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REDUCTION OF CO_2 EMISSIONS IN ESTONIA DURING 2000–2030

H. AGABUS, M. LANDSBERG, H. TAMMOJA*

Department of Electrical Power Engineering
Tallinn University of Technology
5 Ehitajate Rd., 19086 Tallinn, Estonia

This paper presents the results of elaboration of long-term national energy plans. The most important aim was reduction of CO_2 emissions. Long-term national energy plans can be worked out with special computer programs, such as MARKAL, which is one of the well-known programs in this field. MARKAL is a dynamic linear programming "bottom-up" model, which finds the optimal development of the energy system under given technological characteristics and boundary conditions. Estonia differs greatly from other countries in the world. Oil shale is the most important fuel for power stations in Estonia.

Introduction

The energy sector is a basis for the rest of economy. It cannot be examined apart from environmental and social issues. Considering also operation costs and investment needs, it is obvious that operation and development of the energy system have to be optimized.

Elaboration of long-term national energy plans is labour-consuming work. This may be done with special computer programs. One of the well-known programs is MARKAL.

MARKAL is a dynamic linear programming "bottom-up" model which finds the optimal development of the energy system under given technological characteristics and boundary conditions. MARKAL is an optimization model of the energy system presenting alternatives to the current and potential future technologies through the so-called Reference Energy System (RES). The MARKAL model is a generic technology-oriented model tailored by the input data to obtain the cheapest configuration of the energy system for a given time horizon under a set of assumptions about end-use demands, technologies and resource potentials. It presents the time evolution of a specific RES at the local, national, regional, or global level [1, 2].

* Corresponding author: e-mail address *heiki.tammoja@ttu.ee*

Estonia differs greatly from other countries in the world as she uses local resources of oil shalefor fuelling power stations in Estonia.

Indigenous fuels (oil shale, wood and peat) constitute approximately 2/3 of primary energy supply of Estonia. The share of renewable energy sources (mainly wood) is about 10%. Estonian oil shale is unique, its reserves are the largest commercially exploited resources in the world. Oil shale is characterised as a low-grade fuel with a low heating value (average 8.6 MJ/kg) [3].

Starting from 2008, our power plants have to comply with the EU directive on the limitation of emissions into the air from large combustion plants. During accession negotiations with the EU, Estonia was allowed a transition period, but the existing oil-shale pulverized combustion units must be closed by the end of 2015 in accordance with the schedule agreed upon. As a result, only 18% of the capacity of power plants (burning oil shale) of the year 2006 (about 2400 MW) may continue operating after 2015 [4].

Methods

An effective assessment of power policy requires the use of models capable of simulating the technological change necessary to induce long-term economical shifts towards sustainable global energy system(s), simultaneously representing in adequate detail key energy-economy-environment interactions.

The analysis has been carried out using the Estonian MARKAL model [2].

Since its initial development started in the late 1970s, the MARKAL model has become a widely applied tool for evaluating the impacts of policies imposed on the energy system. As for any other MARKAL (Market Allocation)-type modelling exercises, the analyses and results reported herein should also be considered prospective, with emphasis placed on the trends and insights resulting from driving forces determined by implementing the respective policy options [1].

The MARKAL models allow wide flexibility in representation of energy supply and demand technologies. They are typically used to examine the role of energy technologies under specific policy constraints, e.g. CO_2 mitigation, reduction of local air pollution, etc.

Today a new model VEDA is being worked out. VEDA is an elaborated model of MARKAL.

Basic considerations

The development of the main energy indicators until 2010 as forecast in the Draft National Long-Term Development Plan for the Fuel and Energy Sector until 2015 (with a vision until 2030) can be found in the following table [5].

