demonstrates net electricity and emissions trading between the countries.

Table 5: Net electricity and emission trading

	Electricity trading*, TWh				Emission trading**, Mt CO2		
	2005	2015	2025	2035	2015	2025	2035
Norway	-4.5	18.3	14.4	19.1	14.0	12.1	13.3
Sweden	7.4	-9.8	-19.3	-26.4	3.7	7.3	7.1
Denmark	-5.4	-2.4	6.8	6.3	-2.0	-0.4	3.2
Finland	-3.3	-15.1	-8.8	-3.9	12.8	2.6	-3.7
Estonia	-0.9	7.0	4.0	-1.2	-9.0	-7.3	-10.6
Latvia	-2.7	-3.6	-3.7	-3.2	-7.6	-6.1	-5.2
Lithuania	3.7	0.1	1.0	4.0	-11.9	-8.2	-4.1

* + net export. The figures include an import of 6 TWh/y to Finland from Russia. In 2005 Lithuania also has a net export outside the region;
** + net import

According to this scenario, in 2015 the emission allowances trading volume is expected to reach 30 million CO2 per year (sec Table 5). In short-term, Norway and Finland arc the main buyers; in a longer perspective Sweden and Denmark. Finland is self-sufficient in terms of resources - its huge biomass resources are becoming increasingly more competitive. The proximity to Russian gas pipelines is an extra advantage for Finland.

The Baltic countries arc the main sellers of emission quotas. Lithuania can dispose of a large part of CO2 emission allowances while the Ignalina nuclear power plant is still running, In the long-term, when in Estonia most of oil shale will be replaced by natural gas, Estonia will become the main CO2 quotas seller.

CO2 emission reduction marginal costs in the period 2005-2035 vary between US$(1995) 5 to 34 per CO2 ton. The co-operation between countries results in a considerable reduction of marginal costs of emissions in Nordic countries.

Emission market is compatible with the energy market liberalisation. Complying with the Kyoto protocol commitments, the electricity market allows cutting on emission reduction costs by

5%. Yet, they could be reduced even by 25% if emission market is put in place alongside with energy market.

Emission trading between the Nordic and the Baltic countries may considerably reduce emission reduction costs in the Nordic countries and provide an opportunity for the Baltic countries to build a sustainable energy sector.

BASREC[5] electricity and CO2 emission trading simulation includes emission trading in the Baltic region, and made it possible to study the relationship between the electricity and CO2 emission markets in the period 2003-2012. The assigned amount allocated to Latvia, as a part of Kyoto commitments for the period 2008-2012 is 142.8 million tons CO2 equivalent, of these 7 million tons of CO2 equivalent has been allocated to electricity generator. According to the calculations, in the said period Latvia could sell emissions 85.3 million tons CO2 equivalent. Six trading sessions were run, covering the period 2003-2012, and one extra session (grace period) where the participants could execute the concluding deals in order to comply with the Kyoto protocol commitments. The traded emissions volumes and prices are demonstrated in Table 6.

Table 6: Trading statistics

Periods	Latvia's' traded volume, JI[6] transactions included	Traded volume, MtCO2eq.	Number of transactions	Price range, €/tCO2eq.		
				Lowest	Average	Highest
2003–2004	1,918	18,36	103	14,00	16,58	19,00
2005–2006	1,725	52,30	147	12,00	16,51	17,25
2007–2008	1,426	736,16	173	15,00	17,50	18,25
2009–2010	1,645	287,26	114	16,50	17,90	19,00
2011–2012	6,161	1189,07	116	15,50	17,09	18,00
Grace period	1,978	1149,25	126	16,25	17,82	18,50
Total	14,853	3432,40	779	12,00		19,00

Russia was the domineering emission quota seller. Estonia, Latvia, Lithuania and Poland competed on the sell side as well. Irrespective of the fact that it was possible to put out in the market a considerably higher amount of GHG emissions than the countries would need to buy to fulfil the commitments, the emission price was surprisingly high and stable - EUR 12-19 per ton CO2. This is a good prerequisite for JI. Latvia (excluding the generator) altogether sold 11 million tons of CO2 equivalent at average price EUR 17.22 per ton. At the end of the simulation Latvia was left with a considerable stock of GHG emissions unsold: it would be reasonable to put it aside for the future commitments periods, when the economic activity is expected to increase and GHG emission reduction targets will become more stringent.

