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Analysis of current Estonian energy situation and adaptability of LEAP model for Estonian energy sector

Nadežda Dementjeva,

Andres Siirde

Department of Thermal Engineering,
Tallinn University of Technology,
Kopli 116, 11712 Tallinn, Estonia
E-mail: nadezda.dementjeva@energia.ee

The trend of liberalization and changes in the Estonian energy market, related to the European Union's strict technological and environmental requirements, implies the need to develop the modelling of new scenarios for the energy sector in Estonia by mitigating the environmental impacts of electricity production and using a new, less environment-damaging technology. The easiest way to develop such scenarios is to use energy planning modelling.

Modeling is one of the complicated methods of forecast. In recent years, a large number of energy planning models have been developed. They vary considerably, and the question arises which model is the best for a certain purpose or situation.

This paper presents part of a study carried out under a PhD thesis at the Department of Thermal Engineering of Tallinn Technical University. The objectives of the study were analysis and evaluation of the energy models existing in the world; development of selection criteria and selection of several energy models for the analysis of energy market in Estonia; practical testing of the applicability of the selected models to Estonia.

The first part of this paper gives an overview of the current energy supply in Estonia and the future changes of the Estonian energy production system related to restrictions in technology and environment. The second part presents the result of testing the LEAP model adaptability for elaborating scenarios of the Estonian energy system development.

Key words: energy planning model, electricity market, LEAP, reference energy system, liberalization, energy demand, electricity production

1. INTRODUCTION

Energy is an essential part of the social and economic development of any country and nation. Due to increasing awareness of the environmental impact of energy production, the goal of national energy policies is not only to guarantee a secure and cost-effective energy supply, but also to minimize the harmful side effects and, eventually, develop a sustainable energy system.

The trend of liberalization and changes in the Estonian energy market, related to the European Union's strict technological and environmental requirements, gives rise to the need to develop the modelling of new scenarios for the energy sector in Estonia by mitigating the environmental impacts of electricity production and using new, less environment-damaging technology. The easiest way to develop such scenarios is to use energy planning modeling. Instead of developing a new model, the existing ones can be used, but the key problem is to decide which model should be used. Energy models are based on different fundamental approaches and concepts and employ a range of mathematical algorithms.

In order to decide which model is better to use, we explained the model characteristics, structures, data and modelling methods in our previous paper [1].

As part of that work, we presented different scenarios of the Estonian energy system development in the conditions of oil shale-based electricity supply shortage, taking into account the main engagements and figures of the electricity sector by year 2020. The aim of this paper is to present a simplified model of the Estonian energy system with a transparent structure. The purpose of the model is to demonstrate the usage of its features in connection with the Estonian electricity system.

2. CURRENT ENERGY SUPPLY IN ESTONIA

Today, more than 90% of Estonian electricity demand is being covered by local oil shale power plants. Most significant of them are the Eesti Power Plant with the installed electrical capacity 1 615 MW and thermal capacity 84 MW and the Balti Power Plant with the installed electrical capacity 765 MW and thermal capacity 400 MW. The main achievement of late years is introduction of a new technology of oil shale combustion in a circulating fluidized bed at Unit 8 of the Eesti Power Plant and Unit 11 of the Balti Power Plant. Application of the new technology has enabled improvement of the operational efficiency as well as considerably decreased the amount of hazardous emissions.

The Iru Power Plant is the biggest producer of thermal power and the third biggest producer of electrical power in Estonia with the electrical capacity 190 MW and heat capacity 648 MW (398 MW in co-generation mode). The main fuel of the Iru Power Plant is natural gas. The AS Kohtla-Järve Soojus (Kohtla-Järve District Heating Network) uses also oil shale, and its electrical capacity is 30 MW and thermal capacity 138 MW. Power plants using renewable energy, such as the Virtsu wind turbine, Linnamäe and Keila-Joa hydroelectric plants, produced 1.2% of the annual electrical energy production in 2007 [2].

The total electricity and heat production in Estonia by energy sources in 2008 is presented in Figs. 1 and 2 [3].

2.1. Estonian electricity market

The market structure has similarities to the Scandinavian model with the System responsibility given to the transmission system operator.

The Estonian electricity market has a monopolistic market where one energy enterprise (Eesti Energia AS) dominates. Its prices are under state regulation, but it dictates the conditions and connection fees to small producers for access to its network. The Estonian domestic market is divided into three categories – sales to the open market, sales to the closed market and external sales to network operators.

In 2008, the total net generation from all power plants in Estonia was 9 498 GWh, i. e. decreased by 1 456 GWh 13% compared to the year 2007 [3]. The total electricity consumption in Estonia was 7 836 GWh; a decrease was 97 GWh or 1% compared to the year 2007. The Estonian electricity net generation and consumption by months in 2008 is presented in Fig. 3 [4].

