Assessing greenhouse gas emissions in Estonia's energy system

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Abstract
This paper investigates Estonia's prospects in meeting the new European Union climate commitments to reduce greenhouse gas (GHG) emissions till 2030 by 40% and 2050 by 80-95% compared to 1990 emission levels. The contribution of this study is twofold. In a first stage, based on organizations reports and using the Long range Energy Alternatives Planning system (LEAP) it constructs seven long-term scenarios to examine Estonia's energy system till 2050. In a second stage, using the Data Envelopment Analysis (DEA) nonparametric approach it evaluates the efficiency of renewable energy commitments in reducing GHG emissions. The findings show that the main challenge for the Estonia policy makers will be the energy policies associated with the renewable energy usage. It appears that under the seven different energy policy scenarios the higher the participation of renewable energy the higher the reduction of greenhouse gas emissions.

Keywords: LEAP software; Renewable energy sources; Scenarios analysis; Data Envelopment Analysis; Estonia.

JEL codes: Q20; Q40; Q41; Q42; Q50; Q54; Q58.

1. Introduction

Officially the Estonian Republic restored its independence on 20 August 1991. In 1992 Estonia signed the United Nations Framework Convention on Climate Change, ratified it in 1994 and signed the Kyoto Protocol to the UNFCCC in 1998 and ratified it in 2002. Became a member of the North Atlantic Treaty Organization (NATO) in 2004 and the same year became a member of the European Union (EU). It joined the Organization for Economic Co-operation and Development (OECD) in 2010, adopted the euro in 2011, and applied for International Energy Agency (IEA) membership in the same year (Koskela et al., 2007; IEA, 2013).

According to Kyoto Protocol and in the first period of 2008-2012 Estonia had to mitigate 8% of its greenhouse gas (hereafter GHG) emissions in comparison to 1990 levels. This target has been attained mainly due to considerable restructuring and reorganization of industry, energy and agriculture sectors. Estonia does not use the Clean Development Mechanism as it is not a developing country but uses the other Kyoto Protocol flexible mechanisms, the Joint Implementation and the International Emissions Trading. Having achieved Kyoto's target Estonia acts also as a seller within these two mechanisms (EFNC, 2013).[1]

As a former member of the Soviet Union, Estonia inherited energy sectors with a good technical structure. At present, in Estonia, being one of the largest producers of oil shale in the world, almost all electricity is generated by power plants using oil shale, which is found in north-eastern Estonia with almost all of country's GHG emissions coming from oil shale (Miskinis et al., 2006; IEA 2013). This oil shale as main natural resource provides Estonia with independence but it is associated with negative environmental effects (EFNC, 2013). Having electricity production

[1] For more details on these mechanisms see Halkos (2014, pp. 6-11).

relying mainly on oil shale this requires modernization and more environmental friendly production methods. In this situation, the Ministry of Economic Affairs and Communications (MEAC) is responsible for developing energy policy and the National Development Plan of the Energy Sector till 2020.

In February 2011 the European Commission (EC) reconfirmed EU's long-term target of abating GHG till 2050 by 80-95% (25% by 2020, 40% by 2030 and 60% by 2040) compared to 1990 emission levels (European Commission, 2011). Under this decision the ministry started reviewing the National Development Plan, preparing its energy strategy towards 2030 with an outlook to 2050 (IEA, 2013).

In these lines we aim to construct seven scenarios for the time period 1990-2050 to assess Estonia's energy system (demand and supply). Our target is to rely on official organizations' reports and propose and compare various energy scenarios for Estonia meeting the targets of the European Commission in reducing GHG emissions 40% by 2030 and 80-95% by 2050. To achieve this target, we first forecast energy demand and supply derived from renewable energy sources together with the associated GHG emissions using the Long range Energy Alternatives Planning system (LEAP)[2]. Furthermore in a second stage our study applies a nonparametric estimator relying on the mathematical method of Data Envelopment Analysis (DEA) to assess the efficiency of proposed seven scenarios for renewable policies under the European targets set in 2030 and in 2050.

The structure of the paper is the following. Section 2 summarizes the existing relative literature while section 3 presents the background of Estonia's energy system.

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[2] LEAP can be used for both demand and supply side energy modelling. In Estonia, the LEAP model has been used for the national level ex ante Strategic Environmental Assessment of Energy Plan 2020 and in ex post scenario modelling and associated impact assessment for the preparation of Energy Plan 2030 (see Kuldna et al., 2015).

Section 4 analyzes the proposed scenarios and section 5 discusses the structure of LEAP software and the proposed nonparametric methodology of Data Envelopment Analysis. Section 6 presents the derived empirical results and the last section concludes the paper and discusses the policy implications.

2. Literature Review

2.1. Relevant studies

There are not many studies related with Estonia's energy system (demand or supply). Koskela et al. (2007) model the Estonian electricity supply until 2020 using the life cycle assessment (LCA) methodology. Three different scenarios are constructed under the aims of the national energy policy. Lund et al. (2000) aimed to improve Estonian energy system's efficiency by replacing the oil shale power stations. Furthermore, Merikull et al. (2012) examined the oil shale energy associated with the labor force and offer scenario forecasts in labor demand for the Estonian energy sector till 2020.

There are various studies concerning the energy systems in the Baltic States (Lithuania, Latvia and Estonia). Miskinis et al. (2006) examined the role of renewable energy sources (RES) in the primary energy supply for Baltic countries. Similarly, Streimikiene and Klevas (2007) considered the use of RES in the Baltic States and Klevas et al. (2007) presented a review of policies associated with the Baltic States and evaluated the use of RES. Roos et al. (2012) considered the energy system of Baltic States under the ground of energy efficiency, renewable consumption and GHG emissions abatement and Streimikiene and Roos (2009) assessed GHG emissions for the Baltic States.

Additionally, Streimikiene et al. (2007) presented an overview of results from Energy Indicators for Sustainable Development (EISD) tool, and illustrated the relation among the trends, setting energy policy goals and monitoring progress towards these goals for Baltic States. Finally, Streimikiene (2007) examined the activities of BASREC (Baltic Sea Region Energy Cooperation) in the Baltic Sea region for eleven countries (Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia, and Sweden).

2.2. LEAP studies

LEAP is a modelling tool permitting assessment of the effect of different energy policies on energy generation and consumption, together with their associated emissions (Heaps, 2002). Furthermore, LEAP supports various modelling approaches which for the demand-side range from bottom-up, end-use accounting techniques to top-down macroeconomic modelling (Connolly et al., 2010).

Moreover, it is often used to examine national energy systems (demand and/or supply). Many studies have been published for energy systems. Papagiannis et al. (2008) analyzed the economic and environmental effects of applying the Energy Consumption Management System (ECMS), an intelligent demand side management system, in the European countries. Phdungsilp (2010) presented a study on the options for energy and carbon development for the city of Bangkok. Kim et al. (2011) summarized the recent trends in the Republic of Korea’s energy sector.