4.6 Stochastic analyse

Irrespective of the GHG emission reduction target set by the Kyoto protocol, there still exists pretty much uncertainty with the Latvian GHG commitments after Kyoto protocol (after 2008-2012), i.e., it is not clear whether the emissions will have to be reduced, to retained at the same level, or whether they would be allowed to increase. Consequently, Latvia is facing the problem that there is no definite strategy how much and when GHG emissions have to be limited or reduced: this has a direct effect on decision making about investments in the energy sector in the nearest future. This is critical, because energy sector projects have a long life. Stochastic modelling has been applied in the analysis with the purpose to help to answer the questions: what would be the best development strategy for the Latvian energy sector till t*, when the emission reduction targets and timeframe become known.

[5] Baltic Sea Region Energy Cooperation

[6] Joint Implementation projects

The study compares four deterministic strategics scenarios with the stochastic strategy scenario. Four different states of nature varying by energy sector cumulative CO2 emission limitations targets for the period 1994-2034 were chosen:

- With no cumulative bound;
- +30% over the year 2000 level;
- + 15% over the year 2000 level;
- Stabilisation on the year 2000 level.

The stochastic strategy was studied under the Laplace Criterion, which assumes equal 0.25 probability for all four targets. After year 2019 (t*) it will be known which of the four possible cumulative emission limitations will have to be complied with. This means that up to 2014 the development will follow one line (hedging strategy), but after that four different development trajectories are possible - according to the respective target.

CO2 emission trajectories for the four stochastic strategy scenarios (STOCH) and four deterministic (DET) strategy perfect information (PI) scenarios are presented in Figure 9. Stochastic strategy recommends to reduce the emissions as soon as possible, though the actual emission reduction target is not yet known.

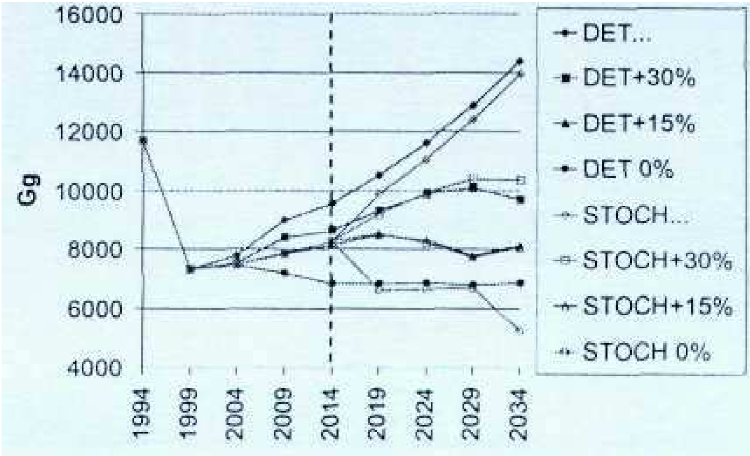

Figure 9: CO2 emissions paths for different strategies, Gg

In order to demonstrate the advantages of the stochastic strategy, the strategy costs of four GHG emission targets have been compared. Table 7 demonstrates the system costs and the cost increase in absolute and percentage terms - regrets. The regret is obtained as the difference between the cost of the strategy and that of the best possible strategy under PI (figures in bold). If one compares the expected value, one can see that not a single one deterministic strategy is less expensive than the stochastic strategy.