According to the European Union requirements, the Estonian electricity market must be opened 35% by the end of 2009 and fully opened by the year 2013. Today, the Estonian electricity market has been open for eligible customers whose annual consumption exceeds 40 GWh since 1999. These consumers have a right to purchase electricity from any producer or seller in the market and are obliged to pay

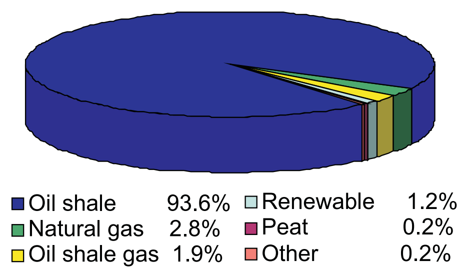

Fig. 1. Total electricity generation by energy sources in 2008

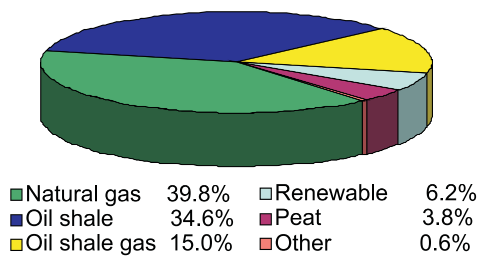

Fig. 2. Total heat generation by energy sources in 2008

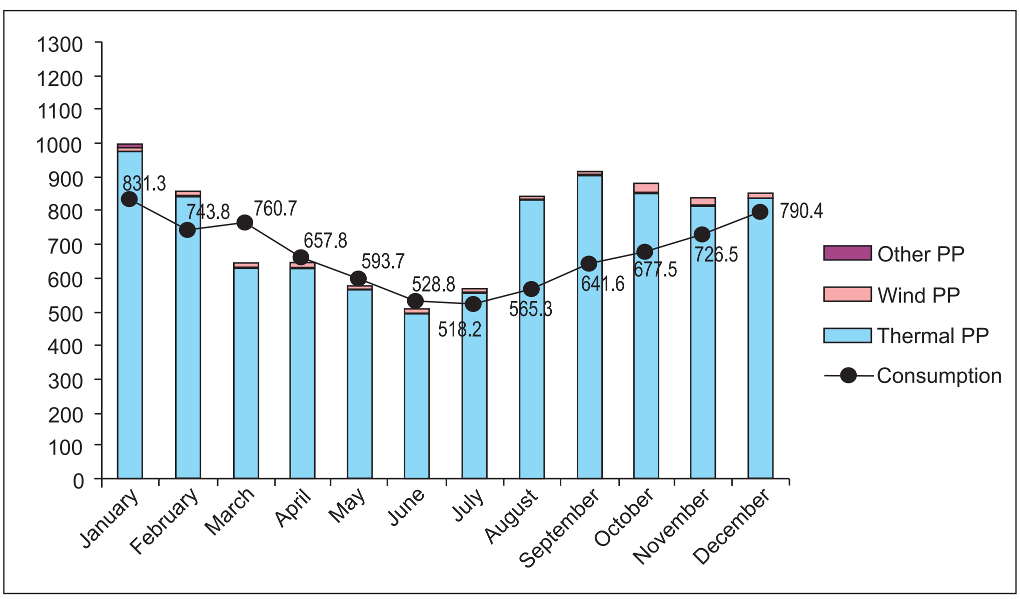

Fig. 3. Estonian electricity net generation and consumption by months in 2008

for network services. At present, there are 13 eligible costumers in the system; they consume about 16% of energy in Estonia. Non-eligible customers can purchase electricity from the grid company they are physically connected to or from the seller named by that grid company. Grid companies and sellers selling energy to non-eligible customers can purchase energy from power plants using oil-shale mines in Estonia as the primary energy source or from small producers with capacities less than 10 MW.

Liberalization of electricity market or opening electricity production and sales for competition will raise the system's efficiency and quality of services in Estonia, but considering the small size of the Estonian electricity market, the complication of power system control, shortage of generation capacity, costs of operating the market, volatile prices and the possible lowering of supply security and reliability due to insufficient investments in the whole region can easily surpass the expected positive effect of liberalization [5].

The strategic objective of the Estonian electricity sector development plan until 2018 is to assure the optimal functioning and development of the Estonian power system in the market economy conditions and to assure in the long-term outlook the proper supply of electricity to the consumers at the lowest price possible, at the same time implementing all reliability and environmental conditions.

Since March 2009, Eesti Energia's electricity weighted average price limit is 32.5 €/MWh. In addition to domestic electricity sales, Eesti Energia exports electricity via the Nordic energy exchange Nord Pool to Finland. Electricity export price is determined by the Nord Pool Finland regional price level (Fig. 4). Besides, the Eesti Energia Group exports electricity to the other Baltic States [6].

The main engagements and figures concerning the energy sector development by year 2020 are as follows [7]:

- diversification of energy sources used in the generation sector, including construction of the Estonian nuclear power plant by 2020 and decreasing the dependency of oil-shale generation;
- by 2010, renewable electricity will form 5.1% of gross consumption;
- by 2020, electricity produced in combined heat and power production plants will account for 20% of gross consumption;
- to open the Estonian electricity market by 35% in 2009 and to all consumers in 2013;
- limitation of energy consumption;
- preconditions will be established for connecting with energy systems of the Nordic and Central European countries, including the new interconnection, Estlink 2, between Estonia and Finland.

After 2015, about 70% of available installed net generation capacity of existing oil shale based units will be shut down. In operation will be two new fluidized bed boilers in the Narva Power plants, the second generation unit in the Iru Power plant and small power plants. The Estlink cable between Finland and Estonia, commissioned right at the end of 2006, increased the possibilities of power imports and export from and to Estonia.

The major investments in electricity production will be:

- peat and biomass CHP-s with the gross capacity of 100 MW in 2010–2015;
- wind turbines with the gross capacity of 618 MW by the year 2015;
- the 1st oil shale CFBC unit with the gross capacity of 270 MW in 2015;
- the 2nd oil shale CFBC unit with the gross capacity of 270 MW in 2016;
- natural gas combined cycle plant with the gross capacity of 100 MW in 2012;
- nuclear plant with the gross capacity of 600 MW in 2020.