For the Japanese energy sector, Takase and Suzuki (2011) described the current trends, including energy demand and supply by fuel and by sector. For China, Wang et al. (2011) provided insights into the latest development of energy production, energy consumption and energy strategic planning and policies. Yophy et al. (2011) overviewed energy supply and demand in Taiwan. For the Greek energy system, Roinioti et al. (2012) built five future energy scenarios focusing on the electricity production system and exploring how these scenarios were reflected in economic, environmental and energy efficiency terms. Another study for Greece by Halkos et al. (2014) refer to the significant role of lignite in electricity generation stating that the decline in Greek lignite stations will offer environmental benefits and will help towards climate change mitigation.

Many researchers using the LEAP software have investigated energy demand and its effects. For instance, Morales and Sauer (2001) investigated the use of demand-side management (DSM) measures that might lead to reduction in fossil fuel demand and thus would mitigate greenhouse gas emissions (GHGs) for Ecuador. Technical and economic assessments were carried out through the construction of two scenarios for the residential sector covering the period from 1995 to 2025. Chedid and Ghajar (2004) examined the effect of energy sector on the Lebanese economy, and evaluated the possibility of imposing appropriate energy efficiency options in the building sector for the period 1994-2040. Davoudpour and Ahadi (2006) evaluated the twin effects of efficiency programs and price reform on energy carriers' consumption and GHG emissions reduction in the housing sector of Iran.

Limmeechokchai and Chaosuangaroen (2006) carried out an assessment of energy savings potential in the Thailand residential sector. Kadian et al. (2007) using LEAP modeled total energy consumption and the resulting emissions from the household sector of Delhi. Another research effort for Delhi by Bose and Srinivasachary (1997) investigated policies to decrease energy use and emissions but this time for the transport sector. Zhou and Lin (2008) using a comprehensive End-Use energy model assessed the effect of a number of scenarios of growth in GDP, energy elasticity, and energy-efficiency progress on energy consumption in Chinese commercial buildings.

Mustonen (2010) investigated household energy demand patterns and the development of electricity demand in a rural village in Lao People's Democratic Republic. Wang et al. (2007) using LEAP developed a model to produce three different CO_2 emission scenarios for industry for the time period 2000 to 2030. Gomez et al. (2014) examined the energy demand (Households, Industry, Services, Transport and Agriculture) of Kazakhstan. For the densely populated Mexico City Metropolitan Area (MCMA), Manzini (2006) described three future scenarios up to the year 2030 for the possible mitigation of CO_2 emissions and the resulting costs when (a) biogenic ethanol blends and oxygenates were replaced with gasoline, and (b) hybrid, flex fuel and fuel cell technologies were initiated in passenger automobiles, including sport-utility vehicles and pickups.

From the supply side, the evolution of the energy sector in Mexico for the period 1996-2025, Islas et al. (2003) examined three scenarios which were subjected to a cost-benefit analysis. These three scenarios had in common the structure of electrical power plants in the period 1996-2000. Shin et al. (2005) using LEAP and the "Technology and Environmental database" examined the costs and effects of landfill gas electricity generation on energy market and the associated GHGs emissions in Korea.

Furthermore a study for Korea by Lee et al. (2008) estimated future abatement potential and costs of CO_2 mitigation options for electricity generation facilities. To assess CO_2 emissions reduction potentials of China's electricity sector, Cai et al. (2007) employed three scenarios to simulate the different development paths in this sector. Again for China, Zhang et al. (2007) calculated external costs of electricity generation under different long-term energy scenarios and environmental policies.

In addition, Mulugetta et al. (2007) constructed power sector scenarios for Thailand to signify the variety of opportunities and constraints related to conflicting set of technical and policy options. Wijaya and Limmeechokchai (2009) examined utilization of geothermal energy scenarios for future electricity supply expansion in Java-Madura-Bali (Jamali) system which was the largest electricity consumer in Indonesia. Dagher and Ruble (2011) evaluated possible future paths for Lebanon's electric sector. Finally, Pagnarith and Limmeechokchai (2015a, b) considered electricity supply of Cambodia, Laos, Thailand and Vietnam and the way it could reduce CO_2 emissions under different energy scenarios.

3. Background of Estonian Energy system

3.1. Overview

In 2013 Estonia's Total Final Consumption (TFC) was 2870.4 thousand toe (tonnes of oil equivalent). The residential sector is the largest consumer of energy with about 32% (934.8 thousand toe) of TFC. The transport sector has almost 27% (762 thousand toe) share of TFC and industry has approximately 22% (644.5 thousand toe) share of TFC. Services have around 15% (419 thousand toe) and Agriculture/Forestry and Fishing have almost 4% (110.2 thousand TOE) share of TFC (Figure 1) (source: Eurostat database).

In Estonia the domestic fuels play an important role in final energy consumption; the liquid fuels (heavy fuel oil, light fuel oil, motor fuels) represented 32% of fuel in final consumption, with 23% of energy consumption accounted by heat. Electricity accounted for 21%, solid fuel (coal, coke, oil shale, peat, firewood, wood chips, wood waste) accounted for 18% and gaseous fuels (natural gas, liquefied gas, oil-shale gas) represented a 6% (Figure 2) (source: Statistics Estonia).

Figure 1: Final Energy Consumption by sector (thousand toe)