Table 1. **Estonian main energy indicators until 2010 [5]**

	2000	2010
Primary energy supply, PJ	189	220–250
Consumption of oil shale, Mt	13.2	11–13
Share of renewables in primary energy supply, %	10.5	13–15
Share of renewables in electricity generation, %	0.1	5.1
Final consumption of electricity, TWh	5.4	6.5–8.0
Necessary net capacity of power plants, MW	1980	2200–2500
Share of CHP in electricity generation, %	12–14	15–20
Maximum net load of Estonian power system, MW	1400	1600–1900
Openness of electricity market, %	10	35–40
Heat consumption, TWh	8.5	8–9
Share of CHP in heat production, %	33	35–40
SO_2 emissions, % of limit in 2008	181	90–100
CO_2 emissions, % of limit in 2008	48	50–55

The following basic assumptions were made in all scenarios:

1. Import of electricity and biomass and nuclear plants are restricted.
2. Electricity net export is allowed until 2015.
3. Price of natural gas will increase rapidly to the European level.
4. GDP forecast is based on the actual value of 2000 GDP at market prices, that in turn bases on the forecast of the Ministry of Finance of Estonia until 2030 [6]. The base-year GDP and energy data are taken from publications of the Statistical Office of Estonia [3, 7].
5. All scenarios use forecast of low energy consumption [4, 5]. Introduction of large-scale energy-intensive industry is not envisaged. A prospective new pulp & paper plant is modelled as a separate unit, and it can be closed and easily excluded from the results, if this investment will not be made actually. It is assumed that high energy prices will stimulate the implementation of conservation measures in all sectors of economy. Heat consumption is assumed to be stable over the planning period, but electricity consumption is forecasted to increase [4, 5].
6. The planning period is 2000-2030, and the discount factor is 0.05.
7. The number of population remains stable around 1.4 millions over the planning period. The number of population is presently actually decreasing [3], but this decrease is assumed to be compensated for by immigration.

The value of Estonian GDP was 5.584 billion EUR (4076 EUR per capita) in 2000 [7]. The annual growth forecast for the current project was taken from [3] (average forecast), and it is depicted in Fig. 1.

The forecasts of population and GDP used in the modelling are presented in Table 2.

The primary energy resources of Estonia are estimated as follows:

Oil shale – total resources of the deposit are ca 8.66 Gt. Mining limit is 20 MT/year. Latest research results of the Mining Department of Tallinn University of Technology estimate that the resources can last for 60 years at the current level of exploitation.

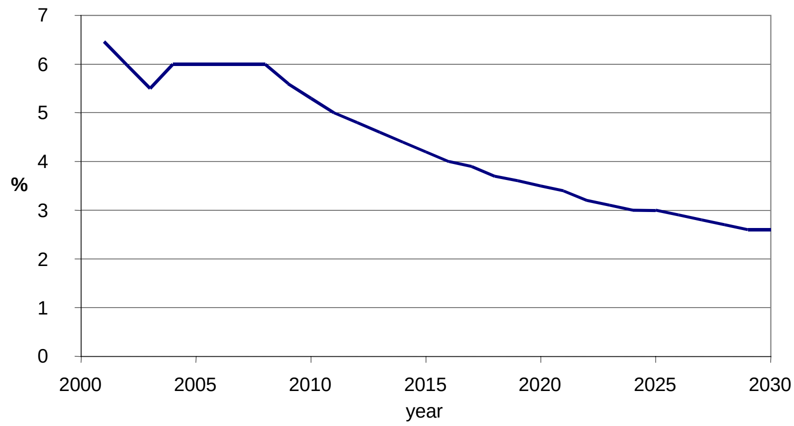

Fig. 1. Estonia's annual GDP growth 2001–2030 [6].

Table 2. **Forecast of population and GDP**

	2000	2005	2010	2015	2020	2025	2030
Population, million	1.37	1.35	1.35	1.4	1.4	1.4	1.4
GD, billion EUR_{2000}	**5.584**	7.469	9.892	12.39	14.88	17.37	19.86
GDP, EUR/capita	4076	5533	7327	8847	10630	12407	14188

Peat – total deposits 775 Mt (annual limit for extraction is 2.78 Mt/year = 31 PJ/year, annual growth is 0.5 Mt/year = 5.6 PJ/year).

Biomass and waste – theoretical total annual resources are 102 PJ, economically feasible annual resources for CHPs are 21 PJ.

Hydropower – potential is 30 MW (corresponds to the annual production of 0.5 PJ/year).