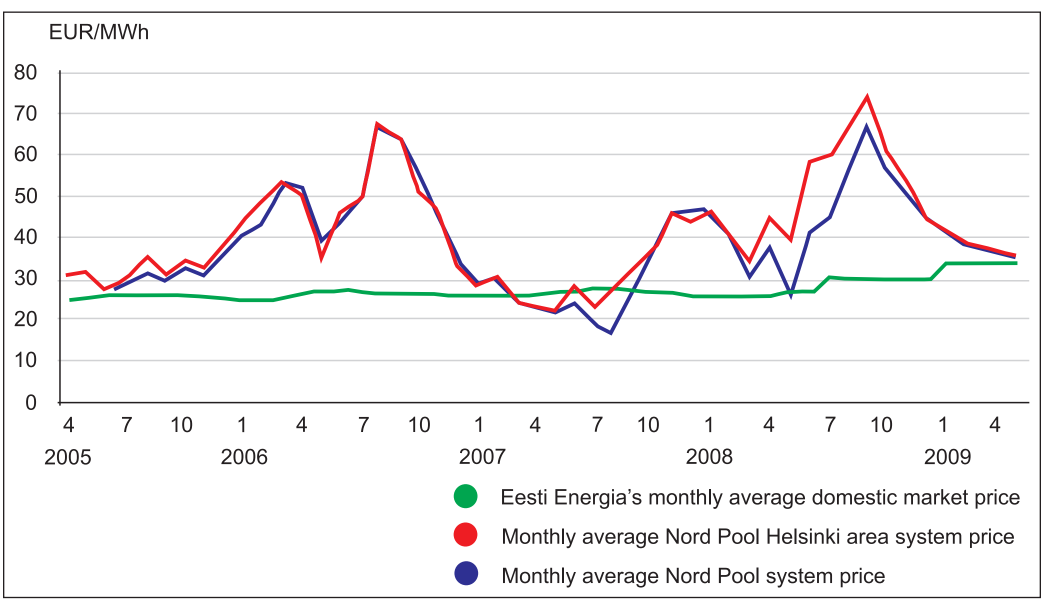

Fig. 4. Eesti Energia's average domestic market prices by months, 2005–2009

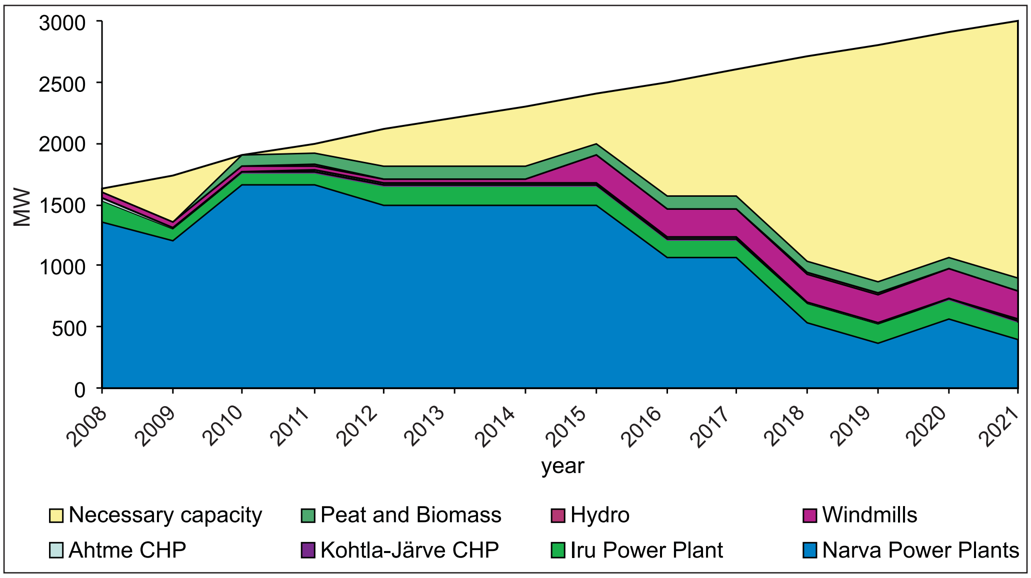

Fig. 5. Electricity supply and demand forecast

The electricity supply and demand forecast in Estonia are presented in Fig. 5 [8].

Countries with liberalized markets need new methods for energy planning, because the uncertainty is increasing and the problems are aggravating. Also, there are more transactions to process, more data and information to manage the planning processes, and more attention should to be paid to how to formulate and implement the models efficiently. In practice, it is not feasible to develop one's own models for energy planning exercises by energy planners and researchers; it is more effective to use existing models, but the key issue is to decide which model should be used.

3. CLASSIFICATION AND BASIC STRUCTURE OF ENERGY SYSTEM MODELS

Models are built for various purposes and consequently have different characteristics and applications.

The nine ways of classification are presented:

1. Purposes of energy models:
   - general: forecasting, exploring, backcasting;
   - specific: energy demand, energy supply, impacts, appraisal, integrated approach, modular build-up.
2. The model structure: internal assumptions and external assumptions.
3. The analytical approach: top-down, bottom-up and hybrid.
4. The underlying methodology: econometric, macroeconomic, economic equilibrium, optimization, simulation, spreadsheet / toolbox and backcasting.
5. The mathematical approach: linear programming, mixed-integer programming, dynamic programming.
6. Geographical coverage: global, regional, national, local, or project.
7. Sectoral coverage: single-sectoral models and multi-sectoral models.
8. The time horizon.
9. Data requirements.

