Estonian electricity production scenarios and their CO_2 and SO_2 emissions until 2030

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Abstract - Closing of old oil-shale based power plants and fast development of wind power has raised several issues regarding possible future electricity production capacities in Estonia and their environmental performance. In February 2009 Estonian government adopted a new Development Plan of Energy Sector until 2020. This study was performed in conjunction to the strategic environmental assessment of the plan highlighting especially the CO_2 and SO_2 emissions of electricity production scenarios. The analysis is carried out using the Long range Energy Alternatives Planning System (LEAP) software, which is suitable for elaborating the scenarios and their impact on power balance and to the environment.

Key-Word s – Estonia, development plan, CO_2 emissions, SO_2 emissions, oil shale, wind power

1 Introduction

Estonian energy system is unique for its oil shale based electricity production, which has been an important energy source for many years. For more than 40 years, the two worlds' largest oil-shale fired power plants situated in the north-east Estonia have been producing over 90% of Estonia's electricity.

As it is visible from Figure 1, the electricity production has been reducing from 19 TWh in 1980 to 8,5 TWh in 2000 and thereafter has been increasing reaching 12 TWh in 2007. The export of electricity has been reducing considerably, as in 1970's and 1980's it formed 60% of the generation and has in recent years been approximately 20% of produced electricity. Currently electricity is exported mainly to Latvia and Finland, but by closing down of Ignalina nuclear power plant in Lithuania in the end of 2009, the export is expected to grow even more. [1]

The electricity consumption has been growing since 1990's and is currently about 7 TWh with an increase of 4% in a year.

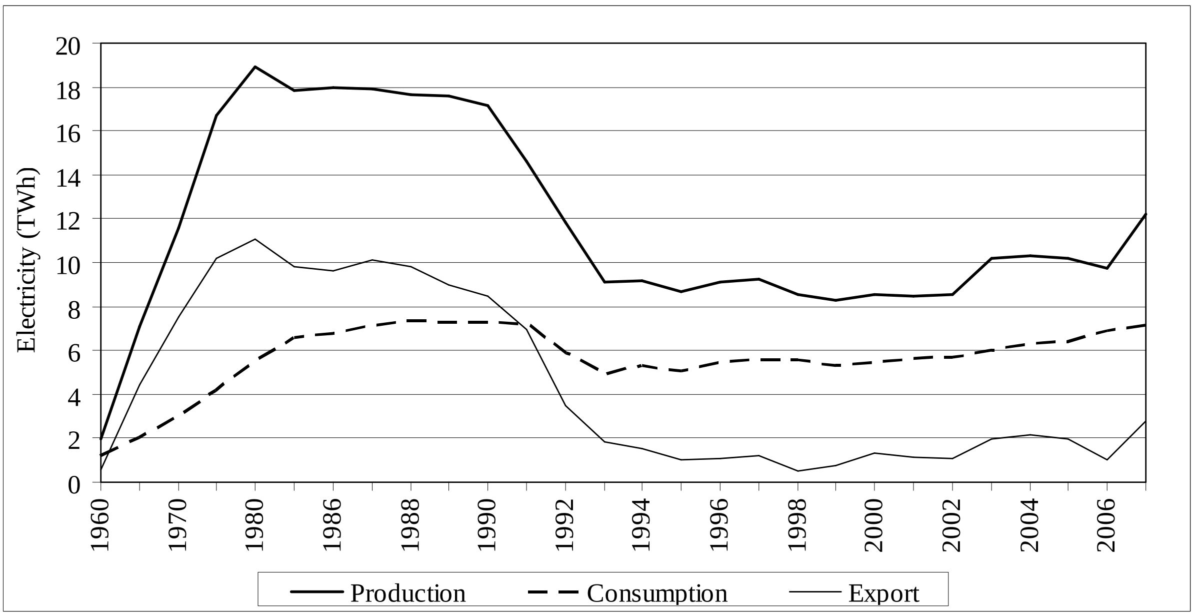

Fig. 1. Production, consumption and export of electricity in TWh

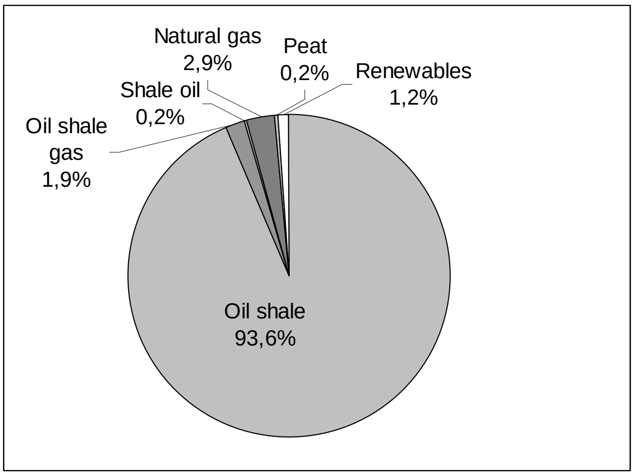

Fig. 2.Electricity generation in 2007

As it is presented on Figure 2 electricity generation in 2007 was 12,2 TWh, of which 93,6% was produced from oil shale, 2,9% from natural gas, 1,9% from oil shale gas and 1,2% from renewable sources. [1]

Oil shale is a local fossil fuel, but there are several environmental issues with regards to its usage. Emissions from oil shale power plants are responsible for most of the CO_2 and SO_2 emissions in Estonia.
The mining quantities of oil shale have been increasing from 11,7 mill. t in 2000 to 16,5 mill. t in 2007 of which 80% is used in electricity and heat production and the rest for producing shale oil (oil product, which can be used alternatively instead of conventional oil) [1].