Wind – theoretically a very large resource, but its use involves several restrictions [8]. Considering the possibilities of the Estonian power system alone to integrate the windmills, the capacity limit is ca 400 MW, corresponding to the annual production of 0.84 TWh/year = 3 PJ/year, which follows from the fact that condensation power plants can operate at the minimum 40% of loading. Maximum long-term annual utilization of wind energy is estimated at 10 PJ/year (requires 1400 MW of installed capacity of windmills and takes into account the systems operating in neighbouring states).

Solar energy – the estimates of annual utilization vary in a wide range: from 0.5 to 8 PJ/year.

Geothermal energy – in principle 0, only ground heat pumps can be used.

All other fuels have to be imported. The existing **natural gas** pipelines can supply up to 70 PJ/year.

Coal and oil products can be imported via rail and harbours.

Average consumer prices of fuels, electricity and heat in 2005 are presented in Table 3 [9].

Table 3. **Average fuel and energy prices for consumers in 2005 [3]**

Fuel and energy	Price	Value, EUR/GJ
Coal, EEK/t	939	40.83
Oil shale, EEK/t	127	14.77
Sod peat, EEK/t	365	36.50
Peat briquette, EEK/t	1350	81.82
Firewood, EEK/m^3 sol.vol.	258	34.40
Wood chips and waste, EEK/m^3 sol.vol.	145	22.31
Natural gas, EEK/1000 m^3	1396	41.67
LPG, EEK/t	–	–
Heavy fuel oil, EEK/t	3384	83.56
Shale oil, EEK/t	2761	69.90
Light fuel oil, EEK/t	6345	149.29
Diesel oil, EEK/t	10017	235.69
Gasoline, EEK/t	12337	283.61
Electricity, EEK/MWh	765	212.50
Heat, EEK/MWh	396	110.00

The forecasts of tax-free production and import prices (without inflation) of the main fuels for MARKAL modelling were as follows:

- The oil shale price 14.2 EEK/GJ = 0.91 EUR/GJ will remain constant until 2020, and thereafter it will rise to the level of 18 EEK/GJ. This forecast is based on the information from the oil shale mining company "*Eesti Põlevkivi*" [10].
- The price of import coal will be stable at the level of 25 EEK/GJ = 1.6 EUR/GJ [11].
- It is assumed that stable prices of oil shale and coal will slow down the growth of the prices of wood and peat. The production price of peat is assumed to grow from 20 to 30 EEK/GJ, and the price of wood fuel from 13 to 30 EEK/GJ during 2000–2030.
- It is assumed that Estonia's member status of the EU brings rapidly about the same price levels and their growth predictions for natural gas and oil products, therefore the growth of the heavy fuel oil price from 50 EEK/GJ = 3.2 EUR/GJ in 2000 to 170 EEK/GJ = 10.9 EUR/GJ in 2030, and the growth of the natural gas price from 35 EEK/GJ = 2.24 EUR/GJ to 125 EEK/GJ = 8 EUR/GJ during the same period.

Forecasts of final energy consumption of industry (without a new large pulp & paper factory) and agriculture are presented in Fig. 2. As mentioned before, the possible new pulp & paper factory was modelled separately.

The transport sector of Estonia as a transit country between East and West is assumed to grow rather fast. The main growth will come from the road transport (trucks, buses, trams, trolleys and company cars) and private cars. The corresponding forecasts are presented in Table 4.

The household sector was modelled to be as modern and economical as possible. The corresponding forecast is depicted in Fig. 3. In addition to the specific electrical appliances, electricity is used also for lighting, cooking, room heating and water heating.

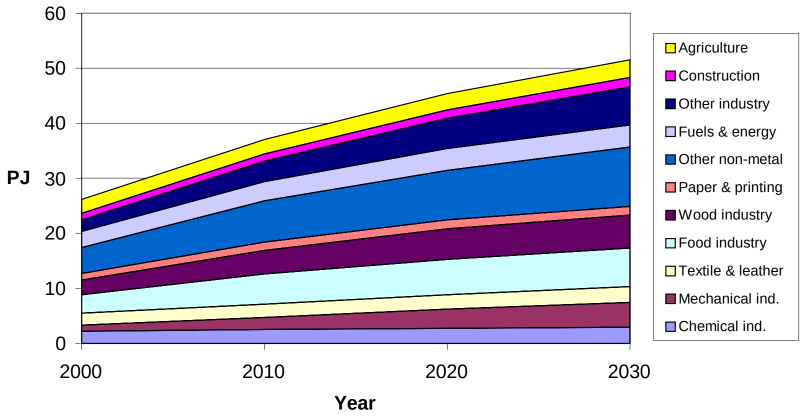

Fig. 2. Final energy consumption forecasts of industry (without a new pulp & paper factory) and agriculture.

