# A nonparametric approach for evaluating long-term energy policy scenarios: An application to the Greek energy system

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# A nonparametric approach for evaluating long-term energy policy scenarios: An application to the Greek energy system*

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**Abstract**
This paper by using the system of LEAP (Long range Energy Alternatives Planning System) constructs four different energy scenarios for the Greek transport, energy and industry sectors. By projecting the renewable energy use for the years 2020 and 2030 and the associated resulting carbon dioxide emissions, the paper constructs through nonparametric analysis efficiency measures evaluating the different energy policy which can be adopted. As a result it provides a quantitative measure of future policy performance under different energy consumption scenarios. The results reveal that the largest policy challenge for the Greek authorities will be the energy usage of the Greek industry since it is robust towards the adoption of renewable energy sources. It appears that under the four different policy scenarios the Greek industry sector will not be able to meet the environmental targets set by the Greek government. Finally, the analysis reveals that the targets for 2020 and 2030 can be met for the energy sector however for transport can only be met for the year 2030.

**Keywords**: Climate change; Renewable energy sources; Greek energy system; linear programming; nonparametric analysis.

**JEL classifications**: C60; C67; Q40; Q53; Q54; Q58.

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ΕΥΔΕ-ΕΤΑΚ

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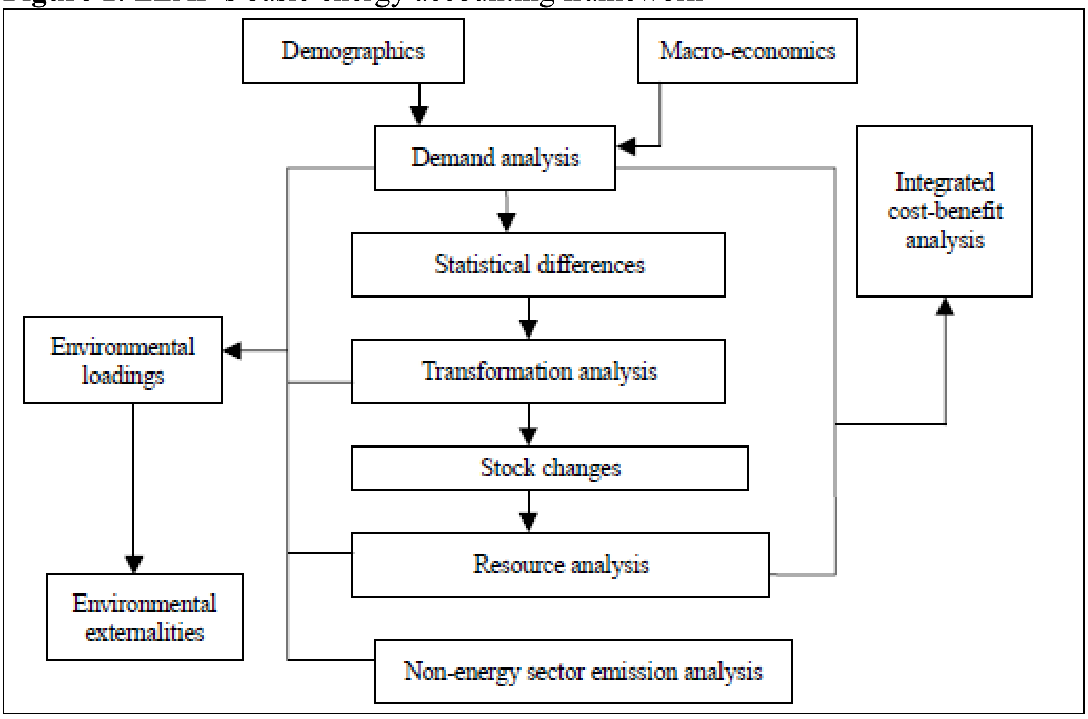
## 1. Introduction

The Long range Energy Alternatives Planning System (LEAP) is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed by the Stockholm Environment Institute. According to Heaps (2008) LEAP is a standard tool that enables countries to contact integrated resource planning, greenhouse gases (GHG) mitigation assessments, and Low Emission Development Strategies (LEDS). Furthermore several countries have been based on LEAP's output in order to report to the United Nations Framework Convention on Climate Change (UNFCCC).