The total capacity of power producers is currently about 2400 MW, of which 2000 MW is the capacity of before mentioned two biggest oil shale fired power plants. These old pressurized fluidized bed combustion (PFBC) power units were built in 1963-1973. Two new power units with a capacity of 430 MW, started operating in 2003 and 2005, which are using circulating fluidized bed combustion (CFBC) technology. The comparison of unit capacity, efficiency and their emissions are presented in Table 1.
From the table 1 it is seen that the new CFBC power units have bigger unit capacity and higher efficiency, but remarkable changes are seen with regards to their emissions compared to the old PFBC units. Especially the SO_2 emissions, which are over 100 times lower. These PFBC units will be closed after the year 2015 as their sulphur dioxide emissions don't comply with the EU directive requirements. Alternatively it is considered to invest into sulphur capture technologies to keep some of old PFBC units operating [2].

Table 1. Comparison of old and new oil shale combustion technologies. [3, 4]

	PFBC	CFBC
Unit capacity, MW	180	215
Building year	1963-1973	2003, 2005
Net efficiency, %	30	36
SO_2, mg/Nm^3	1900-3000	20
CO_2, t/TJ	102,1	98,8
NO_x, mg/Nm^3	240-320	90-175
Fly ash, mg/Nm^3	2100-2800	30

Closing down of PFBC units will mean that 1600 MW of generation capacity will be out of operation, which is 67% of the total production capacity. [2] Therefore Estonia will face a great production capacity shortage unless there would be new power plants built. New production units are therefore needed to be in operation already in 6 years. As the planning and building of power plants takes several years, definite decisions regarding new production capacities are needed to be made within nearest future.

On the other hand big changes are seen with regards to wind power. It has currently only a small share in Estonian electricity production as the capacity of wind turbines is at the moment 108 MW [2]. In the next years wind power will have a growing role in the electricity generation as it has the biggest contribution to meet the target to produce 5,1% of electricity in 2010 from renewable energy sources [5].

The total capacity of planned wind power projects in Estonia reaches already 4000 MW, which is more than two times higher than the peak consumption of the whole country. Most probably all these projects will not be implemented, but at least 200 MW by 2010 and 400 MW by 2012 will be in operation. [2] The wind resources in Estonia are very good, but there are different technical limitations on its utilization, like lack of regulating reserves to compensate the fluctuations in wind power production [6]. As there are no fast start-up production capacities in Estonia, some balancing measures are necessary if the capacity of wind power exceeds 200 MW. According to the plans the balancing would be performed through exporting the electricity to neighbouring countries and building a 120 MW gas turbine by 2013 and a second submarine cable to Finland. [2]

The study was performed in conjunction to the strategic environmental assessment of the Development Plan of Energy Sector until 2020. This development plan replaces the National Long-Term Development Plan for Fuel and Energy Sector until 2015 that is now divided into specific development plans like development plan for electricity sector, for heating sector, for the use of oil shale, for promoting the use of biomass and bio-energy, energy conservation program and action plan of renewable energy. The development plan of energy sector directs the development related to production, consumption, imports and exports of energy resources, including electricity, heat and liquid fuels. It states the strategic objectives until the year 2020 and aggregates the aims and limitations of specific development plans in this sector. [7]

The Strategic Environmental Assessment of the Development Plan of Energy Sector until 2020 was carried out by Stockholmi Environment Institute's Tallinn centre. The aim of strategic environmental assessment is to define and evaluate the consequences of the plan, their correspondence to national and international environmental targets and to propose suggestions for avoiding and mitigating the environmental damage [8]. The strategic environmental assessment analyses the emissions from electricity and heat sector as well as the use of bio fuels in the transport sector. In this paper only the emissions of different scenarios in the electricity sector are analyzed.

2 LEAP model

The aim of the study is to evaluate CO_2 and SO_2 emissions in case of different electricity production scenarios in the period 2000-2030. The analysis is carried out using the LEAP model and a model of Estonian energy sector is created.

LEAP is a scenario-based energy-environment modelling tool, which is suitable for analysing energy consumption, production and emissions in all sectors of economy [9]. It can be used to account for both energy sector and non-energy sector greenhouse gas emissions. It can be used to create models of different energy systems, where each requires its own unique data structures. LEAP supports a wide range of different modelling methodologies: on the demand side these range from bottom-up, end-use accounting techniques to top-down macroeconomic modelling. On the supply side, LEAP provides a range of accounting and simulation methodologies for modelling electricity generation and capacity expansion planning. [10]

For creating the Estonian energy system model, statistical data for the years 2000-2006 was inserted, which is available in Estonia's statistical database [1] and annual results. Final energy consumption data (all primary fuels, electricity and heat) by different sectors (industry, agriculture, transport, commercial and households) were used. The production units for electricity, heat, oil shale mining and shale oil production were created in LEAP and their production was optimized to represent the real situation. This means that a reference model was built, where the production from generating units would be at the same level as the actual numbers in 2000-2006. Thereafter the development of final energy consumption in 2007 – 2030 was predicted and for the each scenario changes in the production capacities (closing of plants and building of new ones) were made.

The main assumptions of the work:

1. The planning period is from 2000-2030, where 2000-2006 is based on historical data and from 2007 the data is either predicted by LEAP based on historical numbers or is user-defined as changes in the production capacities, building of new plants, etc.
2. The electricity consumption is growing based on gross domestic product (GDP) and elasticity coefficient 0,3. This means that electricity consumption increases annually between 0,9 to 1,5%.
3. The evaluation is given only on emissions from electricity sector.
4. The emission coefficients are taken from LEAP-s database.
5. As the development plans do not concern any changes in the production capacities of cogeneration based on natural gas, wood, peat, biogas and also hydropower, therefore it is assumed that electricity production from these production units will remain at the same level as it is been in years 2000 to 2006.
6. Electricity export is assumed to be at the same level as it is been in years 2000 to 2006.
7. Distribution and transmission losses are assumed to be in the same level as in 2006.