Table 4. **Forecast of energy consumption in transport, PJ/year**

	2005	2010	2020	2030
Railways	1.8	2.5	2.8	2.9
Road transport	18.1	18.9	22.6	26.6
Private cars	13 *	15.0	20.0	24.0
Inland waterway	0.3	0.4	0.5	0.6
Air transport	2	1.8	2.6	3.9

* estimation, no adequate data found in [3].

The energy consumption of commercial and public services was modelled via final demand of electricity and heat. The corresponding forecast figures are presented in Table 5.

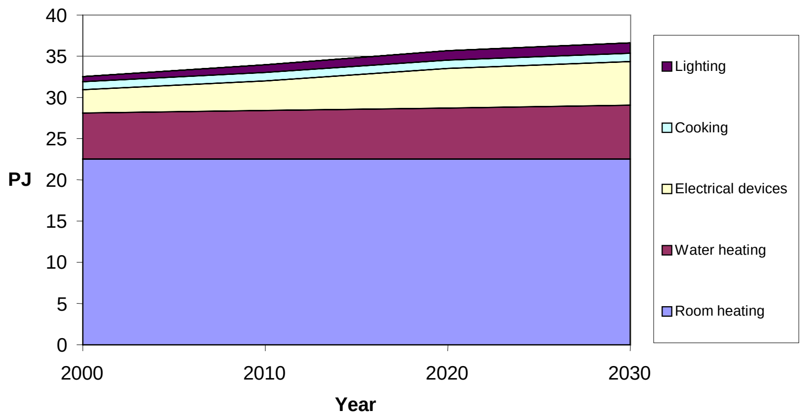

Fig. 3. Consumption projections of useful energy in households.

Table 5. **Forecast of final energy consumption in the service sector, PJ/year**

	2005	2010	2020	2030
Electricity consumption	6.9	8.1	11	14.3
Heat consumption	6.2	6.4	7	7.7

The reference level of total CO_2 emissions from fossil fuel combustion in 1990 is 37.5 Mt. Considering the Kyoto obligation to reduce the emissions by 8% by the years 2008–2012, the limit of emissions of Estonia for the year 2010 can be set at 34.5 Mt. Estonia's net GHG emissions (including all gases, sources and sinks) in 1990 were 37.2 Mt [5, 12]. The lower level of CO_2 emissions proceeds from the much lower local energy and fuel consumption after 1990. Therefore the actual total CO_2 emissions were already 16.43 Mt in the year 2000. It means a 56% reduction compared with the reference year 1990.

Scenarios of energy-related CO_2 emission

WM (with measures) scenario

The following basic assumptions were considered in the scenario:

- Starting from 2008, our power plants will have to comply with the EU directive on the limitation of emissions into the air from large combustion plants. During the accession negotiations with the EU, Estonia was granted some transition periods, but the existing units combusting pulverized oil shale must be closed by the end of 2015 in accordance with the schedule agreed upon. As a result, only 6% of the capacity of power plants that existed in the 1990s (over 3000 MW) may continue operating after 2015.
- Estonia will fulfil the requirements on emission reductions and introduction of renewables. The aim is to introduce renewable energy sources in electricity production in the amount of 5.1% of the total domestic electricity consumption in 2010. Estonian Environmental Strategy and agreements with Finland state that sulphur dioxide (SO_2) emissions in 2005 should not exceed 20% of the 1990 level, emission of solid particles must be reduced by 25%, as compared to 1995, and NO_X emissions should not exceed the 1987 level.
- Environmental taxes continue to increase 20% annually, and they will reach the European forecast values at the end of the planning period.

According to the Estonian Pollution Charge Act, the level of fees for emissions that do not exceed the volume limits in 2006 were as follows (Table 6, 1 EUR = 15.64664 EEK).