There are various studies in Greece that have been conducted in order to provide the literature with long-term projections in the energy sector using LEAP (among others, Papagiannis et al. 2008; Giatrakos et al. 2009; Roinioti et al. 2012). According to Bhattacharyya and Timilsina (2010) LEAP is based on the accounting framework in order to generate energy demand (and supply) and on the physical description of the examined energy system. Furthermore on their extensive review Bhattacharyya and Timilsina (2010) emphasise the fact that LEAP is based on the scenario approach in order for several paths of energy system evolution to be developed. Figure 1 describes this framework in which the LEAP is based on. As can be observed the forecast of the energy demand is based on the effect of alternative market shares, whereas the supply side is based on what-if analysis and possible development scenarios which LEAP integrates through simulation and accounting approaches.

Our paper constructs four different scenarios for the period 1990-2030 in order to evaluate the demand of energy derived from renewable energy sources (RES) and the GHG emissions generated over the same period for the sectors of industry, transport and energy. Therefore in a first stage the paper forecasts the energy demand derived from renewable sources alongside with the generated GHG emissions (under the four scenarios). Furthermore in a second stage analysis it applies a nonparametric estimator based on the mathematical approach known as Data Envelopment Analysis (DEA) in order to evaluate the efficiency of the Greek renewable energy policies imposed under the Law L3851/2010 which was introduced in order to comply with the European targets set in 2007 and in 2014[1]. As a result we will present here a way for evaluating the efficiency of the future implementation of renewable energy policies set by the Greek government and under the four scenarios.

**Figure 1**: LEAP's basic energy accounting framework




**Source**: Heaps (2002)

The article is constructed as follows. Section 2 presents the four scenarios while section 3 presents the methodology adopted. Section 4 presents the empirical results, whereas the last section concludes the paper.

[1]The European targets implies that by 2020 EU countries' renewable energy penetration in final consumption should be at least by 20%, whereas by 2030 it should be at least by 27%.

## 2. A description of the LEAP-based renewable energy policy scenarios[2]

Scenarios are self-consistent story lines of the evolution of future energy systems in the context of a specific set of conditions. Scenarios assemble information about different trends and possibilities into internally consistent images of plausible alternative futures (Wiseman et al., 2011; Carter, 2007; Moss et al., 2010). The main concept of LEAP is an end-use driven scenario analysis with a baseline scenario and alternative scenarios. The scenarios are used for a number of "what if" questions under the arrangement of user-defined assumptions. The set of conditions is detailed in the scenarios and are constructed in order to encompass some factors (parameters) that are anticipated to change.

In our case there are four scenarios generated under different options. The policy options and the key assumptions the scenarios are based on are presented next.[3]

<u>*Baseline Scenario-BASE, BAU:*</u> The first scenario is the "Baseline", which is based on historical trends from 1990 till 2010. Changes in demographic and macroeconomic variables are given in Table 1. Specifically, Table 1 describes the projections for the annual population growth rate, annual GDP growth rate, annual growth rate of income, annual growth rate of GDP per capita till the target year 2030 (Ministry of Environment, Energy and Climate Change, 2013). The projected potential withdrawals of Power Plants may be fount in Halkos et al. (2014).

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[2]The main scenarios presented in this section are based on the analysis presented by Halkos et al. (2014).

[3] Here we are interested in the emissions of pollutants. Details on the calculation of control costs of emissions reductions may be fount in Halkos (1992, 1993, 2010, 2014).