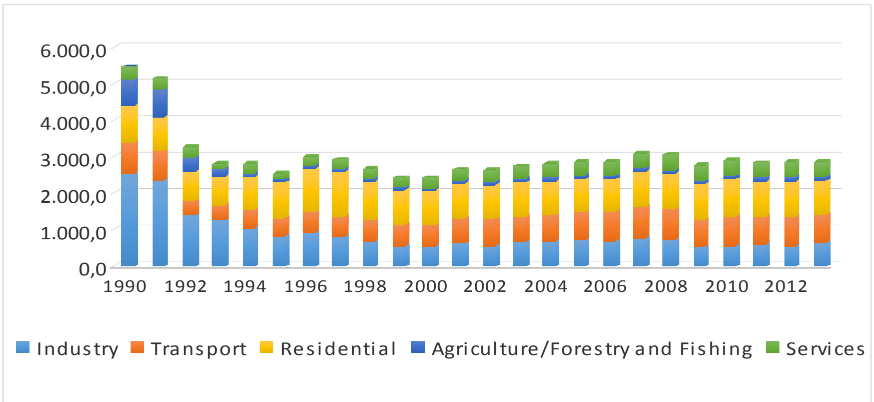


Figure 2: Final Energy Consumption by Energy

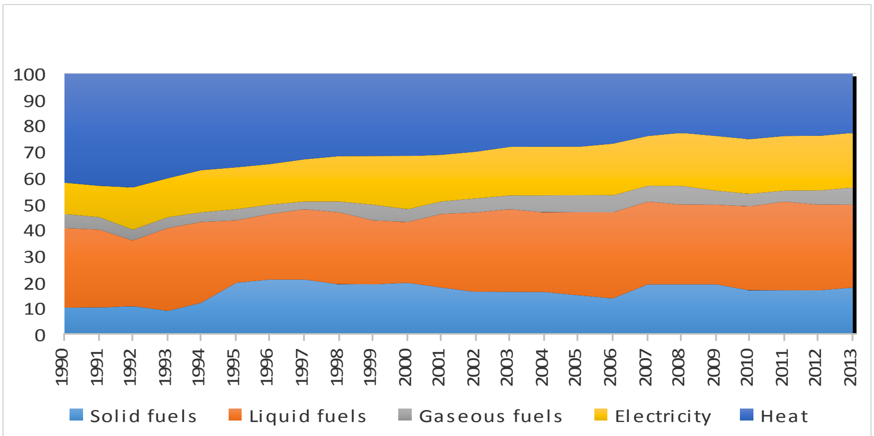
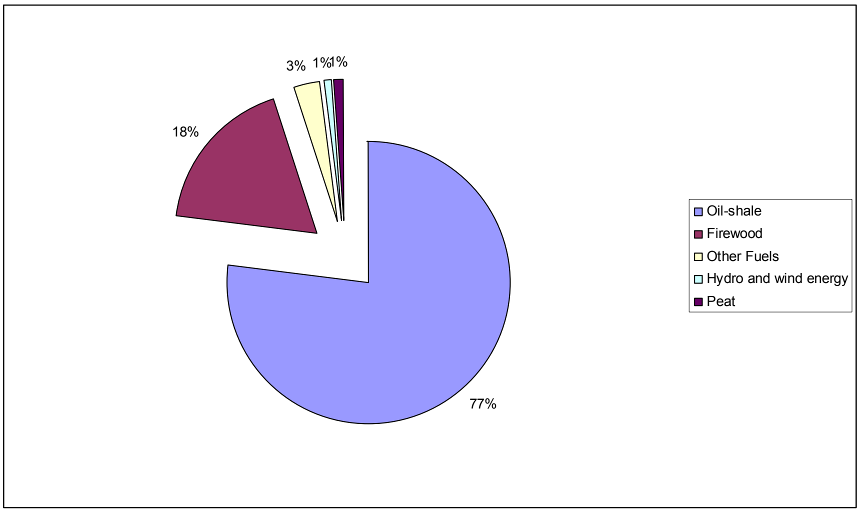


Figure 3: Production of Primary Energy

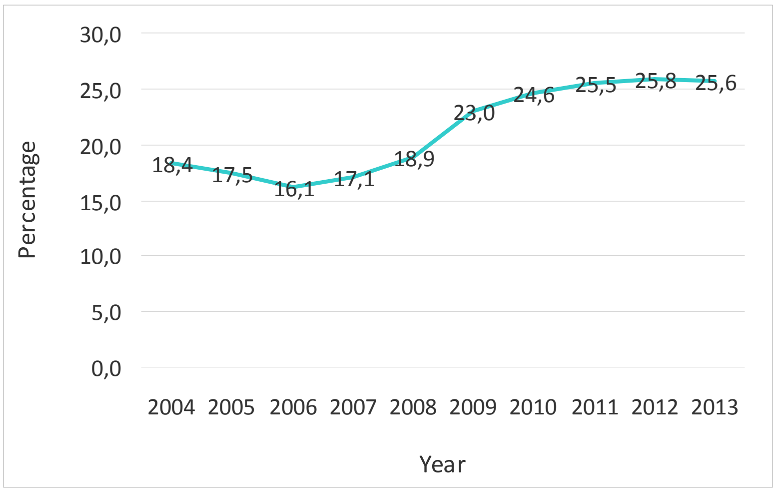


In 2013, the Total Primary Energy Supply (TPES) in Estonia was 236692 TJ (tera joules), with oil shale dominating and accounting for about 77% (182549 tera joules) of TPES. Firewood (including wood chips and wood waste, briguette and pellets) is the second largest energy source with a 18% TPES. Other fuels (including black liquor, biogas, municipal waste and other biomass) accounted for 3% (6201 tera joules) of TPES, and hydro-wind energy and Peat accounted for about 1% each (1996 and 2748 terajoules respectively) of TPES (Figure 3) (source: Statistics Estonia).

3.2. Renewable energy consumption

In 2013 renewable energy provided 25.6% of Estonia's TPES. The changes of the share of renewable energy sources in gross final energy consumption are shown in Figure 4. The share of participation of RES in Estonia's energy balance for 2013 is 22.1% in primary energy production, 15.3% in gross final energy consumption and 13.2% in electricity generation (using wind parks, small hydropower plants and biomass-woodchips). Heating and cooling (in the residential sector) has the biggest share of RES with 43.1%, industry has a 10% and transport only a 0.2% (biofuels) (sources: Eurostat database; Statistics Estonia).

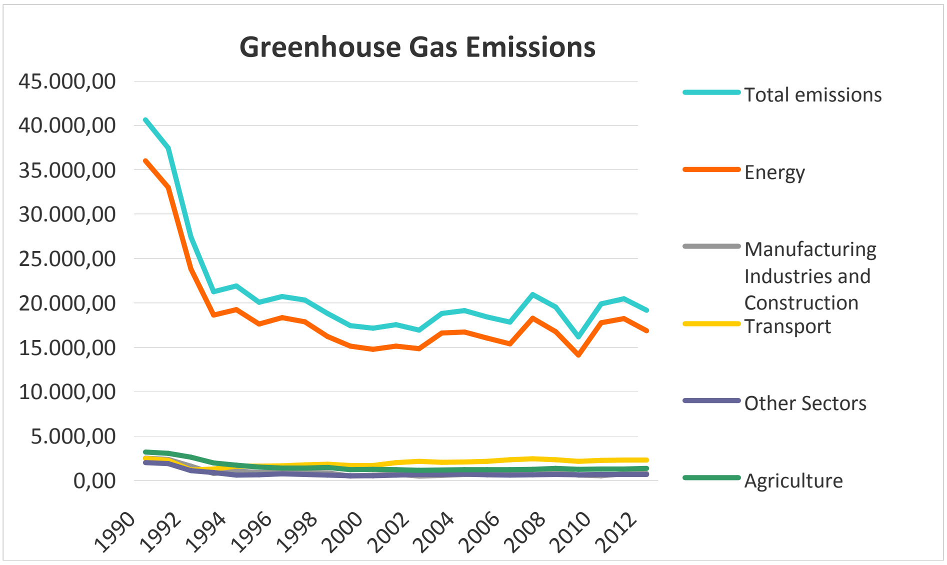
Figure 4: Share of renewable energy in gross final energy consumption



3.3 Greenhouse gas emissions in Estonia

In 2012, the total emissions of GHG in CO_2 equivalent were 16974.4 thousand CO_2 equivalent tons. The carbon dioxide (CO_2) accounted for 88% (14858.2 thousand CO_2 equivalent tons) of GHGs, nitrous oxide (N_2O) for 6% (1016.2 thousand CO_2 equivalent tons), methane (CH_4) for 5% (930.7 thousand CO_2 equivalent tons), and the F-gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) for 1% (169.3 thousand CO_2 equivalent tons) (Figure 5). The energy sector is the main source of GHG emissions in Estonia with 77% (16873.83 thousand CO_2 equivalent tons). The significant amount of energy related emissions is caused by the share of oil shale, which is about 67% of the energy sector total GHG emissions (sources: Eurostat database; Statistics Estonia).