Table 6. **Pollution taxes for the year 2006**

Pollutant	SO_2	CO	CO_2	Non-toxic dust	Oil shale ash, fly ash	Soot and coal dust	NO_X
Charge, EEK/t	275	39	15.65	275	275	275	629

There are different multiplication coefficients of fees (from 1.2 to 2.5) depending on the location of the pollution source. The fees will rise 5–100 times if the permitted volumes are exceeded.

- To fulfil the environmental requirements, reconstruction of two production units of oil shale power plants with the total net capacity of 390 MW and renewal of ash filters of all units were completed in 2005. The new units use circulating fluidized bed combustion technology that raises conversion efficiency from 29% to 34% and minimizes sulphur emissions. Next steps in building of new capacity will be decided after gaining experience from the operation of the first units. Considerable options are also coal, peat and co-combustion of different fuels. It is important to continue research on pressurized fluidized-bed combustion of oil shale. Only this technology could guarantee oil shale plants necessary conversion efficiency (ca 44%) and reduction of emissions in the longer perspective.
- Ash removal systems of oil shale power plants have to be renewed before July 2009.

WM scenario is conservative concerning technological development of oil shale combustion. It trusts only the circulating fluidized-bed combustion (CFBC) technology and does not consider the more advanced and efficient but premature pressurized fluidized-bed combustion (PFBC) option.

New power plant and electric grid investments of this scenario are based mainly on the investment plan [13] which envisages partial reconstruction of oil shale power plants on the basis of CFBC technology, but also investments into gas turbines, biomass CHP and wind turbines.

The investment plan [13] states that the power production capacity of *Eesti Energia Ltd* will decrease from the present 100% of peak load and reserve capacity down to 85% of peak load in 2010. As a result of this statement, new independent producers or imports (import is restricted under this modelling exercise) have to cover the rest of the necessary capacity.

There were no specific “forced solutions” in the heating sector.

Estonian CO_2 emissions will never climb up to the Kyoto limit under any scenario. Therefore the additional reduction targets were set concerning the MARKAL model estimate for the year 2010 under WM scenario. This estimate was 16.52 Mt.

WAM (with additional measures) scenario

The following basic assumption was made in this scenario:

- The long-term objective of the National Programme is reduction of greenhouse gas emissions by 21% by 2010 as compared with the 1999 emission level. This includes reduction of carbon dioxide emissions by 20%, reduction of methane emissions by 28%, and an increase in nitrogen dioxide emissions by 9%.

Development in accordance with the information given above yields an unfeasible solution with the assumptions described before.

Instead, the following scenarios are used:

a. WAM-LEVEL1 – gradual reduction of CO_2 emissions by 1% during 2010-2030 compared to the 2010 level in WM scenario.
b. WAM-LEVEL2 – gradual reduction of CO_2 emissions by 15% during 2010-2030 compared to the 2010 level in WM scenario.

WOM (without measures) scenario

All measures described in WM scenario are excluded.

Comments on results

General remarks

Estonia has two main two renewable energy sources – biomass and wind. Hydro potential is only ca 30 MW. Wind power is limited by the balancing capability of the existing power system. The model uses these resources up to their limits.

Future solutions in the Estonian energy system are very sensitive to the price of natural gas. The security of the Russian gas supply is an extremely important factor as well. Here the high gas price scenario was used. The share of natural gas determines largely the CO_2 reduction. If the gas price forecast were lower, condensing power plants and CHP plants mainly on natural gas would be built instead of those using oil shale. Considering the carbon emission factors (tonnes of carbon per 1 TJ of fuel) of oil shale (29.1 tC/TJ for combustion of pulverized fuel or CFB combustion under atmospheric conditions, and 22 tC/TJ for PFBC [14]) and natural gas (15.6 tC/TJ) and the efficiency coefficients of condensing power plants using oil shale (29% for pulverized combustion, 34% for CFBC, 44% for PFBC) and combined-cycle natural gas plants (56%) as well as the lower specific investments and operation & maintance costs and other advantages of natural gas plants, the preference of natural gas is not surprising.