**Table 1:** Changes of demographic and macroeconomic variables used

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Annual population growth rate | 0,1% | 0,0% | -0,2% | -0,2% | -0,1% | -0,3% | -0,2% |
| Annual GDP growth rate | -4,0% | -2,6% | 1,1% | 2,1% | 2,1% | 2,6% | 2,6% |
| Annual growth rate of income | -4,0% | -3,7% | 0,8% | 2,8% | 2,5% | 2,6% | 2,6% |
| Annual growth rate of GDP per capita | -9,0% | -2,0% | 0,9% | 1,8% | 1,6% | 2,6% | 2,6% |
| | **2018** | **2019** | **2020** | **2025** | **2030** | | |
| Annual population growth rate | -0,1% | -0,1% | -0,2% | -0,2% | -0,4% | | |
| Annual GDP growth rate | 2,5% | 2,5% | 2,9% | 2,2% | 1,5% | | |
| Annual growth rate of income | 2,5% | 2,5% | 2,9% | 2,2% | 1,5% | | |
| Annual growth rate of GDP per capita | 2,5% | 2,5% | 2,9% | 2,2% | 1,5% | | |

**Note**: Projections are based on estimates by the Ministry of Environment, Energy and Climate Change (2013).

*Target 2020 Scenario-TAR20:* The second scenario is based on the European target set in 2007, in order to develop an energy efficient and low carbon Europe via an increase in the share of EU energy consumption produced from renewable resources to 20%. According to the government and to Law L3851/2010 it is stated that the protection of the climate or the reduction of GHG emissions, through the promotion of electrical energy production from RES is a crucial element of the energy sector of the country. In order to achieve the national target of 20% contribution of the energy produced from RES to the gross final energy consumption, specific targets include increasing RES electricity share by 40%, RES heating and cooling share for the household sector by 20%, and RES transport share by 10%. This target will be achieved through the large penetration of RES technologies in electricity production, heat supply and in the transport sector.

The changes in demographic and macroeconomic variables that are used *in target 2020 scenario* are also presented in Table 1. Finally, we assume a 50% increase of RES capacity, which corresponds to 5.311,7 MW. Specifically, as the Hellenic Transmission System Operator S.A. publishes binding and final Offers for Connection System or Network for power stations of Renewable Energy and Stations and cogeneration plants of Electricity & Heat and High Performance (CHP), we assume that till 2020 will be achieved half of the non binding offers. Table 2 describes in details the structure of the assumed generated capacity per RES category.

*Target 2030 Scenario-TAR30:* We follow the target set in 22 January 2014 by the European Commission towards a renewable energy economy. Specifically, the share of renewable energy penetration in final consumption is set to increase at least up to 27% by 2030. This will be achieved by the introduction of RES in industry. Following Heaps et al. (2009) concerning the industry sector, $CO_2$ emissions can be further reduced through the increased use of biomass, natural gas and increased participation of RES in electricity, the iron and steel production sector, the cement production, chemicals production and other industrial subsectors. As far as the changes in demographic and macroeconomic variables that are used in *target 2030 scenario* these are given also in Table 1. Furthermore, we assume a 100% increase of RES capacity, which corresponds to 10.563,2 MW. Specifically, as in the previous scenario and relying on the Hellenic Transmission System Operator S.A., the last column of Table 2 describes in details the structure of the assumed generated capacity per RES category.

*Green Scenario-Green*: Under this scenario we follow as in TAR30 the target set in 22 January 2014 by the European Commission towards a renewable energy economy. However, and in contrast to TAR30 we assume that the share of renewable energy penetration in final consumption is set to increase at least up to 27% by 2020 instead of 2030. The same assumptions imposed for TAR30 are also imposed for the Green scenario however under the *Green* scenario the Greek government should increase the share of energy consumption produced from renewable resources to 27% by 2020.

**Table 2:** Generation capacity projections per RES category till 2020 and 2030

| RES | Capacity (MW) 2020 | Capacity (MW) 2030 |
|---|---|---|
| Photovoltaics | 207,5 MW | 415 MW |
| Wind Park | 4.666,5 MW | 9.333 MW |
| Small Hydro | 350,2 MW | 640,2 MW |
| Biomass | 87,5 MW | 175 MW |
| TOTAL | 5.311,7 MW | 10.563,2 MW |

**Source**: HELLENIC TRANSMISSION SYSTEM OPERATOR S.A. available at: http://www.desmie.gr/ape-sithya/stathmoi-ape-sithya-me-prosfora-syndesis/

Figure 2 below presents the projections of GHG emissions for the sectors of industry, transport and energy. As can be observed industry produces the lowest levels of GHG emissions, whereas the transport sector produces the highest GHG emissions levels. As can be viewed the emissions produced by the Greek industry have been declined especially during the financial crisis period. The same is reported for the energy sector. However, the emissions generated by the transport sector have been monotonically increasing (Base and TAR20 scenario). In all cases as expected and under the base scenario the sectors will be generating higher levels of GHG emissions compared to the Green scenario.