Figure 5: Greenhouse gas emission by gas and year



4. Scenario Analysis

In the lines of Halkos and Tzeremes (2015) we propose seven different scenarios constructed in LEAP under dissimilar options. Namely,

1. Relying on historical trends our first scenario is the *Business As Usual (BAU)*
2. Following the European Commission (2009)[3] our second scenario is *EC 2030*
3. Relying on the assumptions of IEA (2012)[4] our third scenario is *IEA 2030*
4. Based on the assumptions of Greenpeace/EREC (2012)[5] our fourth scenario is *Greenpeace 2030*
5. *Following* the assumptions of European Commission (2011)[6] our fifth scenario is *EC 2050*
6. Based on the assumptions of EREC (2010)[7] our sixth scenario is *EREC 2050*
7. Following the assumptions of SEI (2009)[8] the seventh scenario is *SEI 2050*

Apart from the BAU scenario the other proposed scenarios rely on official organizations' reports. Three scenarios have as target the year 2030 (EC 2030, IEA 2030, Greenpeace 2030) while the other three scenarios have as target the year 2050 (EC 2050, EREC 2050, SEI 2050). The basic assumptions and all policy options are presented in Table 1.[9]

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[3] http://ec.europa.eu/clima/policies/package/docs/trends_to_2030_update_2009_en.pdf
[4] https://www.iea.org/publications/freepublications/publication/ETP2012_free.pdf
[5] http://www.greenpeace.org/eu-unit/Global/eu-unit/reports-briefings/2012%20pubs/Pubs%203%20Jul-Sep/E%5BR%5D%202012%20lr.pdf
[6] http://www.roadmap2050.eu/attachments/files/Volume1_ExecutiveSummary.pdf
[7] http://www.erec.org/fileadmin/erec_docs/Documents/Publications/ReThinking2050_full%20version_final.pdf

[8] http://sei-us.org/Publications_PDF/SEI-EuropeShareOfClimateChallenge-09.pdf

[9] Details of all assumptions of integrated scenarios can be found in the corresponding official organizational report.

Table 1: Policy options and assumptions for scenario generation

Scenarios	Policy options	Main assumptions
BAU		- Historical trends continue
EC 2030	Report on *Energy Trends 2030* by EC (2009)	- 36% RES in Electricity - 12.5% RES in Transport - 21.3% RES in H&C - 22.2% RES in Final Demand
IEA 2030	Report on *Energy Technology Perspectives* by IEA (2012)	- 48% RES in Electricity - 14% RES in Transport - 19% RES in H&C - 27% RES in Final Demand
Greenpeace 2030	Report on *Energy [R]evolution European Union* by Greenpeace/EREC (2012)	- 61% RES in Electricity - 17% RES in Transport (with electricity providing 12%) - 51% RES in H&C - 18.5% RES in Industry - 42.6% RES in Final Demand
EC 2050	Report on *Energy Roadmap 2050* by EC (2011)	- 97% RES in Electricity - 65% Electricity in Transport - 36–39% Electricity in final energy demand - 55% RES in Final Demand
EREC 2050	Report on *RE-thinking 2050: 100% Renewable Energy Vision for the European Union* by EREC (2010)	- 100% RES in Electricity - 10% Biofuels in Transport - 41% RES-Electricity in final energy demand - 45% RES-H&C - 90-95% RES in Final Demand
SEI 2050	Report on *Europe's Share of the Climate Change* by SEI (2009)	- 75% RES in Electricity - 100% RES, Electricity and H&C in Households and Services - 60% RES, Electricity and Heat in Industry - 50% Electricity in Transport

5. Methodology

5.1. LEAP dataset structure

5.1.1. Demand Sectors

In the case of Estonia LEAP's "tree" consists of a demand dataset illustrating energy use in each branch of the "tree''. It also consists of various socio-economic and demographic indicators. The sources of energy demand data are Statistics of Estonia[10] and Eurostat[11].

Table 2 refers to energy demand structure with various activities like number of households, economic output, fuel shares and energy intensities. More analytically, it includes sectors, sub-sectors and fuel categories and the data sources. Demand consists of six sectors. Namely, households, Agriculture and Fishing, Services, Industry, Transport, Non Specified and the Non-Energy Fuel Use.[12]

LEAP permits each technology within the seven sectors of demand and supply by the various sectors to be directly associated with emission factors in the Technology and Environmental Database (hereafter TED). In this way the constructed model estimates emissions coming from energy demand relying on various emission factors and technical characteristics as provided by TED (SEI, 2011).

5.1.2. Transformation modules

The fuel supply part or transformation module of the dataset is separated into five transformation modules. Namely, and as shown in Table 3, transmission and distribution losses, own use, electricity generation, heat production and bio-fuel production. The most important sub-sector of transformation is the "Electricity generation" which has many functions and features such as capacities, efficiencies, availabilities and merit orders.

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[10] http://www.stat.ee/en

[11] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

[12] This is accompanied by various demographic and economic indicators not presented here.

Table 2: Energy Demand Structure

Sectors/ Indicators	Sub-sectors	Fuel categories	Sources
Households		coal, oil, natural gas, solar, biomass, heat, peat electricity,	Statistics Estonia, Eurostat
Agriculture and Fishing		coal, oil, heat, natural gas, electricity, biomass	
Services		coal, oil, heat, peat, solar, electricity, biomass, natural gas	
Industry	Iron and Steel, Chemical and Petrochemical, Non Ferrous Metals, Non Metallic Minerals, Transport equipment, Paper Pulp and Printing, Wood and Wood Products, Textile and Leather, Construction, Mining and Quarrying, Non Specified	oil, coal, electricity, natural gas, biomass, heat, peat	
Transport	Road, Rail, Domestic Air Transport, Transport Inland Water, Pipelines, Non Specified	oil, coal, electricity, natural gas, biofuel	
Non Specified		oil, coal, electricity, natural gas, heat, biomass	
Non Energy Use		oil,coal, natural gas, solar	

Table 3: LEAP's fuel supply dataset of Estonia

Module	Process types	Fuels	Sources
Transmission and Distribution Losses	Process	Electricity, natural gas	Statistics Estonia
Own Use	Process	Electricity	
Electricity Generation	Output Fuels	Electricity	
	Process	Biomass, Wind onshore, Wind offshore, New Nuclear, Oil, Natural gas, Oil Shale, Peat, Biogas, Small Scale Hydro, Municipal Solid Waste, Oil Shale CHP, New Oil Shale, Firewood CHP, Solar	
Heat Production	Output Fuels	Heat	
	Processes	Coal, Natural gas, Oil, Biomass, Oil Shale, Peat, Biogas	
Biofuel Production	Output Fuels	Biofuel	
	Processes	Biomass	

5.2. Data Envelopment Analysis

To assess Estonian energy system's efficiency it is required to calculate also the capacity to mitigate GHG emissions under the seven energy policy scenarios presented earlier (BAU, EC 2030, IEA 2030, Greenpeace 2030, EC 2050, EREC 2050 and SEI 2050). More analytically, it is necessary to assess under the seven proposed scenarios constructed in LEAP for the period 1990-2050 the calculated energy usage of RES in the main sectors (demand and supply) of Estonia together with the associated GHG emissions. This can be achieved by constructing a composite performance index comparable among both the proposed scenarios and the sectors into examination for the examined time period 1990-2050. In this way we are able to assess the renewable energy policy efficiency (REPE) relying on future predictions as calculated by using LEAP.[13]

To do so we use the nonparametric approach data envelopment analysis (DEA), mathematical programming method allowing us to assess a particular method relying on the calculation of a benchmark frontier – a virtual frontier against which decision making units (DMUs) are evaluated, using specific inputs and outputs for each DMU (Daraio and Simar, 2007). Then the efficiency is estimated together with the distance of each DMU from the calculated ('efficient') frontier. In our analysis we treat as DMU each year which reflects the outcome of the renewable energy policies adopted among the sectors.