Such classification of energy models is helpful for understanding their need, role and specificity in relation to the studies under consideration [9].

The structure of a model is often illustrated by a reference energy system (RES) which is a network depicting flows of commodities through various processes. This network includes all energy carriers involved with primary supplies (e. g., mining, petroleum extraction, etc.), conversion and processing (e. g., power plants, refineries, etc.), and end-use demand for energy services (e. g., boilers, automobiles, etc.). The building blocks depicted in Fig. 6 represent a simplified RES [10].

According to the model's main characteristics we proposed the selection criteria of the energy planning models from the point of view of the Estonian energy sector in [1]. We selected also several existing energy models: (EFOM, TIMES, LEAP, MARKAL, MESAP, MESSAGE, MIDAS, PowerPlan, RETScreen and EnergyPlan) for the analysis of the energy market in Estonia. The application of these models is given in the next chapter.

3.1. Application of existing models

The selected energy planning models were applied to various practical cases. This chapter presents an overview of their application.

The effects on the entire energy system by a reduction in the amount of imported energy are studied by applying the EFOM model to the energy situation in Denmark [11] and for investigating the emission control strategies of Turkey [12].

The TIMES model is usually applied to the analysis of the entire energy sector, but it may also be applied to study in detail single sectors (electricity and district heat). Using the TIMES framework, there were developed several works for different countries: an energy system model for the Southern

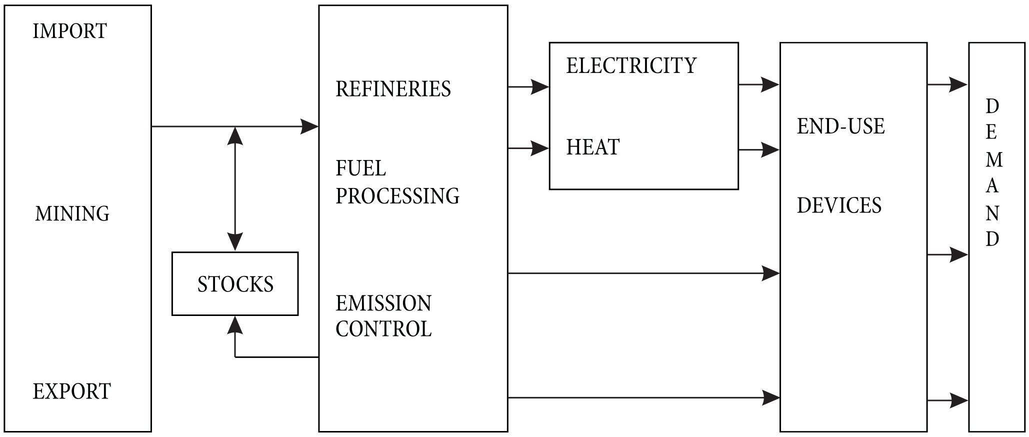

Fig. 6. Reference Energy System (RES)

African Development Community region [13], the Nordic Electricity Production System [14], estimation of CO_2 marginal abatement costs for Portugal [15], and several works on the optimisation of the electricity, heat and natural gas markets of 25 trading regions in [16, 17].

Hundreds of governmental agencies, academic organizations, utilities and consulting companies worldwide use LEAP for a variety of purposes including, energy forecast, greenhouse mitigation analysis, integrated resource planning, production of electricity and heat energy sectors and energy scenario studies. Numerous countries have used LEAP to prepare greenhouse gas mitigation assessments as part of their initial national communications to the United Nations Framework Convention on Climate Change. The Department of Energy of the Government of the Philippines presents the National Energy Plan [18], and scenarios for five cities in South Africa have been modelled using LEAP [19]. The LEAP model was used to compare scenarios of oil shale long-term trends in the report of Estonian Electricity Sector Development Plan until 2018 [7].

MARKAL is a model well-known in Estonia for modelling the entire energy sector. The analysis has been carried out using the Estonian MARKAL model [20, 21]. Recently, two doctoral theses at the Tallinn University of Technology have been defended, based on MARKAL calculations [22, 23].

An industrial module was developed to form part of the applicable energy system analysis tools, namely the Reference Energy Model for PlaNet (PlaNet: Planning Network) under the MESAP (Modular Energy System Analysis and Planning Environment) for Slovenia [24] and for neighbouring Latvia [25].

MESSAGE was used [26] for the entire energy supply system in the Baltic states.

MIDAS covers the whole energy system, including energy demand by sector and fuel, power generation, oil refineries, natural gas, solid fuel production, imports and energy market prices. The results of MIDAS application in France and EU are given in [27, 28].

The PowerPlan model is simulating a country's power sector and its emissions. A study based on scenarios developed in PowerPlan was carried out in China's power sector [29].

The RETScreen model includes the whole energy sector, and the list of its applications is given in [30]. Numerous examples of implementing commercially viable energy-efficient and renewable energy technologies around the world, such as Wind Farm in Ireland, Solarwall on High School in Northern Canada, the Photovoltaic Water Pumping System in Africa, Solar Water Heating at the Vancouver International Airport and many others. An investigation of the future project of a waste incineration plant at the Iru Power Plant in Estonia was carried out.