Finally, Figure 3 presents the estimated energy consumption from RES under the four scenarios. It can be viewed that under the Green scenario the different sectors will have more investments on RES and therefore the consumption levels will be higher. However, again it can be noticed that the energy levels generated from RES of industry sector (subfigure 3a) will be significant lower compared to the sectors of transport (subfigure 3b) and energy (subfigure 3c).

**Figure 2**: Estimated projections of GHG emissions under the four scenarios

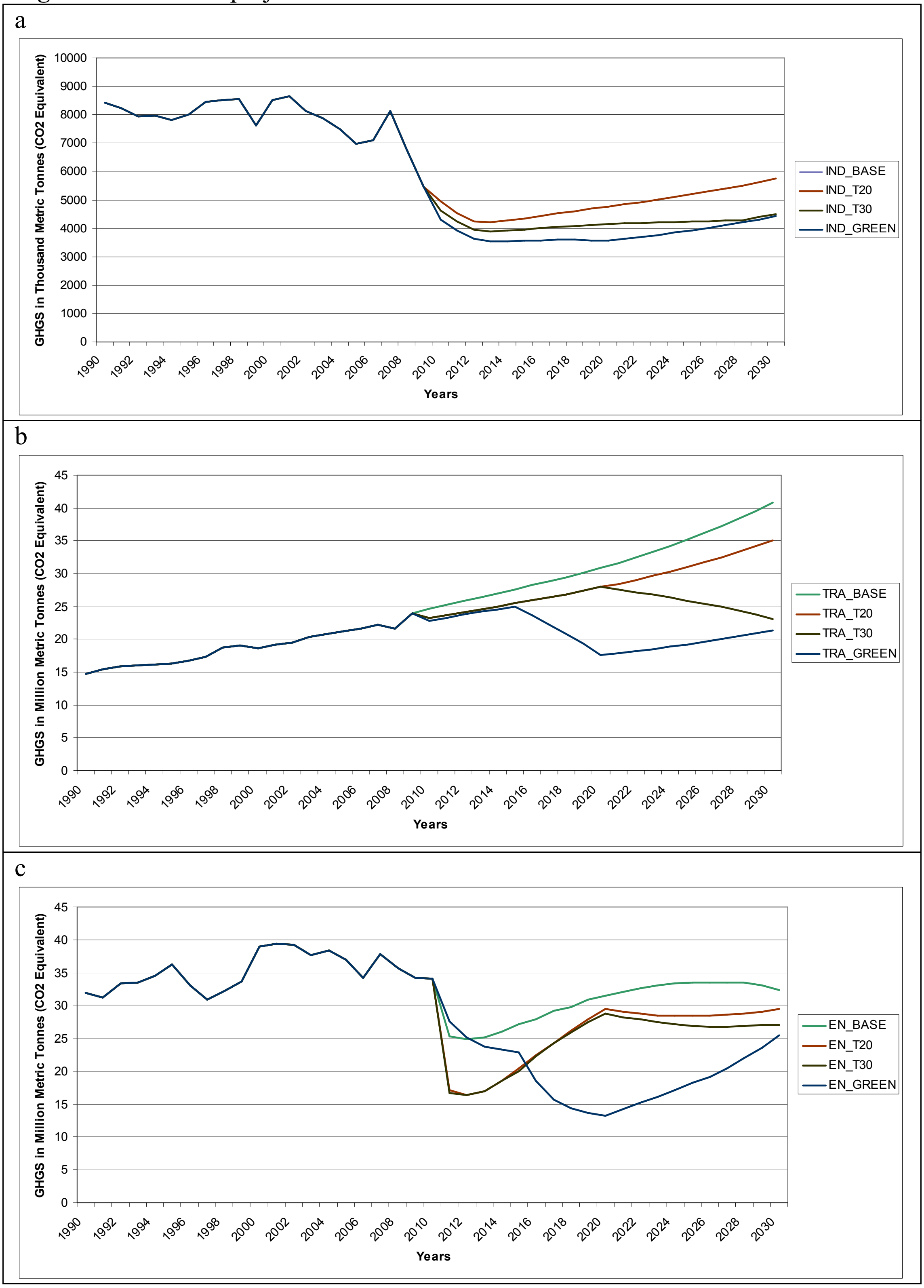
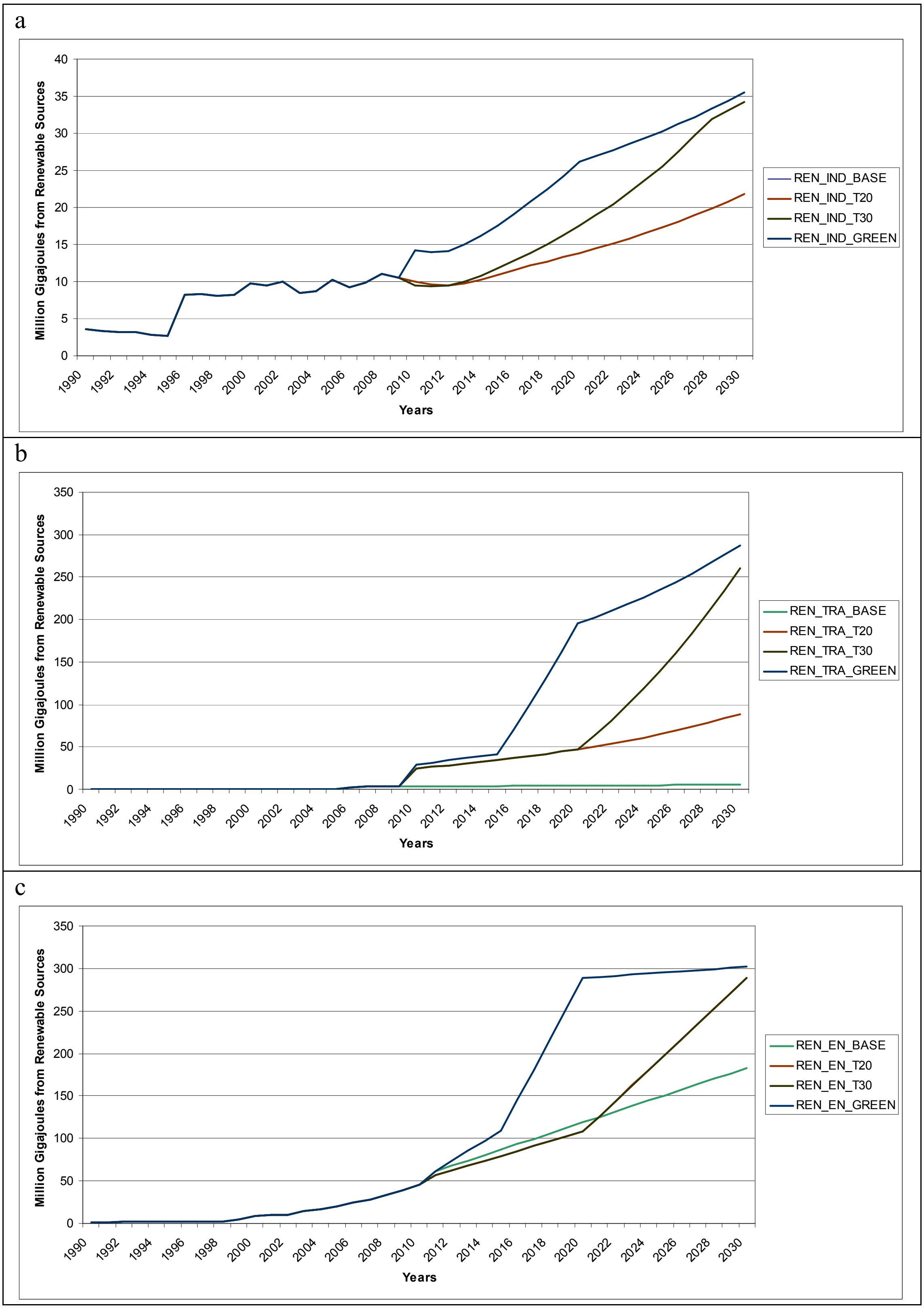