Characteristically, DEA is used in a production framework examining the efficiency of specific inputs to result to specific outputs. Nevertheless, in our case we apply a similar method to the one used in Kuosmanen and Kortelainen (2005) and

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[13] The influence of electricity consumption from RES on countries′ economic growth levels is discussed in Halkos and Tzeremes (2014a), while empirical evidence on the effect of countries compliance with Kyoto protocol's agreement policies may be fount in Halkos and Tzeremes (2014b).

recently Halkos et al. (2015). Kuosmanen and Kortelainen (2005) propose an eco-efficiency indicator entailing the estimation of the ratio of value added (i.e. good output/GDP) to environmental degradation or a kind of pressure index (i.e. bad output/pollutant), coming close to environmental efficiency from a social aspect rather than from a managerial viewpoint. In this way their proposed index eliminates primary production factors although they are significant cost factors in carrying out a technical and economic efficiency analysis (Kuosmanen and Kortelainen 2005, p. 64).

In our analysis the value added to the Estonian energy system (from the renewable energy policy perceptive) is the energy consumption (measured in millions Gigajoules) derived from renewable sources. In contrast bad output is Greenhouse emissions (CO_2, CH_4 and N_2O) to be released in the future from the Estonia energy system as predicted by LEAP according to the proposed scenarios. These may be considered as the result of bad policy designs and lack of adoption and implementation of renewable energy policies.

Relying on the method by Koopmans (1951) we may classify renewable energy policy efficiency in a multiple dimensional Euclidean space. In our study we assume M pollutants (Greenhouse emissions - CO_2, CH_4 and N_2O) measured by a set of variables $z = (z_1, ..., z_m)$. Also w denotes energy demand of the sectors considered derived only from RES (measured in millions Gigajoules). Thus we may identify pollution generating technology set as:

$$T = \left\{ \begin{array}{l} (w, z) \in \Re_{+}^{1+M} \middle| \text{the energy consumption derived from renewable sources w} \\ \text{can be generated also with damage z derived from non-renewable energy sources} \end{array} \right\} \quad (1)$$

Expression (1) entails that although and under the specific energy scenarios there is a specified percentage of commitment of energy consumption from RES, but, there is also pollution associated with energy consumption from non-RES. Consequently, in our analysis REPE employed by the Estonia energy system will aim to decrease generated pollution. This efficiency may be symbolized as:

$$REPE_n = \frac{W_n}{D(Z_n)} \qquad (2)$$

In ratio (2) D stands for the degradation (damage) function of pollutants M in a weighted average index of the form:

$$D(z) = v_1 z_1 + v_2 z_2 + ... + v_m z_m \qquad (3)$$

As the problem of proper weighting (v) on pollutants is important we rely on Kuosmanen and Kortelainen (2005) proposing that *the benefit of the doubt* weighting scheme. This applies weights maximizing relative REPE of the industry and the year under consideration in comparison with the maximum feasible REPE. It can be estimated as[14]:

$$\begin{aligned}
&\max_v EREP_n = \frac{W_n}{v_1 Z_{n1} + v_2 Z_{n2} + ... + v_M Z_{nM}} \\
&s.t. \\
&\frac{W_1}{v_1 Z_{11} + v_2 Z_{12} + v_M Z_{1M}} \leq 1 \\
&\frac{W_2}{v_1 Z_{21} + v_2 Z_{22} + v_M Z_{2M}} \leq 1 \\
&\vdots \\
&\frac{W_N}{v_1 Z_{N1} + v_2 Z_{N2} + v_M Z_{NM}} \leq 1. \\
&v_1, v_2, ..., v_M \geq 0
\end{aligned} \qquad (4)$$

As a result weights $v_m \left(m = 1,...,M\right)$ are applied to maximize REPE ratio subject to the condition that the highest achievable efficiency score does not go above the maximum index value of one when same weights are applied across all other

[14]In our analysis the letters with the upper case are referring to the observed data, whereas the lower case letters are referring to theoretical values.

industries and years. It is worth mentioning that weights are not negative, efficiency score can take values between 0 and 1 with values of 1 indicating efficient renewable energy policies and values less than implying inefficient policies.

Moreover, the mathematical set-up in (4) is fractional and difficult to be solved. But following Charnes and Cooper (1962) and Charnes et al. (1978) we are able to convert the fractional program presented in (4) into a linear program as:

$$
\begin{aligned}
&\min_{v} EREP_n^{-1} = v_1 \frac{Z_{n1}}{W_n} + v_2 \frac{Z_{n2}}{W_n} + \ldots + v_M \frac{Z_{nM}}{W_n} \\
&s.t. \\
&v_1 \frac{Z_{11}}{W_1} + v_2 \frac{Z_{12}}{W_1} + \ldots + v_M \frac{Z_{1M}}{W_1} \geq 1 \\
&v_1 \frac{Z_{21}}{W_2} + v_2 \frac{Z_{22}}{W_2} + \ldots + v_M \frac{Z_{2M}}{W_2} \geq 1, \\
&\vdots \\
&v_1 \frac{Z_{N1}}{W_N} + v_2 \frac{Z_{N2}}{W_N} + \ldots + v_M \frac{Z_{NM}}{W_N} \geq 1 \\
&v_1, v_2, \ldots, v_M \geq 0.
\end{aligned}
\tag{5}
$$

For the purpose of our analysis we apply the distance function approach as proposed by Shephard (1970) allowing also for variable returns to scale-VRS (Banker et al. 1984). Since our study relies on a large time period (1990-2050) variations entailed among pollutants generated from the use of non-RES and in energy demand from RES are anticipated. In accordance with several researchers the assumption of VRS is more appropriate when examining the effect of changing energy use over time and such variations are to be expected (Honma and Hu 2013; Fang et al. 2013).