The electricity production scenarios were constructed based on scenarios from Estonia's Long-term Electricity Sector Development Plan until 2018 [11] and National Oil Shale Development Plan for 2008-2015 [12]. Additionally one scenario was added by authors of strategic environmental assessment of the development plan.

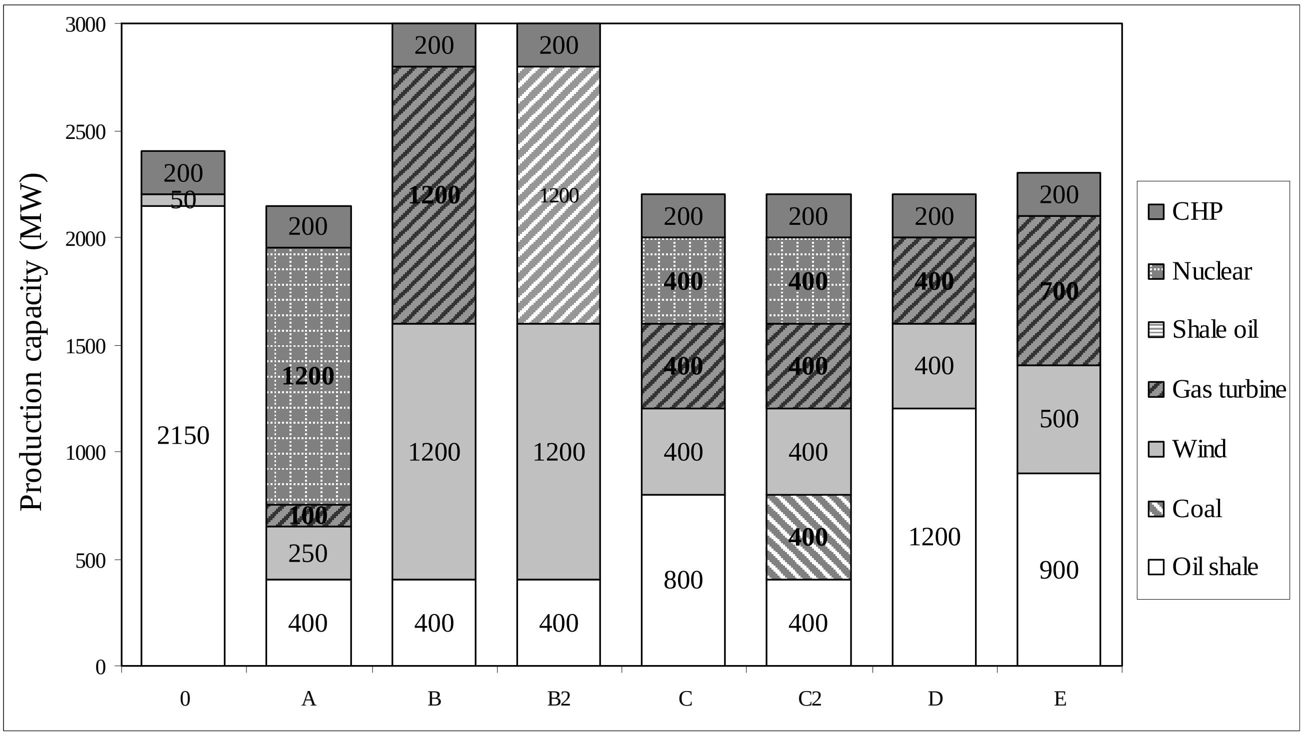

Fig. 3. Production capacities in 2030 of all scenarios

The overview of electricity production capacities in 2030 are presented in the Figure 3. Below each of the scenarios 3 is described separately.

Scenario 0 is the base model, where it is assumed that the current situation will be continuing - there will be no power plants built or closed. There will be 2150 MW of power plants in operation using oil shale (including shale oil, oil shale gas, also CHP), 200 MW of CHP-s (including natural gas, wood, peat, biogas) and 50 MW wind power.

For the all other scenarios it is assumed that the old PFBC units will be closed in 2015. Two CFBC units with a total capacity of 400 MW, 200 MW CHP-s and 50 MW of wind power will remain in operation. In addition the mining capacity is limited. The National Oil Shale Development Plan for 2008-2015 sets the annual mining quantities to 20 mill. t and reducing it to 15 mill. t after 2015 [12].

Scenario A is a nuclear power scenario, where a 1200 MW nuclear power plant will be available in 2025. New wind parks are built and by 2010 the wind power capacity reaches 250 MW. To balance the fluctuating production of wind power, a 100 MW gas turbine will start operating in 2013.

Scenario B foresees a major wind power development, reaching 1200 MW in 2013 and a 1200 MW gas turbine (using natural gas) is built on the same year to balance the production.

As a one sub-scenario B2, a case was studied, when shale oil is used in gas turbine instead of natural gas. This case is derived from discussions in media where it is proposed that in case the old oil shale power plants will be closed; there will be large amounts of oil shale available for shale oil production, which could then be used in gas turbine.

Scenario C is a mix of oil shale, wind, gas turbine and nuclear power, where 400 MW of new oil shale units will be built in addition to existing 400 MW. The capacity of wind turbines reaches 400 MW in 2012 and a 400 MW gas turbine starts operating in 2013. Also 400 MW of nuclear power will be available in 2025.

Scenario C2 is a modification of Scenario C, with the only difference that instead of 400 MW new oil shale units there will be a 400 MW coal based production unit built.

Scenario D is an oil shale scenario, where it is assumed that in addition to existing CFBC units there will be new capacities built for 800 MW. The capacity of wind turbines reaches 400 MW in 2012 and a 400 MW gas turbine starts operating in 2013.

Scenario E is a development of oil shale power plants and wind turbines together with balancing gas turbine. It is foreseen that in addition to existing CFBC units there will be new capacities built for 500 MW. The capacity of wind turbines reaches 500 MW by 2012 and a 700 MW gas turbine starts operating in 2013.