In 2005–2007, the EnergyPlan model was used in the EU-funded project DESIRE (Dissemination Strategy on Electricity Balancing for Large Scale Integration of Renewable Energy). In six countries (Denmark, Germany, the UK, Poland, Spain and Estonia), models of electricity supply were made and the magnitude of CHP regulation systems was evaluated against other relevant measures including expansion of interconnectors [31].

4. ADAPTABILITY OF THE LEAP MODEL

4.1. Energy power system development scenarios

According to selection criteria applied in the current study, the LEAP model was selected as the preferred framework for elaborating scenarios of the development of the Estonian energy system, in which the most essential reasons for selecting were a free use of a model and training materials, public technical support and discussion, user-friendly interface; it allows for a transparent arrangement of data, various possible scenarios and can be developed in energy system configurations.

The whole study presents the adaptability of models freely available for users: RETScreen, EnergyPlan and LEAP. A more detailed result of application of RETScreen, EnergyPlan models is given in the calculations of heat energy supply alternatives of modelling in the Narva city [32]. This chapter includes only the results of testing the LEAP model.

A significant part of the study is devoted to input data collection for the LEAP model and could not be reflected to a full extent in this paper. Using the input data, taking them mainly from the Statistics of Estonia [3], Eesti Pank's forecasts [33], energy savings in Eesti Energia AS webpage [6] and the training exercises of LEAP [34], the database of Estonia's key assumptions in the LEAP model was compiled.

Using the Estonia LEAP model, eight alternative scenarios were elaborated for the Estonian electricity production system for the period 2009–2035 in the conditions mentioned in Chapter 2:

1. Reference scenario (REF)

The Reference Scenario represents a today's situation of Estonia's energy sector. This scenario suggests that the CFBC oil shale units will be renovated and the production of electricity from oil will prevail. The penetration of various renewable energy technologies, such as wind and biomass power generation, is considered for the existing situation. In the REF, the −12.3% GDP growth rate in the year 2009 and the forecasts are based on Eesti Pank's revised forecast of the first quarter [33].

2. Low-growth scenario (LG)

This scenario assumes a low GDP growth rate of −15.3% in the year 2009 relative to the −12.3% GDP growth rate assumed in the REF scenario in the same year, and the forecasts are based on Eesti Pank's revised forecast of the first quarter [33]. All other assumptions and other parameters are similar to the REF scenario.

3. High-growth scenario (HG)

This scenario assumes a high GDP growth rate of −8.4% from year 2009 relative to the GDP growth rate of −12.3% assumed in the REF scenario in the same year, and the forecasts are based on Eesti Bank's revised forecast of the first quarter [33]. This scenario shows an optimistic view of the Estonian economy. All other assumptions and other parameters are similar to the REF scenario.

4. Nuclear capacity scenario (NUC)

In this study, nuclear-energy-based power generation has been included as per Eesti Energia plans. The installed capacity of nuclear power plants is 600 MW in year 2020. The nuclear energy-based power generation capacity is expected to be in the amount of 5 000 GWh per year from the start of the nuclear power plan. Additional information about nuclear power plant scenarios is given in [22].

5. Renewable energy scenario (REN)

In this scenario, a high penetration of renewable energy is considered. The potential places are identified for wind-based power plants in the country, such as offshore wind farms in Estonian waters and a wind farm on the closed ash field at the AS Narva Elektrijaamad. The availability capacity of wind power plants is assumed to increase to 618 MW by the year 2012 versus the existing 117 MW in 2009.

6. Hybrid scenario (HYB)

This scenario is a combination of the REF, REN and NUC scenarios. It describes the energy forecast of the Estonian economy by incorporating the entire range of renovation and development of oil shale technologies, penetration of nuclear energy-based power generation technologies, renewable energy sources and the starting up of a new gas turbine with the capacity of 100 MW after year 2012. The GDP growth rate is as in the REF scenario.

7. Low-growth-hybrid scenario (LHYB)

This scenario combines a low GDP growth rate like in the LG scenario and the HYB scenario with energy technologies development.

8. High-growth-hybrid scenario (HHYB)

This scenario combines a high GDP growth rate like in the HG scenario, coupled with a high nuclear capacity and penetration of renewable energy like in the HYB scenario. This scenario is representative of the most optimistic scenario in terms of both economic growth and technological achievements.

4.2. LEAP model results across various scenarios

A comparative analysis of the key results across all the scenarios is presented in this chapter.

Figure 7 presents the sectoral energy demand across the various scenarios that include commercial, transport, industrial and residential sectors. The requirements under the demand category show only the primary energy required to meet the domestic demands. In the REF, REN, NUC and HYB scenarios, the total energy demand increases annually by 1.43% during the period 2009–2035, taking into account the economic growth projections of the country in these scenarios. However, it increases annually by 0.7% and 1.6% in the LG and HG scenarios, respectively. Also, in the LHYB and HHYB scenarios the total sectoral energy demand increases the same as in LG and HG scenarios.

Figure 8 shows primary energy consumption across various scenarios, where the primary energy requirements under the resources category account for converted energy system requirements.

In the REF, REN, NUC scenarios, the primary energy consumption decreases annually by 0.76% during the period 2009–2035, taking into account the shortage of electricity production in the country after 2020 in the REF. It decreases annually by 1.0% in the LG and by 0.72% in the HG scenarios. It also decreases annually by 0.67% in the HYB scenario, by 0.92% in the LHYB and by 0.64% in the HHYB scenarios. The sharp drop of primary energy consumption after 2020 is caused by reduction in the consumption of oil shale by almost 50% of the total amount. This reduction is attributed to the old oil shale units closing after 2020. Estonia has applied it for the transition period to solve the problems of the oil shale-based energy sector development and to reduce the hazard emissions.