6. Empirical Results

6.1. LEAP results

Figure 6 illustrates the reduction of GHG emissions of Estonia's energy system by each scenario. Moreover, figure 7 represents the energy demand (sub-figure 7a) and supply (sub-figure 7b) in the seven scenarios. The best choice for the target 2030 is Greenpeace 2030 scenario with a 43.6% reduction of GHG emissions (from 15.6 $MtCO_2e$ in 1990 to 8.8 $MtCO_2e$ in 2030) and follow the IEA 2030 and EC 2030 scenarios. The reductions are 41% (from 15.6 $MtCO_2e$ in 1990 to 9.2 $MtCO_2e$ in 2030) and 39.1% (from 15.6 $MtCO_2e$ in 1990 to 9.5 $MtCO_2e$ in 2030) respectively. The Greenpeace 2030 scenario and IEA 2030 achieve the target while the EC 2050 scenario almost achieve the target. For 2050, the best scenarios are EREC 2050 and EC 2050 with 90.4% (from 15.6 $MtCO_2e$ in 1990 to 1.5 $MtCO_2e$ in 2050) and 83.3% (from 15.6 $MtCO_2e$ in 1990 to 2.6 $MtCO_2e$ in 2050) respectively. The SEI 2050 scenario will not achieve the target. The reduction is 66.6% (from 15.6 $MtCO_2e$ in 1990 to 5.2 $MtCO_2e$ in 2050) (see Table 4).

Table 4: GHG emissions for Estonia's energy system, demand and supply by scenario ($MtCO_2e$)

	1990 Total	1990 Demand	1990 Supply	**2030 Total**	2030 Demand	2030 Supply	**2050 Total**	2050 Demand	2050 Supply
BAU	15.6	5.5	10.1	16	8.2	7.8	31.5	18.4	13.1
EC 2030	15.6	5.5	10.1	9.5	5	4.5	9.9	5.4	4.5
EC 2050	15.6	5.5	10.1	6.2	2	4.2	2.6	1.8	0.8
EREC 2050	15.6	5.5	10.1	5.9	2.1	3.8	1.5	1	0.5
Greenpeace 2030	15.6	5.5	10.1	8.8	4.8	4	9.1	5	4.1
IEA 2030	15.6	5.5	10.1	9.2	4.7	4.5	9.7	5.4	4.3
SEI 2050	15.5	5.5	10.1	7.4	2.9	4.5	5.2	1.9	3.3

Figure 6: GHG emissions for Estonia's energy system by scenario ($MtCO_2e$)[15]

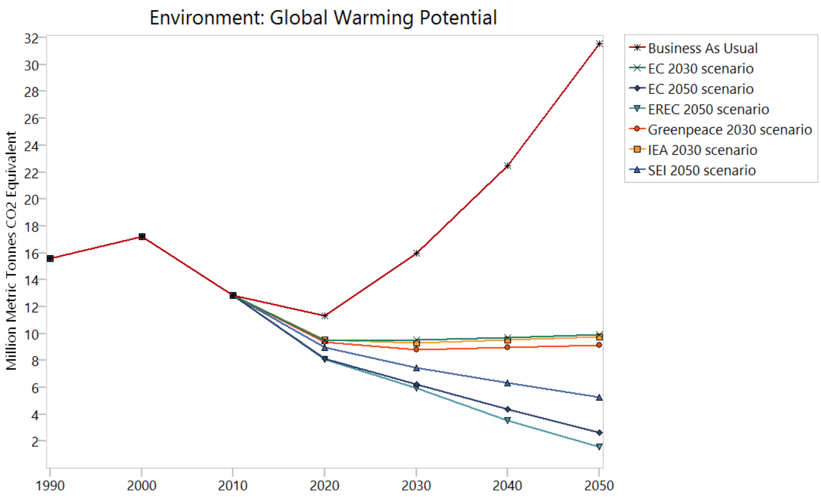
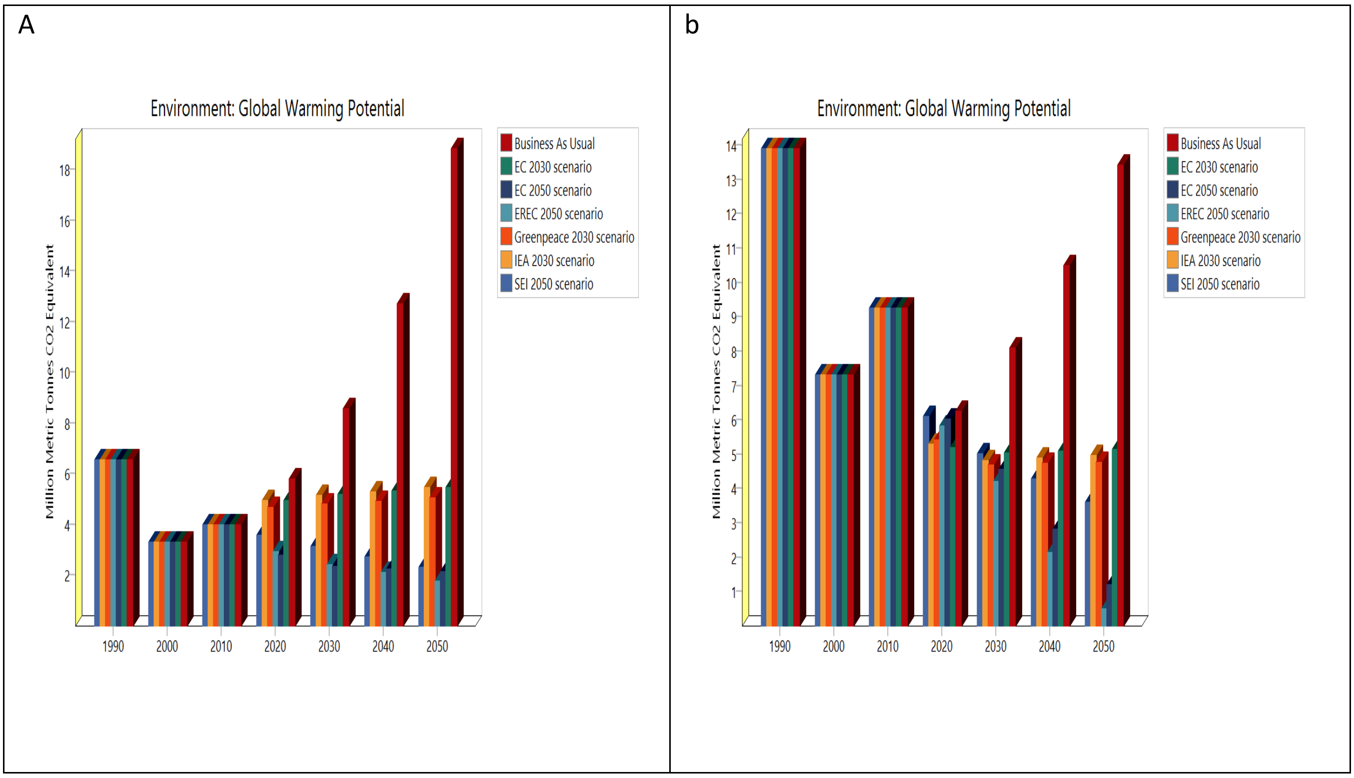


Figure 7: Energy demand and supply emissions for Estonia ($MtCO_2e$)



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[15] Global Warming Potential (GWP) is an index measuring different GHGs emissions with different atmospheric lifetimes and different radiative properties. To maintain climate impact constant, GWP measures allow comparisons and substitutions among different gases to attain the target. CO_2 has a GWP equal to 1, CH_4 equal to 25 and N_2O to 298. (Halkos, 2014, p. 13).