The electricity generation of Scenarios O, A, B, C, D and E are presented in Figures 4 to 9.

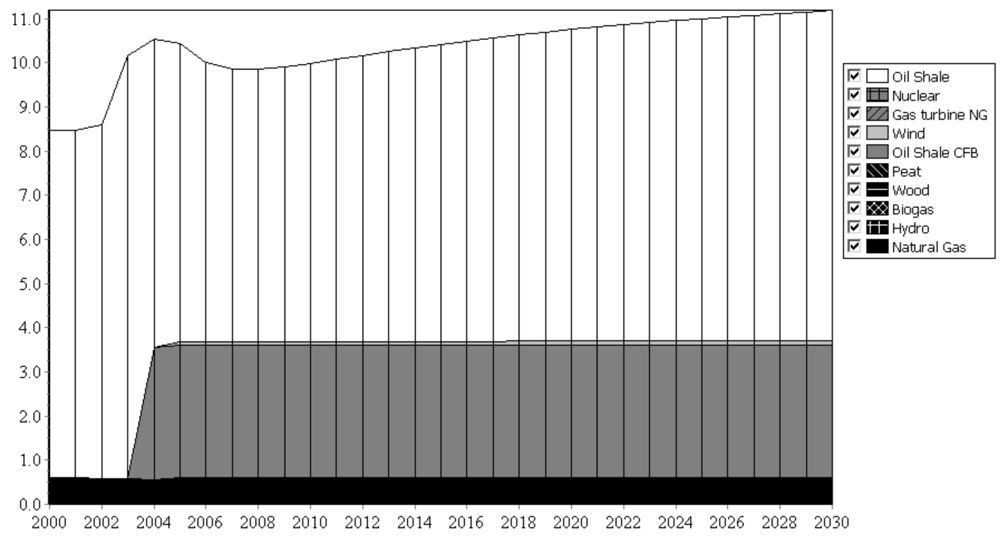

Fig. 4. Electricity generation in TWh of Scenario 0

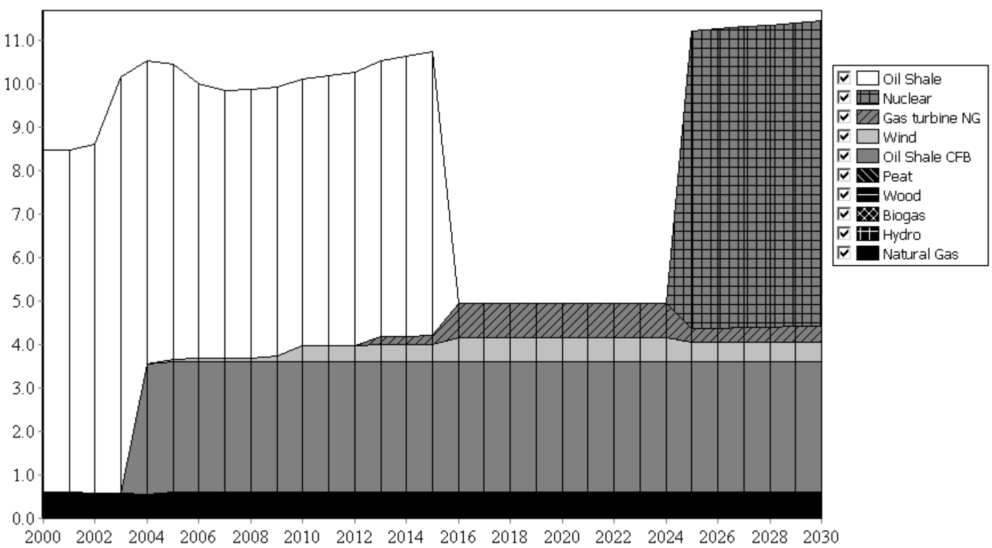

Fig. 5. Electricity generation in TWh of Scenario A

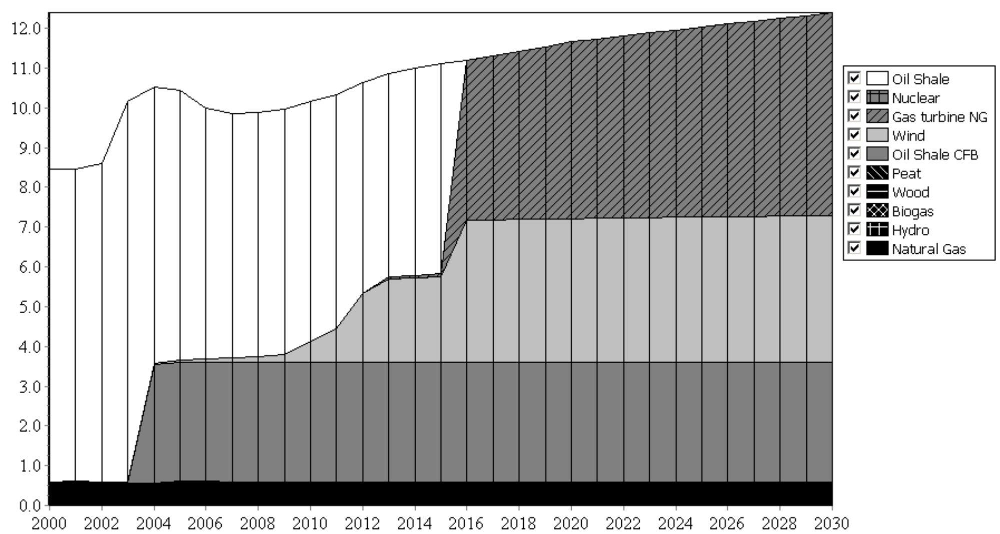

Fig. 6. Electricity generation in TWh of Scenario B

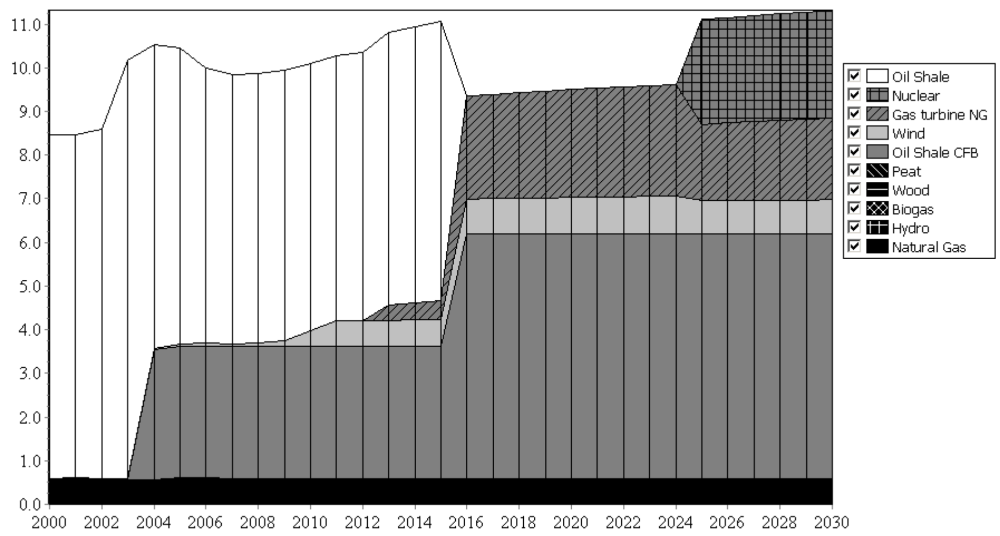

Fig. 7. Electricity generation in TWh of Scenario C

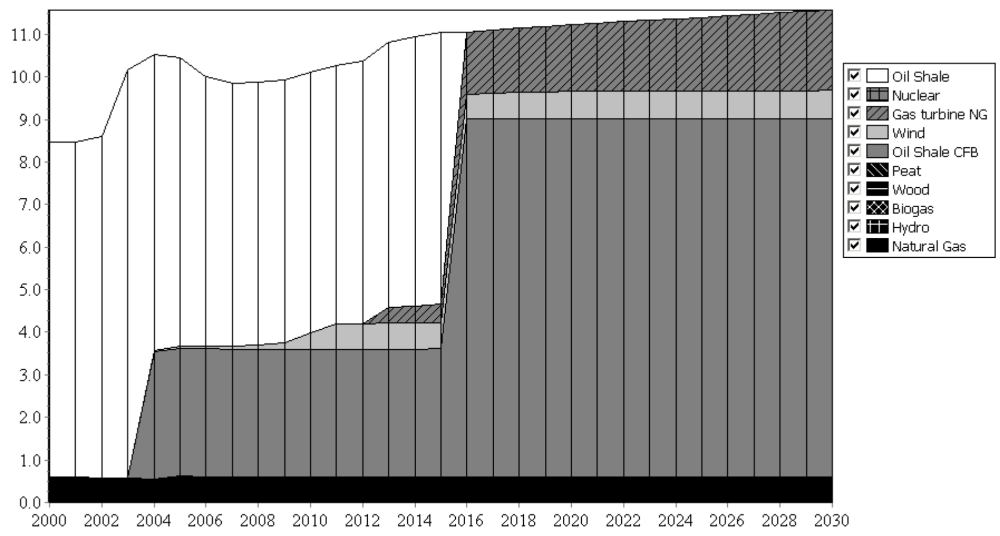

Fig. 8. Electricity generation in TWh of Scenario D

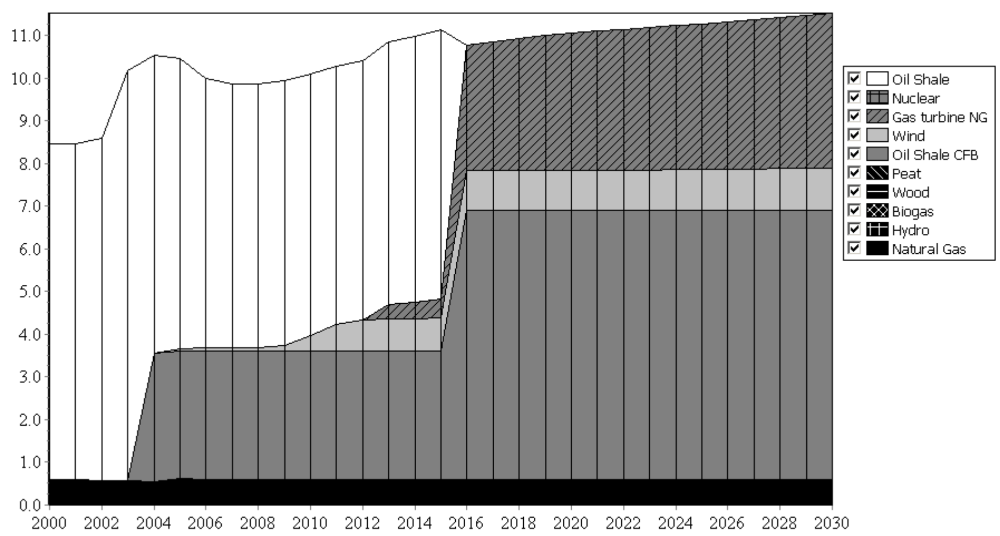

Fig. 9. Electricity generation in TWh of Scenario E

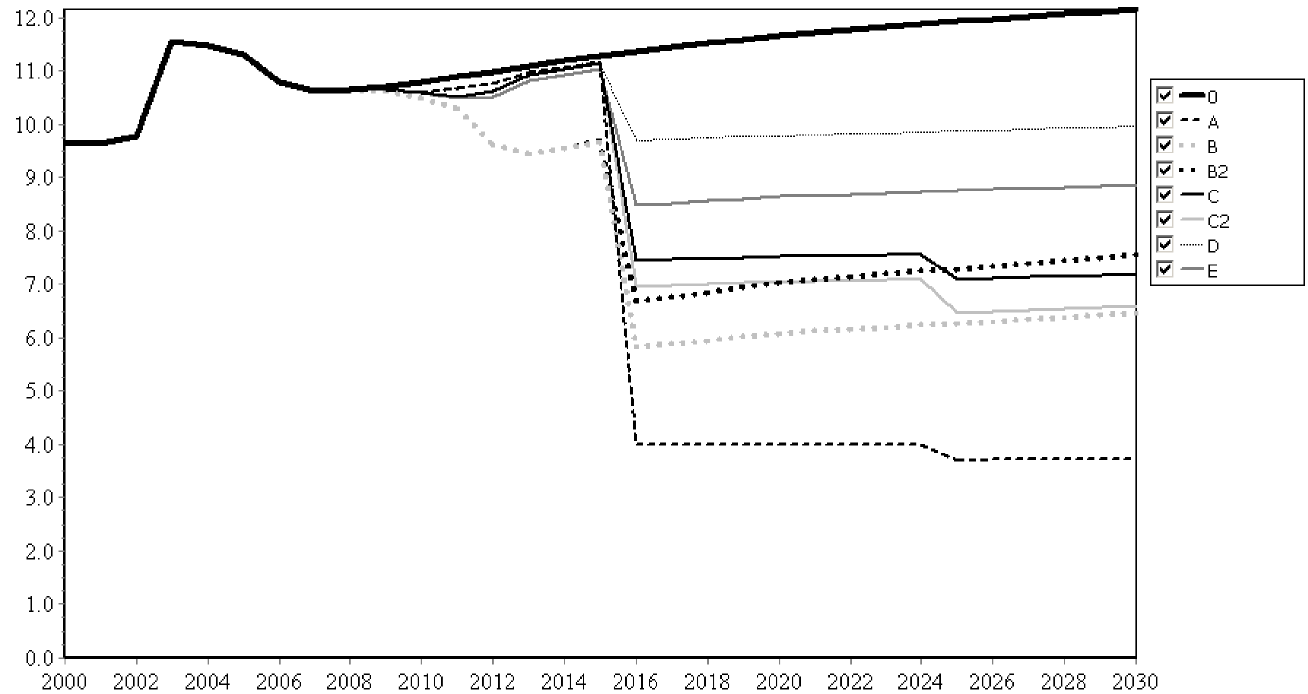

Fig. 10. CO_2 emissions from electricity sector of all scenarios in million tonnes

3 Comparison of emissions

3.1 Comparison of CO_2 emissions

The comparison of CO_2 emissions from electricity sector of above described scenarios is visualized on Figure 10.

From Figure 10 can be seen, that the CO_2 emissions from the electricity generation have been increasing from 9,6 mill. t to 11,6 mill. t in 2003 and the starting point for all scenarios in 2006 is 10,8 mill. t. The emissions are decreasing after 2003 when