Figure 9 presents a comparison of electricity generation across various scenarios. In the REF, LG and HG scenarios, the total electricity generation decreases from 9 TWh in 2008 to

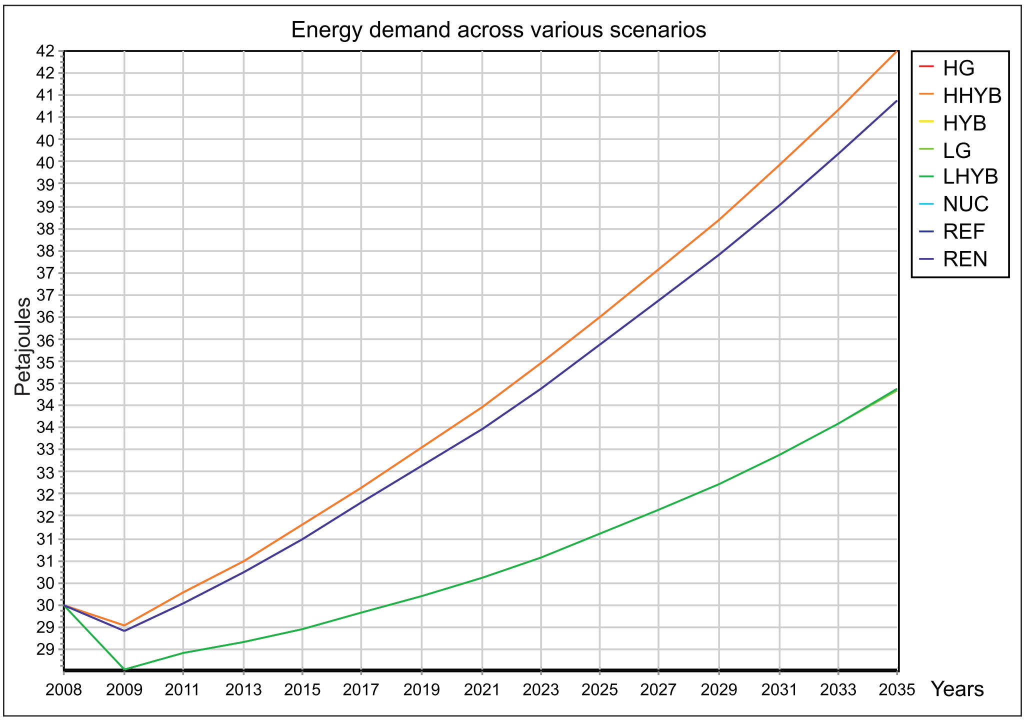

Fig. 7. Energy demand across various scenarios

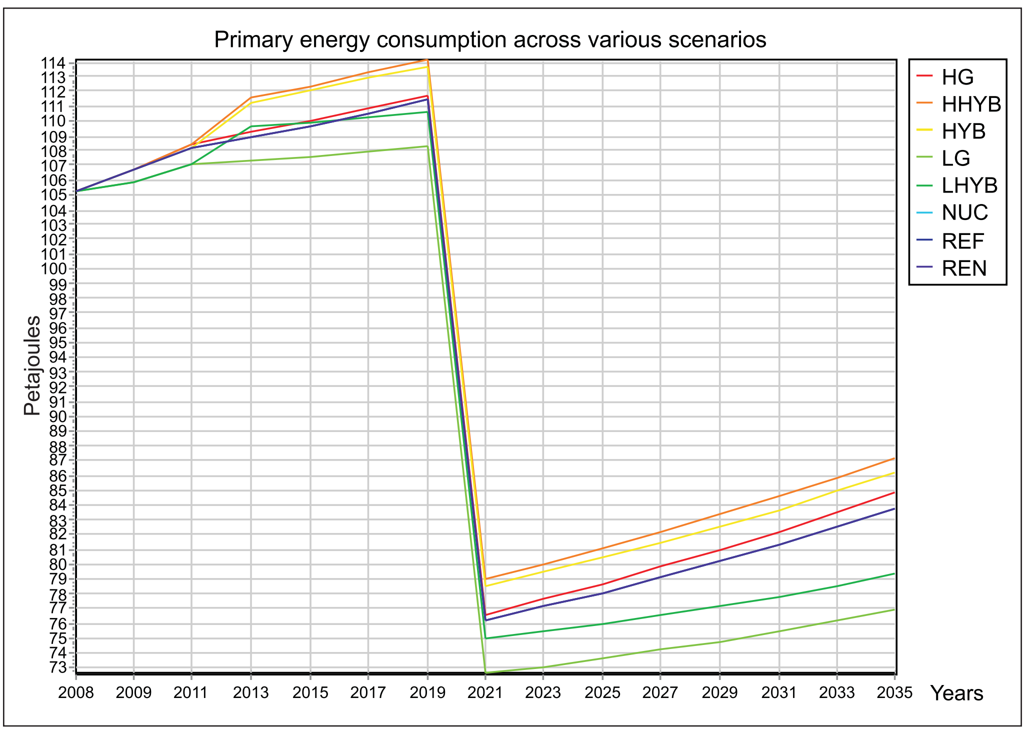

Fig. 8. Primary energy consumption across various scenarios

5.5 TWh in 2035, and the shortage of electricity generation will be 3.6 TWh in 2035. The oil-shale-based generation decreases from 8.7 TWh in 2008 in the REF scenario to 4.5 TWh in 2035. Gas-based generation has the same level as in the base year, because no new power plants will be built in this scenario. The growth of biomass and wind power generation is 0.36 TWh and 0.3 TWh, respectively. In the HYB, HHYB and LHYB scenarios, the total power generation increases from 9 TWh in 2008 to 12.7 TWh in 2035. The oil-shale-, gas-, biomass- and wind-based energy production is the same as in the REF scenario. However, there exists a variation in the technology deployment for power generation across these scenarios: the new nuclear and gas power generation is added to replace the oil-shale-based generation. In 2035, in the NUC scenario the total power generation increases by 1.4 TWh, and in the REN scenario the shortage of electricity generation will be 2.2 TWh.

For simplicity, we show trends of CO_2 emissions in the REF and HYB scenarios over the modelling time frame (Fig. 10).