6.1.1. Contribution of each scenario to reducing the GHG emissions

Figure 8 (and Table 5 as summary) illustrate the evolution of emissions in relation to the business as usual (BAU) scenario. The top line on this chart shows the BAU scenario for GHG emissions reduction. Below that, a series of "wedges" is displayed showing the contribution of each scenario to reducing the BAU emissions down to the final level.

Figure 8: GHG emissions wedges by scenario ($MtCO_2e$)

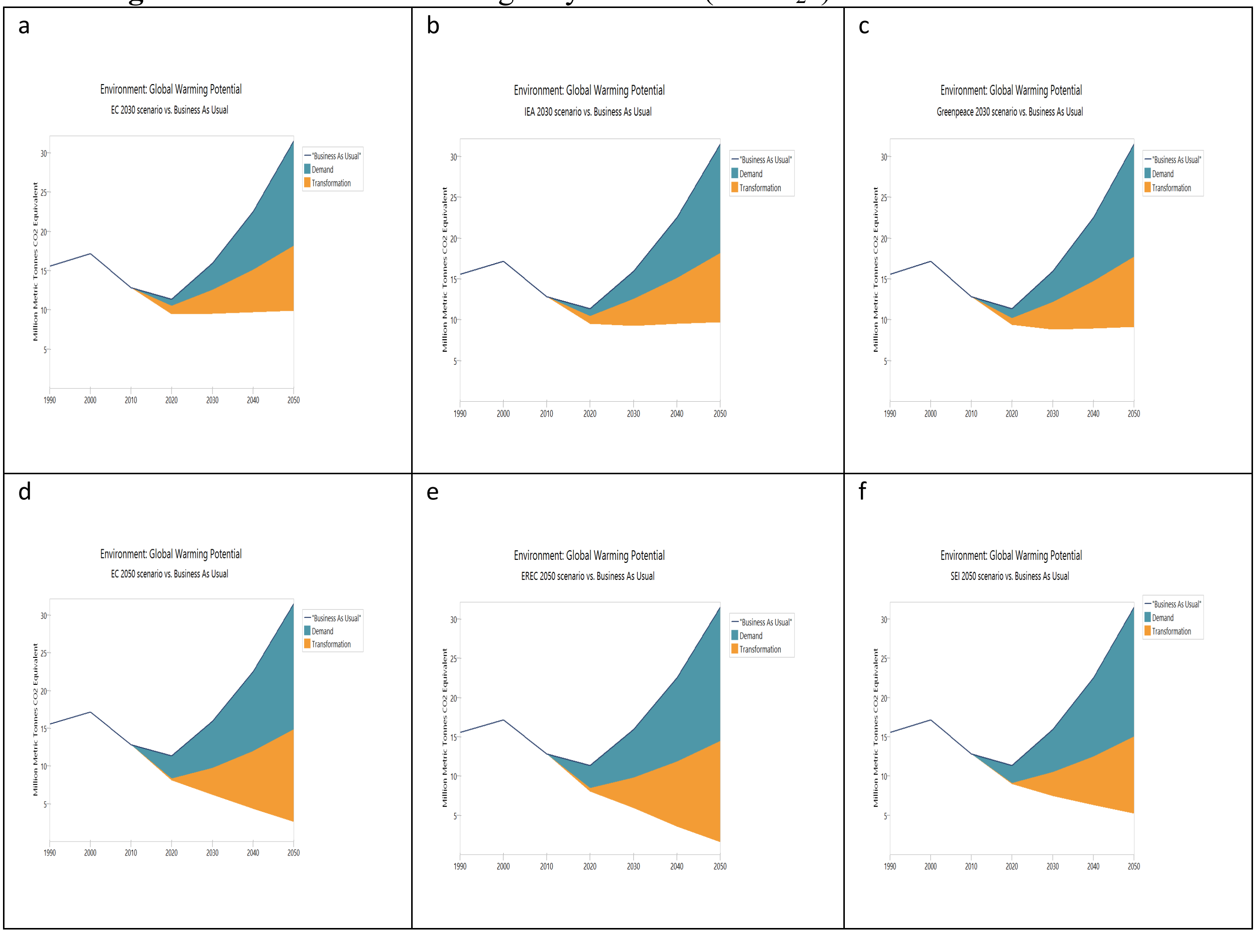

Table 5: GHG emissions scenarios wedges ($MtCO_2e$)

	BAU	EC 2030	IEA 2030	Greenpeace 2030	EC 2050	EREC 2050	SEI 2050
1990	15.6	0	0	0	0	0	0
2030	16	6.4	6.7	7.2	-	-	-
2050	31.5	-	-	-	28.9	29.9	26.3

Each scenario plays an important part in the reduction, but the largest reductions for the year 2030 come from measures in Greenpeace 2030 scenario with

7.2 $MtCO_2e$ (sub-figure 8c) reducing 44.9% in relation to BAU scenario, followed by the IEA 2030 scenario with 6.7 $MtCO_2e$ (sub-figure 8b) reducing 42% and EC 2030 scenario with 6.4 $MtCO_2e$ (sub-figure 8a) and an associated reduction of 40.4%. For the 2050 year the largest reduction comes from EREC 2050 scenario with 29.9 $MtCO_2e$ (sub-figure 8e) reducing 95%, followed by EC 2050 scenario with 28.9 $MtCO_2e$ (sub-figure 8d) reducing 91.6% and finally the SEI 2050 scenario with 26.3 $MtCO_2e$ (sub-figure 8f) with 83.3% reduction.

6.2. DEA results

Figure 9 shows efficiency estimates under the seven scenarios for the sectors under examination. When analysing the “Demand 2030” (subfigure 9a) we realise that the efficiency of the renewable energy policies adopted under the BAU will decrease over the years. That is their ability to decrease GHG emissions over the examined period will be weak and for the EC 2030 and IEA 2030 scenario (same line) the efficiencies are in similar levels. As a result this indicates that the assumptions especially for BAU will be not sufficient to tackle the increased GHG emissions. Under the Greenpeace 2030 it appears that the REPE will increase.

Moreover, subfigure 9b represents the efficiency levels for the "Supply 2030". It appears that under the BAU the REPE will decrease over the examined period indicating that under this scenario the assumptions of BAU will not succeed on reducing efficiently the GHG emission in the "Supply 2030". Under the EC 2030 and IEA 2030 the efficiency will increase over the examined period and only under the Greenpeace 2030 the efficiency of the Estonia policy scenarios will be efficient in reducing the projected GHG emissions.