the new CFCB production units have been replacing the old ones, which have 3% lower [13] CO_2 emissions. But after 2006, the predicted emissions have a slight increasing trend, as the production from conventional power plants is growing due to electricity consumption growth.

It is also clear from Figure 10 that all scenarios will have a lower emission level than the base-scenario 0.This means that closing down of old oil shale power units will have a positive effect on CO_2 emissions.

The highest emissions of scenario 0 are caused by greater oil shale production capacities. Scenarios D (oil shale) and E (oil shale with wind and gas turbine) have also high CO_2 emissions, which is verifying that highest emissions have the scenarios with high oil shale based production capacities This is due to a fact that most of CO_2 emissions are originating from oil shale. Therefore, in this matter the extensive shale oil production should be avoided.

Figure 10 is also showing that the scenario with the lowest emissions is A. The emissions of Scenario A (nuclear power) are remarkably lower than from other ones, as no new oil shale units either wind power plants are constructed, and also due to reason that nuclear power plants are not emitting any CO_2.

It can also be observed from Figure 10, that in spite that the Scenario B (wind power) is the greenest scenario; the CO_2 emissions will be not as low as Scenario A. This is due significant increase in natural gas usage for balancing the wind power production.

The emissions of scenarios B2 (wind with shale oil), C (mixed) and C2 (mixed with coal) are in the medium level.

The level of CO_2 emissions will have a growing importance in Estonia, as already now it is necessary for the power producers to buy some amounts of CO_2 allowances from the market. The national development plan foresees that also in the future Estonia should have production capacity sufficient to supply the domestic consumption. Also it is highly probable that Estonia will continue exporting electricity, as other two Baltic countries are facing shortage of production capacity. Therefore it is very important to make right decisions with regards to building new production capacities when taking into consideration different emission levels from all scenarios. This is a topical question also in other countries [14] of European Union, as the emission allowances will be even more reduced in the future.