Table 7: System costs and regrets for..., +30%, +15%, 0% targets

	With no cumulative bound	+30% over 2000 level	+15% over 2000 level	Stabilization on 2000 level	Expected value*
	...	+30%	+15%	0%	
Total discounted system costs, million US$(1994)					
DET...	**29580**	29738	30106	30917	30085
DET+30%	29620	**29711**	30010	30677	30005
DET+15%	29686	29739	**29985**	30597	30002
DET 0%	29926	29928	30059	**30503**	30104
STOCH	29669	29725	29989	30605	29997
Regrets, million US$(1994)					**Max regret**
DET...	**0**	27	121	414	414
DET+30%	40	**0**	25	174	174
DET+15%	106	28	**0**	94	106
DET 0%	346	217	74	**0**	346
STOCH	89	14	4	102	102
Regrets, %					
DET...	0%	0,09%	0,40%	1,36%	1,36%
DET+30%	0,14%	0%	0,08%	0,57%	0,57%

DET+15%	0,36%	0,09%	0%	0,31%	0,36%
DET 0%	1,17%	0,73%	0,25%	0%	1,17%
STOCH	0,30%	0,05%	0,01%	0,33%	0,33%

*expected cost is equal to the weighted sum of the individual scenario system costs, the weight being the scenario's probability of occurrence

When we compare the strategies, it turns out that the stochastic strategy demonstrates the lowest worst regret compared to worst regrets of" deterministic strategy PI scenarios, i.e., US$(1994) 102 million, or 0.33% of the emission stabilisation on the year 2000 level PI scenario system cost. Under the stochastic strategy, the expected discounted system cost is by US$(1994) 52 million higher than the weighted average of the four system costs obtained for the deterministic PI scenarios. This is how much it would be worth to us to know the truth about the future right now and shows that it is economically important to speed up the acquisition of knowledge on the global warming issue.

5 Conclusion

With theoretical value

1 When developing optimal strategies for the energy sector development, alongside with technical and economic factors, the environmental factor needs to be considered as well. Therefore, the decision taking would hardly be possible without a complex analysis and forecasting of the national economy and environmental development. Adequate mathematical tools need to be developed for the purposes of solving and analysing these complex issues.

2 The expected electricity import price increase in a foreseeable future; a sole supplier of natural gas; a more extensive use of the renewable energy sources; the dependence of the economy on imported energy resources; market liberalisation process; energy sector as the major GHG emission and indirect GHG emission source; the increasing demands in environmental policy - these are the elements that make the analysis of the situation in the Latvian energy sector increasingly complicated. Therefore, to attain a growth of economy, the importance of the energy sector optimal development management will still increase in the future.

3 Different mathematical models, varying by the purpose, geographic coverage, mathematical approach, covered timeframes, have been applied for the analysis of the energy sector development scenarios. MARKAL model is efficient for the Latvian situation; it is based on minimising the total cost objective function, taking into account the discount rate and applying the simplex method. A more extended period (25-45 years) has been split in shorter periods (as a rule in 5 year periods).

4 Based on an in-depth Latvian energy sector and environmental system policy analysis, the model has been adapted and modified, creating the Latvian energy sector and environmental system database. The modifications include the existing and the potential future energy carrier and technology types, as well as the emission abatement technologies, transformation, industry, services, agriculture, transport and residential sectors.

5 Alongside with such study objects as costs, production capacity, and the investments model also allows to evaluate the direct and indirect GHG emission reduction measures and the use of renewable energy sources. The energy sector and the environmental system have been linked in the target function, thus taking into account their reciprocity. The final energy consumption has been identified by optimising the mix of energy technologies and energy carriers that satisfy the useful energy demand.

6 The mathematical methods in the energy sector analysis may serve both as a cognitive instrument, as well as a tool for doing quantitative analysis. This quantitative analysis, complemented by the qualitative study of the economic regularities, would prevent biased conclusions and development scenarios and increase the quality of planning.

7 The comparing of several scenarios allows including the future uncertainty phenomenon in the analysis. The paper demonstrates the efficiency of the stochastic approach while developing the energy sector development strategy, taking into account the future uncertainties, i.e. what would be the advisable to do in the near term in the light of long-term uncertainties. This is critical in case an important decision has to been taken in the nearest future, that would have a significant effect on the future development.

8 The created Latvian model database may be integrated into regional models, in order to make the energy and emission market analysis possible.