A nuclear plant was excluded under the considered scenarios. The Baltic States are still discussing very seriously the construction of a new joint nuclear plant after Ignalina 3 GW plant will be closed down. A nuclear plant appears in the optimal solution of energy modelling when it is allowed, emission taxes are high and CO_2 targets are strict. It appeared also in the scenario LEVEL1 in the model special test run. A nuclear plant changes the scenario results significantly.

Research on co-combustion of different fuels with oil shale in the fluidized-bed boilers of large power plants is being conducted in Estonia [11], but it has not been implemented. The options are coal, peat and wood-chips. It is estimated that the co-combustion of wood in oil shale power plants would require wood import.

This study did not use the electricity and biomass import options as possible ways for reducing GHG emissions.

MARKAL model is based on the concept of Reference Energy System, and therefore the representation of energy flows differs slightly from the official energy balance statistics.

Scenario without measures

Power plants continue to use oil shale as the main fuel. The existing capacity of power plants will be utilized before the end of the planned lifetime. During 2004–2010, 200 MW of new condensing and 190 MW of new CHP net capacity will be built using CFBC technology to replace the capacity of the old pulverized combustion plants. Coal will dominate after 2015. This presumption is based on different advantages (over oil shale) of coal characteristics – higher caloricity; the existence of larger resources in the earth; more extensive range of effective supply range etc.

Scenario with measures

Power plants continue to use oil shale as the main fuel. During 2004–2015, 1230 MW of new condensing and 190 MW of new CHP net capacity will be built using CFBC technology. The new capacity will replace installed capacity of the old plant combusting pulverized oil shale. This will raise the average conversion efficiency from 28% to 34%, eliminate sulphur emissions and solve fly ash problems.

The more advanced PFBC technology will not be used for oil shale power plants under WM scenario. This technology could give conversion efficiency of 44% and lower the specific CO_2 emissions, but its large-scale implementation is technically questionable today.

At the end of the planning period, a coal power plant will be built.

The total capacity of the CHP plants will increase quite rapidly providing the main future solution for heat production as well. This tendency is common in all scenarios. The CHP potential will be used fully at the end of the planning period in all scenarios, only market shares of different fuels differ by scenarios.

Renewable fuels will be used extensively under this scenario. Wood fuels will reach their resource limit quite fast, and the capacity of windmills will reach the limit at the end of the planning period. More extensive use of renewable energy would require import of cheap biomass (wood).

Condensing power plants using natural gas will be built starting from 2010. Their capacity will be substantial, but their utilization factor will be very low.

They will be used for covering sharp peak loads, balancing wind power, and for reserve capacity. One reason for the low utilization factor is the limited possibility of MARKAL model to describe the load curve in detail.

The main driving factors for CO_2 reduction are the improvement of the conversion efficiency of fossil technologies and the increase in the share of CHP and renewable fuels. In spite of decreasing specific emissions, the total CO_2 emissions will increase after 2005 due to growing energy consumption. The increase is not fast, and the emissions will not reach the 1995 level, not to speak about the 1990 level.

Scenarios with additional measures

CO_2 emission limits will be met mainly by wider use of natural gas in high-efficiency condensing power plants. Use of oil shale in electricity generation will decrease, and PFBC technology will be a considerable option starting from 2015.

The higher the target for CO_2 reduction, the higher will be the share of imported energy carriers (mainly natural gas in addition to motor fuels, coal and fuel oils).

The main modelling results for all scenarios are presented in the following figures. If Estonia decides to build a nuclear power station (600 MW), the primary fuel supply will be more diverse (Fig. 9).

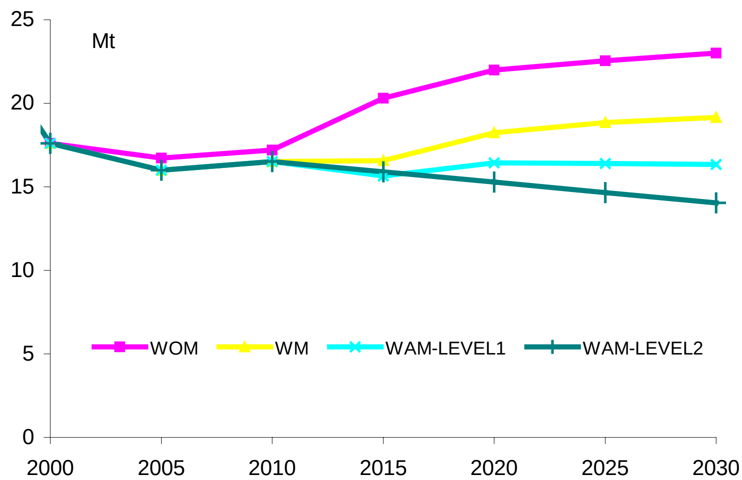

Fig. 4. CO_2 emissions from the energy system.