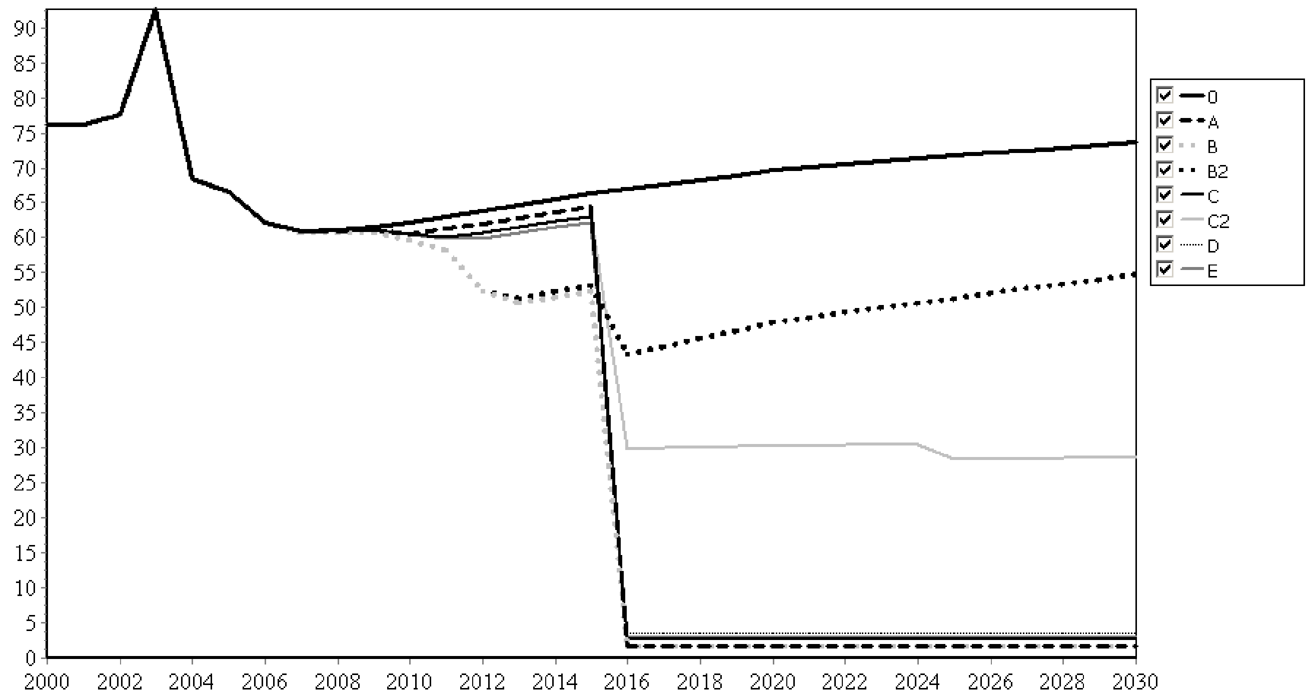

Fig. 11. SO_2 emissions from electricity sector of all scenarios in thousand tonnes

3.2 Comparison of SO_2 emissions

The comparison of SO_2 emissions of eight electricity production scenarios is presented on Figure 11.

From Figure 11 it is evident, that emissions of SO_2 have been decreasing from 93 th. t in 2003 to 62 th. t in 2006, as about one third of electricity is now produced using more efficient CFBC production units, which have remarkable low SO_2 emissions. From 2007 there is again a slight increase in emissions as the production from oil shale power plants is growing.

But from 2016 emissions of most of the scenarios are in the same, low level, which is the point when old oil shale units are closed. Only in Scenarios B2 (using shale oil in the gas turbine instead of natural gas) and C2 (building a 400 MW coal power plant instead of oil shale power plant) the emissions are higher than for the rest of scenarios.

From the Figure 11 can be also seen, that the scenario with highest SO_2 emissions is base-scenario 0. This is due to being the only scenario with so high share of oil shale in the electricity production.

What is interesting is that the scenarios with the lowest SO_2 emissions (A, B, C, D, E) are in the same pollutant level after the year 2015 in spite of fact, that the capacity of oil shale power units are different, which is between 400-1200 MW. The reason for this is that most of the SO_2 emissions are caused by burning oil shale in the old PFBC units, which will be closed in 2015. Whereas the new CFBC units emit over 100 times less SO_2 [3] and therefore the level of emissions will be so low, that the difference in oil shale based generation will not affect the results in a significant way.

The SO_2 emissions are proving that sub-scenarios B2 and C2 have higher emissions as their main models. In the Scenario B2, where shale oil is used in gas turbine instead of natural gas, also the CO_2 emissions will be higher than in B Scenario, but remarkable difference is seen in relation to SO_2 emissions. If in the Scenario B the SO_2 emissions in 2030 are 2 th. t, then in Scenario B2 they are 55 th. t. Therefore, looking in point of view of SO_2 emissions, the use of shale oil in gas turbine instead of natural gas should be avoided.

As for other sub-scenario C2 (400 MW coal instead of oil shale), the emissions will be higher than of Scenario C. Therefore in sense of environmental impact, it is advisable to invest into 400 MW oil shale generation units and not to use coal. As the emissions are dependent on combustion technology used, which in this case was selected from LEAP-s database, the selection of different combustion technology for coal power plant could result in a different outcome.

3.2 Import of electricity

During the analyzing process it was noticed, that in some scenarios the available production units cannot meet the whole electricity demand and therefore import is needed. This means that emissions from imported electricity will be not represented in the emission numbers. Therefore, a question arises whether the results would be different if there is needed to cover the whole demand with local production units. It conflicts also with the national development plan, which foresees to have production capacity sufficient to supply the domestic consumption. The overview of imported electricity in TWh is presented on Figure 12.

From the Figure 11 it is seen, that in the period from 2000-2006 the import has been below 0,5 TWh, which corresponds to real situation, as only small amounts of electricity is needed to balance differences between consumption and production, as the regulating ability of current power producers is not sufficient. After the year 2009 model foresees a growing need for import for some of the scenarios, especially for Scenarios A, C and C2.

As seen from Figure 12, the highest imported electricity quantity has Scenario A, where import reaches 7 TWh in 2024. This is the nuclear power scenario, where in the period 2015-2024 annually about 53-60% of electricity demand will be covered with import. This is caused by situation where the old oil shale power units are closed and no power units are built until the year 2025, when nuclear power plant is starting its operation.

Also in case of Scenario C (mixed version) and C2 (mixed with coal) 20% of electricity comes from imports due to lack of production capacity before the nuclear plant starts operating. Therefore it should be considered to invest into sulphur capture technologies to keep old PFBC units operating until 2025 and thereby reducing the need for import. This of course means that the CO_2 and SO_2 emissions for these scenarios would be higher in the period 2015-2024.