With practical value

1 Due to restructuring of the national economy, during the past decade the primary energy consumption in Latvia and emissions have considerably decreased, and currently the emission volume is notably below the one specified in international commitments. However, in a more distant future the international requirements as to the permissible emission volumes will become more stringent. Considering the present economic growth rates, Latvia might have problems to fulfil these commitments. In order to avoid in future costly emission reduction measures, the issue of optimal development is becoming increasingly topical for Latvia already today. To attain sustainable development, all resources should be employed efficiently, and adequate emission limitation strategies should be developed. Consequently, when choosing the development strategy, a question comes to the foreground - what emission level should be retained for the development phase.

2 The research paper analyses optimal energy sector development strategies, taking into consideration a number of factors - limitation of emission volume, a more extensive use of local and renewable energy resources, emission trading, the future uncertainties about GHG emission commitments etc.

3 While analysing the potential energy sector development scenarios, it has been identified that emissions (CO_2, SO_2, VOC and NOx) within the next coming twenty-five years will not exceed the emission levels as stipulated by the present legislation. Some problems might arise if in future more stringent emission target limits are approved (next commitment periods). NOx emissions are the closest to the permissible level, and the increase is due to the growth of transport sector. Therefore, already in the nearest future it is necessary to pay consideration to NOx emission reduction measures.

4 The analyses testify that the effect from reduction of a specific emission extends further, and other emissions reduce, too. For example, while reducing NOx emissions, VOC, CO_2 and SO_2 emissions reduce as well, because the energy source and technology system structure changes. This allows arriving at a conclusion that integrated approach is critical for emission reduction strategy development.

5 The analysis of CO_2 emission limitation and costs demonstrate that energy efficiency measures in the buildings arc an important source of emission reduction. The less expensive energy efficiency measures arc to be implemented already in the present phase. With the enforcement of CO_2 tax, more expensive and efficient sets of activities will be implemented.

6 In Latvia in the year 2010 49.3% of the gross national electricity consumption is to be generated by renewable resources. Provided that the electricity demand increases 2% per year, average extra costs incurred in order to attain this target will be 0.07% of GDP.

7 The study shows that RES-E share cannot be increased considerably via introducing CO_2 tax. In this case, the demand ill electricity increases, since its generation is not so CO_2 emission

intensive. Together with increase of the RES-E share, or subsidising RES-E sources, electricity consumption slightly decreases, because electricity becomes more expensive. In the future, the use of wood for efficient energy generation in the transformation sector is going to play an important role.

8 Emission market is well compatible with energy market liberalisation. The analysis indicates that, fulfilling the Kyoto protocol commitments in the Baltic region countries, the emission reduction costs in the region can be cut by 5%, if regional electricity market is in place. Yet, they can be further cut down even by 25%, if emission market operates alongside with electricity market. The analysis shows that the emission trading between the Nordic and Baltic countries may considerably decrease the emission reduction costs for the Nordic countries, and contribute to sustainable development of the energy sector in the Baltic countries.

9 Building the Latvian climate changes policy, alongside with the Kyoto protocol commitment period limitations one has to take into account that there are many uncertainties as to the next commitment periods. Therefore, we have to evaluate with due care what to do with the GHG emissions saved during the Kyoto commitment period: to sell, or else, to reserve for the future commitment periods, because GHG emission volume is expected to grow together with the increasing economic activity.

10 When we compare the stochastic and deterministic emission reduction strategy, it has to be pointed out that the stochastic strategy has the advantage of specifying a hedging strategy, which takes into account the possible conditional positions in the future till a specified time when a condition is fulfilled. This allows retaining certain flexibility in decision making till the time when the uncertainties are resolved.

11. The stochastic strategy demonstrates the lowest worst regret compared to worst regrets of deterministic strategy perfect information scenarios. Under the stochastic strategy, the expected discounted system cost is by USS(1994) 52 million higher than the weighted average of the four system costs obtained for the deterministic PI scenarios. This testifies how critical it is from the economic point of view to speed up the building of knowledge on the global worming problem, so that the countries could agree between themselves, as soon as possible, about the emission reduction targets and avoid redundant expenditures in the future.

12 The analysis of the Latvian energy sector issues has been used in the Latvian environment policy and energy development documents, prepared by public institutions.