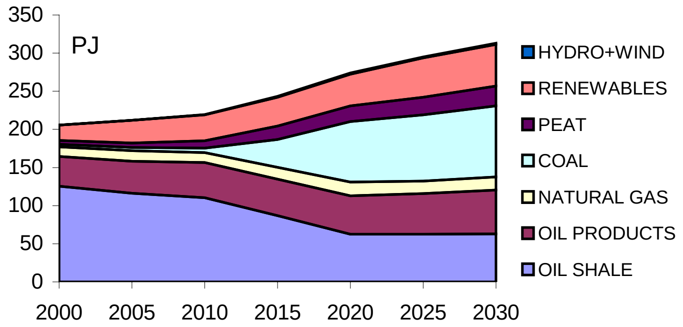

Fig. 5. Primary fuel supply for the scenario without measures.

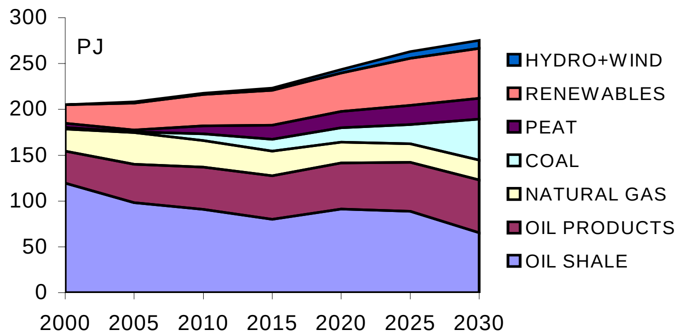

Fig. 6. Primary fuel supply for the scenario with measures.

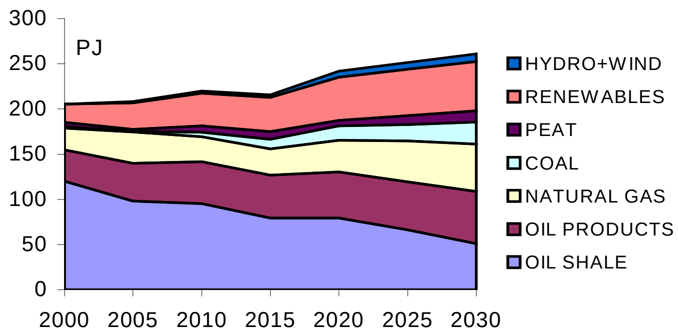

Fig. 7. Primary fuel supply for the scenario with additional measures – LEVEL1.

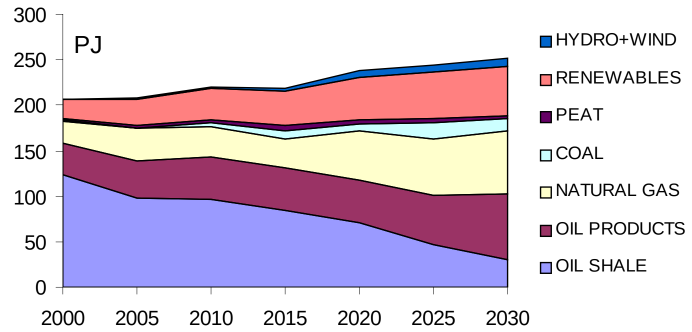

Fig. 8. Primary fuel supply for the scenario with additional measures – LEVEL2.