Also Scenario 0 has growing import requirements during the whole planning period, as there is lack of regulating power units in the Estonian power system. Additionally, the limitations of the oil shale mining quantities start to limit the production of oil shale power plants as the electricity consumption is growing and no new power plants will be built.

It is also visible on Figure 11, that the lowest import requirements have scenarios B (wind power) and B2 (wind power and shale oil). The import of these two scenarios is exactly at the same level and therefore you can see only a line for Scenario B on the figure. These scenarios have sufficient production capacities as well as regulating power units, as gas turbine is used to balance the fluctuating wind power.

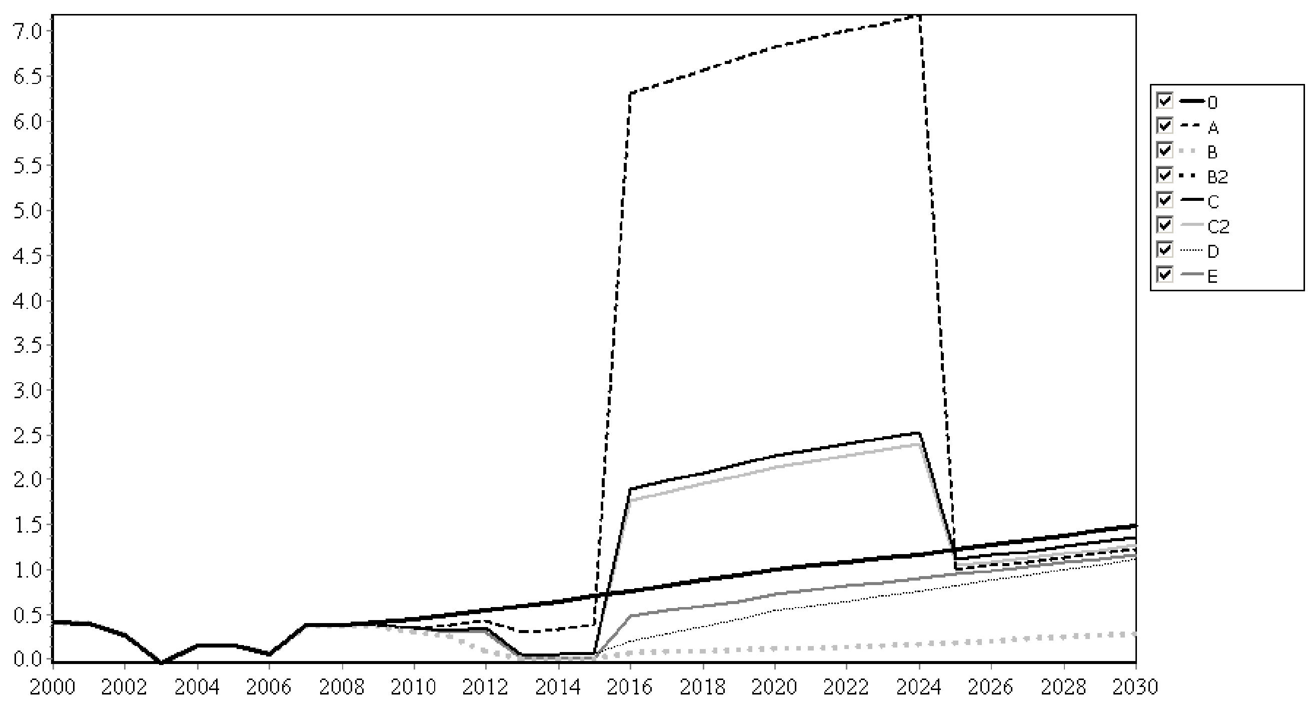

Fig. 11. Import of electricity in TWh of all scenarios

4 Conclusions

Model for Estonia's energy system was created in LEAP software and eight different electricity generation scenarios were designed based on the long term development plans. The CO_2 and SO_2 emissions of these scenarios were presented and analyzed in this study.

Based on analyzed CO_2 and SO_2 emissions it is evident, that all scenarios are showing a reduction of emissions compared to Scenario 0, where continuation of current situation is assumed. Closing down of old oil shale PFBC units will have a significant impact on pollution reduction. The new CFBC units have lower emissions; particularly the SO_2 emissions are over 100 times lower.

The best scenarios regarding the pollution level are A and B. Scenario A foresees use of nuclear power and has the lowest emissions, but during a ten year period more than half of the electricity consumption would be imported. This is due a fact that the old oil shale power units are closed in 2015 and no power units are built until the year 2025, when nuclear power plant stars operating.

As the emissions from imported electricity will be not represented in the emission numbers, a question arises whether the results would be different if there is needed to cover the whole consumption with local production units. One possible way is to invest into sulphur capture technologies to keep some of old PFBC units operating until 2025.

Scenario B is with large wind power development, but its CO_2 emissions will be hence higher than for Scenario A. These additional emissions are coming from gas turbine for balancing wind power. But unlike the Scenario A, in this scenario electricity import is kept on a low level, as there is sufficient production capacity and balancing units available.

Shale oil usage in the gas turbine instead of natural gas was also investigated in Scenario B2, but due to higher emissions it would not be environmentally thoughtful.

Scenarios with high oil shale share, like 0, D and E verified that is very important to limit oil shale mining and extensive oil shale power production, as emissions from these scenarios are higher than for the others. Analysis of Scenario C2 proved that it's also not advisable to invest into coal power plant instead of oil shale. But selection of different combustion technology for coal power plant could result in a different outcome

The level of CO_2 emissions will have a growing importance, as also in the future Estonia should have production capacity sufficient to supply the domestic consumption as well as some export to neighbouring countries. As the emission allowances set by European Union will be reduced even more in the future, therefore it is very important to make right decisions with regards to building new production capacities when taking into consideration different emission levels from scenarios presented in this study.

Acknowledgements

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