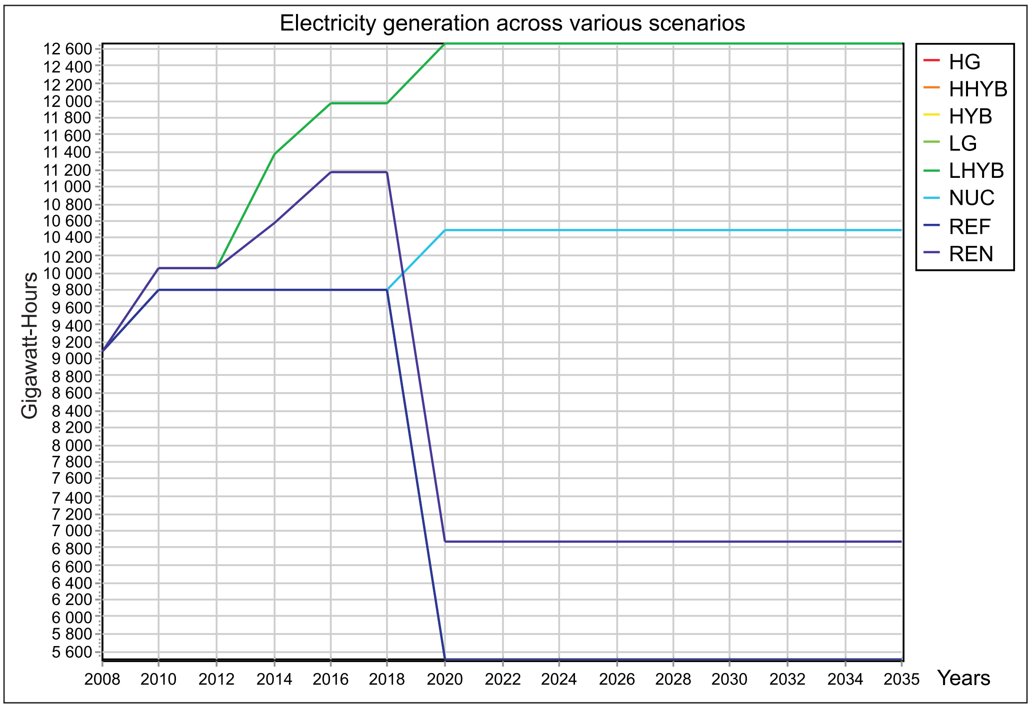

Fig. 9. Electricity generation across various scenarios

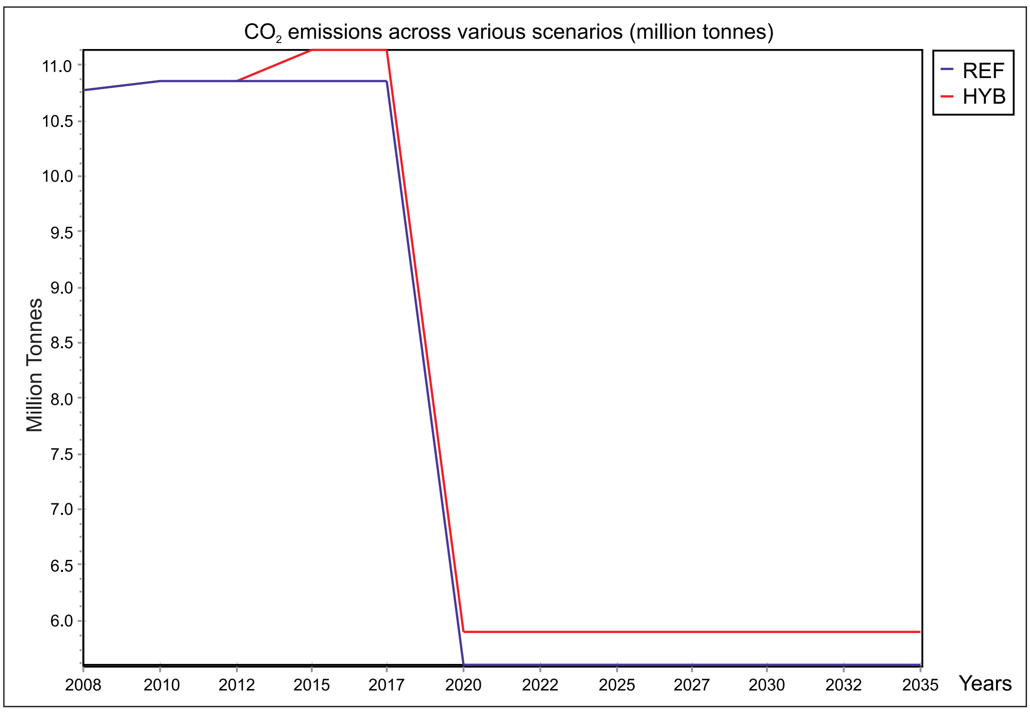

Fig. 10. CO_2 emissions across various scenarios

The REN, NUC, LG and HG scenarios have the same trend as the REF scenario. The HHYB and LHYB scenarios have the same total emissions of carbon dioxide as in the HYB scenario. As is shown in the REF and HYB scenarios, the total emissions decrease sharply after 2020 due to shutting down the old units of the Narva Power Plant and reducing oil-shale-based electricity production. The HYB scenario has the advantage of the new nuclear plant that it has no CO_2 emissions, however, in the REF scenario about half of the electricity will be imported after 2020. The trends of carbon dioxide emissions are similar to energy generation trends. The trends of energy generation in the REF scenario are different from those of the HYB scenario because of a new natural gas power plant with an additional electrical capacity 100 MW.

5. CONCLUSIONS

This paper presents the result of testing the LEAP model suitability for elaborating scenarios of the Estonian energy system's development. An overview of the current energy supply in Estonia and future changes of the Estonian energy production system related to the restrictions in technology and environment is given. The major investments in the Estonian electricity production system are defined.

The application of the selected existing energy models across several countries was provided. According to the situation in the Estonian energy market, described in Chapter 2, eight alternative scenarios were elaborated for the Estonian electricity production system in the period 2009–2035. A comparative analysis of the key results across all the scenarios is presented in Chapter 4.2.

The LEAP model, a user-friendly and freely available tool, demonstrated the usage of the model's features in connection with the Estonian electricity system and could be suitable for elaborating scenarios for the whole energy sector and separately for the electricity and heat sectors. Using the database of Estonia key assumptions provided in the LEAP model, this model may serve as a basis for a more accurate model of Estonia in further research.

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ESTIJOS ENERGETIKOS DABARTINĖS SITUACIJOS ANALIZĖ IR LEAP MODELIO ESTIJOS ENERGETINĖJE SISTEMOJE TAIKYMAS

Santrauka