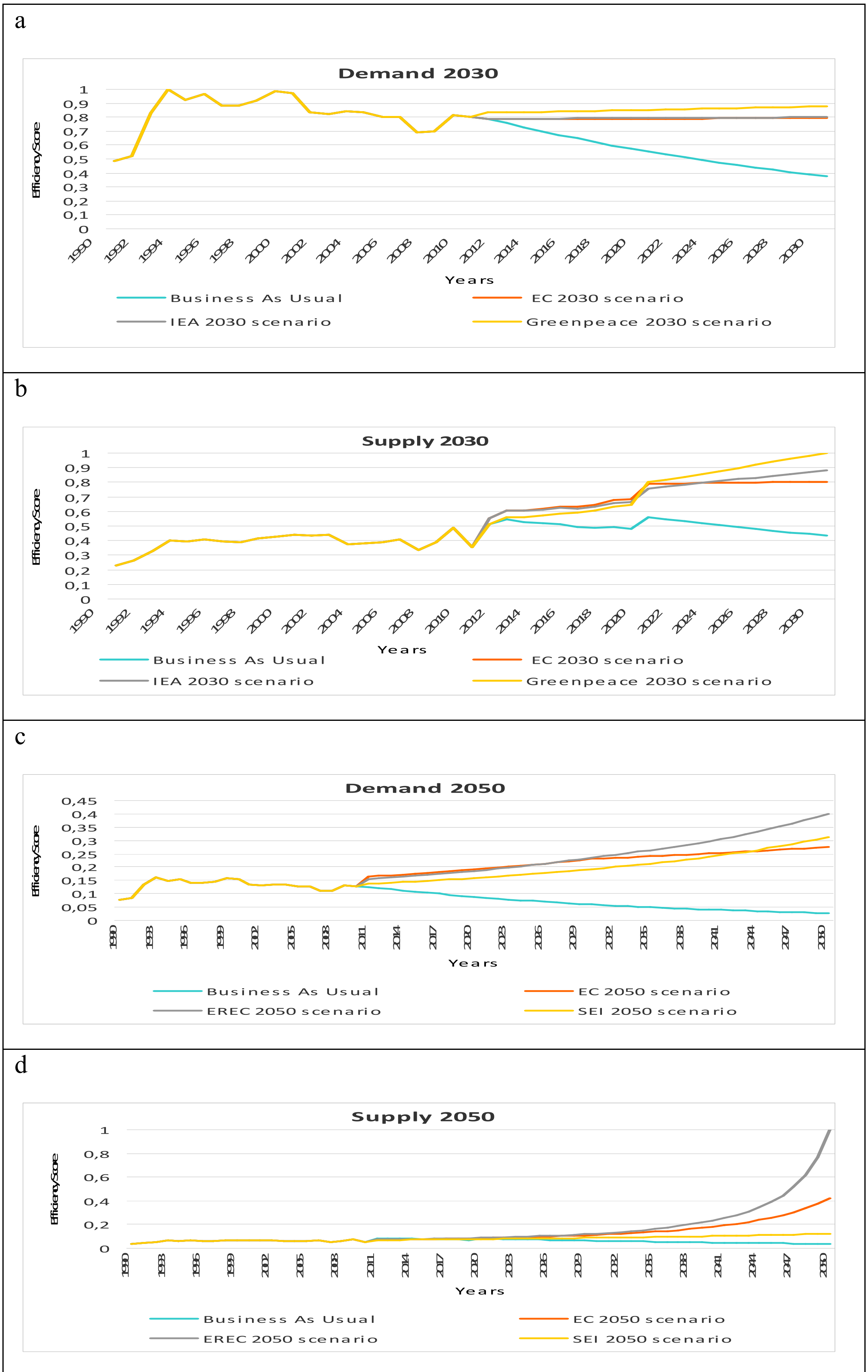

Figure 9 Efficiency plots based on the seven scenarios (**a**-demand 2030, **b**-supply 2030, **c**-demand 2050, **d**-supply 2050).

Furthermore, subfigure 9c illustrates the efficiency level for the "Demand 2050". The BAU scenario will decrease over the years, and the other three (EC 2050, EREC 2050 and SEI 2050) scenarios will increase over the examined period. From the "Supply 2050" side, the BAU scenario will decrease slightly over the years, the SEI 2050 scenario will increase modestly over the period. Under the EC 2050 scenario it appears that the REPE will increase and only under the EREC 2050 the efficiency of the Estonia policy scenarios will be efficient in reducing the projected GHG emissions (subfigure 9d).

7. Concluding remarks

Our paper analyses seven long-term renewable energy scenarios using LEAP software for Estonia's energy system. The main aim is to examine and compare scenarios based on organizations reports and seek a forecast to the 2030 and 2050 horizon in terms of GHG emissions abatement scenarios, in such a way as Estonia to attain the objectives of abating 40% of GHG emissions by 2030 and 80-95% by 2050 as set by the European Commission. The results show that for the 2030 horizon all scenarios (EC 2030, IEA 2030 and Greenpeace 2030) with their assumptions achieve the target (abating 40% compared to 1990 emission levels). Conversely, for 2050 target two of the four scenarios achieve the target for abating 80-95% reduction with BAU and SEI 2050 failing in satisfying the target.

In a second stage analysis we use DEA methodology and compare for each scenario the energy demand and the energy supply in order to evaluate the efficiency of renewable energy commitments on decreasing GHG emissions. The results imply that efficiency of RES under each scenario will be sufficient to reduce systematically the associated generated GHG emissions over the examined period for the energy demand 2030 only for Greenpeace 2030 scenario, and all scenarios for the energy demand 2050. From the supply side, for 2030 all scenarios will be efficient and for 2050 only EREC 2050 and IEA 2050.

Obviously, Estonia requires energy efficiency and further use of RES as more than 90% of power is produced by conventional fuels (fossil fuels – oil shale). Estonian electricity sector demands substantial changes as the external effect of electricity generation has to be tackled and reduced. Following EERC (2013), the use of oil shale has to be done in a more sustainable way with expansion of combined heat and power production and significant increase in the capacity of wind turbines (onshore and offshore wind farms). The plans consider even the construction of a nuclear power plant. Use of flue gas abatement methods[16] in oil shale pulverized combustion are also needed (EERC, 2013).

Following EPDC (2012), RES is mainly produced by smaller hydroelectric power plants and wind farms. Hydroelectric power has modest potential with no opportunities for larger plants, solar energy potential is small and with no thermal waters geothermal energy potential is poor. In contrast, Estonia has a great potential for energy production using biomass and especially wood-based fuels. Additionally, wind power generation potential in the coastal zone is high (EPDC, 2012).

Economic instruments like energy taxation may be used to internalize external effects with excise duties and pollution charges to have a serious effect on GHG emissions. Electricity fuel and electric excises and other energy production and fuel taxes may be a source of revenues[17] to be used in encouraging the various efforts towards sustainability and implementation of various National Development Plans.

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[16] For details on abatement methods see Halkos (1993, 1996).

[17] In 2011, the revenues from environmental taxation were 449 m € with 87% coming from fuel and electricity excise duties, 8% from pollution taxation, 2% from taxes on transportation and 3% from resource taxes (EERC, 2013, p. 19).

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