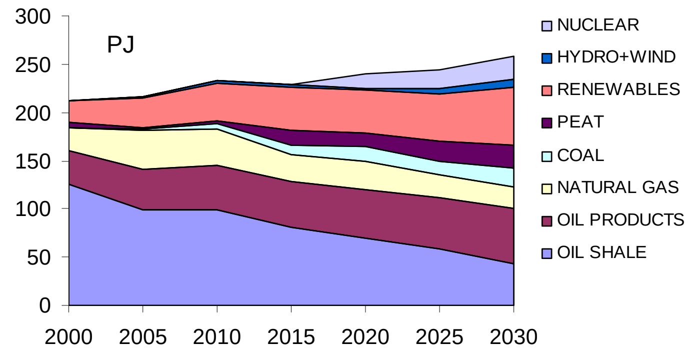

Fig. 9. Primary fuel supply for the scenario with additional measures – LEVEL2, nuclear power available from 2020 on.

Conclusions

During 1990–1993 the energy demand fell due to the economic decline and a sharp rise in the fuel and energy prices, as well as a decrease in electricity exports; this resulted in ca 45% reduction of CO_2 emissions. The trend of CO_2 decrease continued until 2000, and now the emissions are stabilized at a level more than twice below of 1990. For the same reasons, Estonia has been able to meet the requirements set in the agreements on SO_2 and NO_X emissions. To meet the more rigid SO_2 restrictions and growing energy consumption in the future, Estonia must invest in abatement and in new clean and efficient oil-shale combustion technology. Along with the closing of the old oil-shale plants and growing electricity consumption, other fuels will be used. The future increase in energy demand should not be fast due to constantly rising prices and efficient energy use. Usage of different fuel types reduces SO_2 and NO_X emissions which will also reduce the amount of

CO_2. In MARKAL runs the Kyoto Agreement level of CO_2 emissions will never be exceeded. Restricted availability of imported fuels, acceptability of nuclear power or enabling large-scale electricity import can change the results significantly. The results presented here can also change because the database is being improved.

Real actions will be affected also by their social costs and political considerations not taken into account in the modelling. Substitution of oil shale is not easy. It will bring about increasing imports. Being an indigenous fuel, oil shale creates a sophisticated complex of economic, political, national security, social and environmental problems.

The reference level of 1990 for total CO_2 emissions from fossil fuel combustion is 37.5 Mt. Considering the Kyoto obligation to reduce the emissions by 8% by the years 2008–2012, the emissions limit of Estonia for the year 2010 can be set at 34.5 Mt. Estonia's net GHG emissions (including all gases, sources and sinks) in 1990 were 37.2 Mt [7]. The actual total CO_2 emissions were 16.43 Mt in the year 2000. It means a 56% reduction compared with the reference year 1990.

The main findings are as follows:

- According to the Kyoto agreement, Estonia's CO_2 emissions will never climb up to the Kyoto limit under any scenario. There is no need to buy emission permits in the future.
- Main driving factors for CO_2 reduction are the improvement of conversion efficiency of fossil technologies and an increase in the share of CHP and renewables, but also the reduction of grid losses of heat and electricity, as well as energy conservation and efficiency measures.
- This study did not use options of electricity and biomass import as possible ways to reduce GHG emissions. The analysis of markets of neighbouring countries and the EU shows that import possibilities of those commodities may be very limited after 2010.
- Total capacity of CHP plants will increase quite rapidly giving the main future solution for heat production as well. This tendency is common in all scenarios. The CHP potential will be used fully at the end of the planning period in all scenarios, only market shares of different fuels will differ by scenarios.
- Future solutions in the Estonian energy system are very sensitive to the price of natural gas. The security of Russian gas supply is an extremely important factor as well.
- In the WAM (with additional measures) scenarios, the more rigid CO_2 emission limits compared with the WM (with measures) scenario will be met to a great extent by larger use of natural gas in high-efficiency condensing power plants. Use of oil shale in electricity generation will decrease, but the PFBC technology is a considerable option starting from 2015. This shows that it is important to continue the research of pressurized fluidized-bed combustion of oil shale. Only this technology

could provide oil shale plants with the necessary conversion efficiency and reduction of emissions in the longer perspective.

- The higher is the target for CO_2 reduction, the higher will be the share of imported energy carriers (mainly natural gas in addition to motor fuels, coal and fuel oils).
- As for gas supply and also national security, high dependence of the power and heating sector on natural gas (economically optimal under strict environmental restrictions and taxes) is not desirable so long as Estonia has only one gas supplier – Russia.

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