Analizavimo tendencijos ir pokyčiai Estijos energetikos rinkoje yra glaudžiai susieti su ES technologiniais reikalavimais. Todėl būtina kurti naujus Estijos energetikos sektoriaus scenarijus, įvertinančius elektros energijos gamybos poveikį aplinkai naudojant naujas ir mažiau žalingas technologijas. Optimaliausias būdas – tai energetinio planavimo modeliavimas.

Modeliavimas yra vienas sudėtingiausių prognozavimo metodų. Pastaraisiais metais tokių metodų buvo sukurta gana daug. Kadangi jie tarpusavyje reikšmingai skiriasi, todėl svarbu optimaliai pasirinkti modelį, tinkantį konkrečiam tikslui ir situacijai.

Šis straipsnis yra dalis tyrimų rezultatų, analizuojamų Talino technologijos universiteto Šiluminės energetikos fakultete parengtoje PhD disertacijoje. Čia išsamiai pateikiama Estijos energetikos rinkos apžvalga ir pokyčiai jos energetinėje sistemoje, susieti su technologijų ir aplinkosaugos apribojimais. Pateikiami LEAP modelio testavimo rezultatai juos pritaikant Estijos energetinės sistemos plėtrai.

Raktažodžiai: energetinio planavimo modelis, elektros energijos rinka, LEAP, energetikos sistema, liberalizavimas, energijos vartojimas, elektros energijos gamyba

Надежда Дементьева, Андрес Сиирде

АНАЛИЗ СОВРЕМЕННОЙ СИТУАЦИИ ЭНЕРГЕТИКИ ЭСТОНИИ И ПРИМЕНЕНИЕ МОДЕЛИ LEAP ДЛЯ ЭНЕРГОСИСТЕМЫ ЭСТОНИИ

Резюме

Тенденция либерализации и изменения на эстонском энергетическом рынке, связанные с жесткими технологическими и экологическими требованиями Европейского Союза, приводят к возникновению необходимости разработки новых сценариев развития энергетического сектора Эстонии с учетом необходимости уменьшения воздействия на окружающую среду производства электроэнергии и применения новых, менее вредных, технологий. Самым простым способом для разработки сценариев является использование моделирования энергетического планирования.

Моделирование является одним из сложных методов прогнозирования. В последние годы было разработано большое количество моделей энергетического планирования. Модели энергетического планирования значительно отличаются друг от друга, и возникает вопрос о выборе модели для определенной цели или ситуации.

Данная статья является частью исследований, проведенных в рамках диссертации, подготовленной на Факультете теплоэнергетики Таллиннского технического университета.

Дается обзор современного энергетического рынка в Эстонии и будущих изменений в эстонской энергосистеме, связанных с ограничениями в области технологий и окружающей среды.

Представлены результаты тестирования применимости модели LEAP для разработки сценариев развития Эстонской энергосистемы.

Ключевые слова: модель энергетического планирования, рынок электроэнергии, LEAP, энергосистема, либерализация, потребление энергии, производство электроэнергии