**Figure 3**: Estimated projections of energy consumption produced by RES under the four scenarios



## 3. Methodology

In order to evaluate the efficiency of the Greek government's energy renewable policies, we need to evaluate also their ability to reduce greenhouse gases (GHG) under the four energy policy scenarios described previously (BAU, TAR20, TAR30 and GREEN). Specifically, we need to evaluate under the four scenarios generated in LEAP for the period 1990-2030 the estimated energy usage of renewable sources of the Greek main sectors (industry, transport and energy) alongside with the generated greenhouse gases (GHG) produced. This can be accomplished by creating a composite performance index which can be comparable among the four renewable energy scenarios and among the sectors for the period 1990-2030. As a result this will enable us to evaluate the efficiency of the renewable energy policy (EREP) based on the future estimates produced using LEAP.[4]

In order to do so we apply a nonparametric approach known as data envelopment analysis (DEA). DEA is a mathematical programming technique which enables us to evaluate a specific process which is based on the estimation of a benchmark frontier – a relative frontier against which the decision making units (DMUs) are assessed, using specified DMUs' inputs and outputs (Daraio and Simar, 2007). Then the efficiency is calculated as the distance of each DMU from the estimated ('efficient') frontier. In our case the role of the DMUs are the years of each sector under the four energy scenario. Typically the DEA methodology is applied in a production framework investigating the efficiency of specific inputs to produce specific outputs.

However, in our study we follow a similar approach as the one initiated by Kuosmanen and Kortelainen (2005). They suggest an eco-efficiency indicator which

[4] Halkos and Tzeremes (21014a) discuss the effect of electricity consumption from renewable sources on countries′ economic growth levels while Halkos and Tzeremes (2014b) and Halkos (2014) show empirically the effect of countries compliance with the Kyoto protocol agreement (KPA) policies.

involves the calculation of the ratio of value added (i.e. the good output/GDP) to the environmental damage or pressure index (i.e. the bad output/pollutant), approaching therefore the environmental efficiency from a social point of view rather than from the managerial point of view. Therefore their proposed index excludes the primary production factors even though they are important cost factors in technical and economic efficiency analysis (Kuosmanen and Kortelainen 2005, p. 64).

In our case the value added from the renewable energy policy perceptive is the energy consumption (measured in millions Gigajoules) from renewable sources whereas the bad output is the Greenhouse emissions ($CO_2$, $CH_4$ and $N_2O$) which will be produced in the future (based on the scenarios entered in LEAP) from the sectors of industry, energy and transport. Based on the approach by Koopmans (1951) we can define the efficiency of renewable energy policy in a multiple dimensional Euclidean space. For the purpose of our analysis let us have M pollutants (Greenhouse emissions - $CO_2$, $CH_4$ and $N_2O$) measured by the variables $\mathbf{u} = (u_1, ..., u_m)$ and let $\rho$ to denote the energy demand of the three sectors derived only from renewable energy sources (measured in millions Gigajoules). As a result we will be able to define the pollution generating technology set as:

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

Expression (1) implies that even though and under the specified energy scenarios there will be a specific percentage of commitment of energy consumption from renewable sources, however, there will be also pollution generated from energy consumption from non-renewable sources. Therefore, in our case for efficiency the renewable energy policies implemented by the Greek government will have the aim to reduce the generated pollution. This efficiency can be represented as:

$$EREP_n = \frac{\mathrm{P}_n}{D(\mathbf{U}_n)} \quad (2)$$

In ratio (2) $D$ represents the damage function of the $M$ pollutants in a weighted average indicator represented as:

$$D(\mathbf{u}) = v_1 u_1 + v_2 u_2 + \ldots + v_m u_m \quad (3)$$

Since the problem of a proper weight $(v)$ on the pollutants is crucial we follow Kuosmanen and Kortelainen (2005) suggesting the *benefit of the doubt* weighting scheme. This approach applies weights that maximize the relative EREP of the evaluated year and industry in comparison with the maximum attainable EREP. This can be calculated as[5]:

$$\begin{aligned}
&\max_{v} EREP_n = \frac{\mathrm{P}_n}{v_1 U_{n1} + v_2 U_{n2} + \ldots + v_M U_{nM}} \\
&s.t. \\
&\frac{\mathrm{P}_1}{v_1 U_{11} + v_2 U_{12} + v_M U_{1M}} \le 1 \\
&\frac{\mathrm{P}_2}{v_1 U_{21} + v_2 U_{22} + v_M U_{2M}} \le 1 \\
&\vdots \\
&\frac{\mathrm{P}_N}{v_1 U_{N1} + v_2 U_{N2} + v_M U_{NM}} \le 1. \\
&v_1, v_2, \ldots, v_M \ge 0
\end{aligned} \quad (4)$$

Therefore we use weights $v_m \ (m = 1, \ldots, M)$ to maximize the EREP ratio, subject to the condition that the highest attainable efficiency score does not exceed the maximum index value of one when the same weights are applied across all other years and industries. As can be observed the weights are not negative and the efficiency score can take the values between 0 and 1. As can be realised the value of 1 indicates an efficient renewable energy policy whereas values below 1 indicate inefficient policies.

[5]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.

Furthermore, the program in (4) is fractional can is difficult to be solved. However by following Charnes and Cooper (1962) and Charnes et al. (1978) we can transform the fractional program presented in (4) into a linear program as:

$$
\begin{aligned}
&\min_{v} EREP_n^{-1} = v_1 \frac{U_{n1}}{\mathrm{P}_n} + v_2 \frac{U_{n2}}{\mathrm{P}_n} + \ldots + v_M \frac{U_{nM}}{\mathrm{P}_n} \\
&s.t. \\
&v_1 \frac{U_{11}}{\mathrm{P}_1} + v_2 \frac{U_{12}}{\mathrm{P}_1} + \ldots + v_M \frac{U_{1M}}{\mathrm{P}_1} \geq 1 \\
&v_1 \frac{U_{21}}{\mathrm{P}_2} + v_2 \frac{U_{22}}{\mathrm{P}_2} + \ldots + v_M \frac{U_{2M}}{\mathrm{P}_2} \geq 1, \\
&\vdots \\
&v_1 \frac{U_{N1}}{\mathrm{P}_N} + v_2 \frac{U_{N2}}{\mathrm{P}_N} + \ldots + v_M \frac{U_{NM}}{\mathrm{P}_N} \geq 1 \\
&v_1, v_2, \ldots, v_M \geq 0.
\end{aligned} \tag{5}
$$

Then by using the distance function approach Shephard (1970) having $k$ years in our analysis we can express our linear program as:

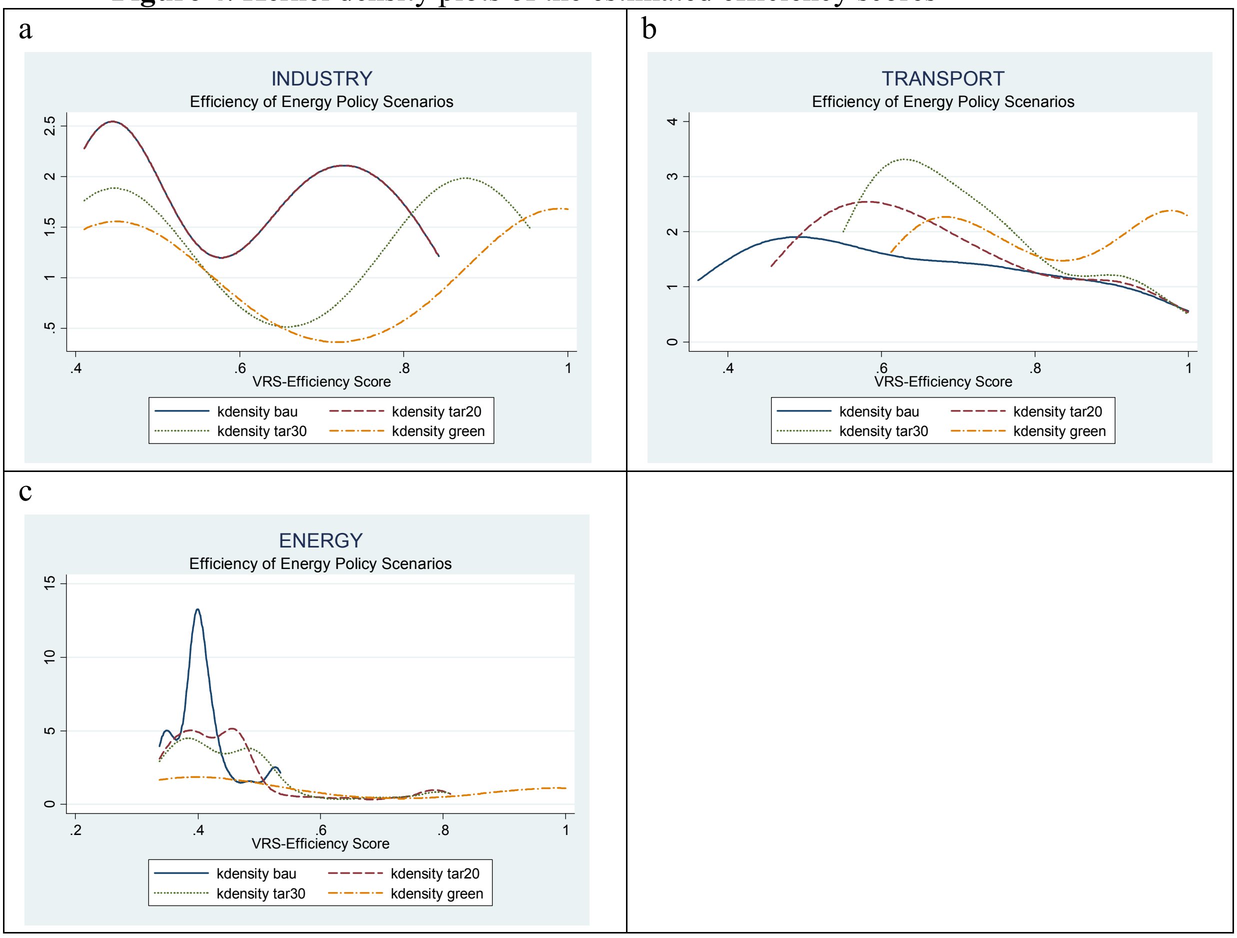
$$
\begin{aligned}
&\min_{\lambda} EREP_{\mathrm{n}} = \theta \\
&s.t. \\
&\theta U_{nm} \geq \sum_{k=1}^{N} \lambda_k Z_{km} \forall m = 1, \ldots, M \\
&\mathrm{P}_n \leq \sum_{k=1}^{N} \lambda_k \mathrm{P}_k \\
&\sum_{k=1}^{N} \lambda_k = 1, \lambda_k \geq 0 \forall k = 1, \ldots, N.
\end{aligned} \tag{6}
$$

It must be noted that in the above linear programming we have also added an extra condition $\left( \sum_{k=1}^{N} \lambda_k = 1 \right)$ allowing therefore for variable returns to scale-VRS (Banker et al. 1984) in our measurement. Since our analysis is based over a large period of time (1990-2030) it is expected that there will be a lot of variations involved in the demand of energy from renewable sources and variations among the pollutants generated from the consumption of non-renewable energy sources. According to several authors the assumption of VRS is more suitable when investigating the impact of changing energy use over time and you expect such variations (Honma and Hu, 2013; Fang et al., 2013).

## 4. Empirical results

As analysed previously we compared for each sector separately the EREP for each year between the four scenarios. Therefore in our case and within the framework of DEA the decision making units (DMUs) are the years of our analysis which are compared against each other and among the four scenarios presented previously. More analytically Figure 4 presents the kernel density plots of the estimated efficiency scores using Gaussian kernels (Silverman, 1998).

**Figure 4**: Kernel density plots of the estimated efficiency scores



For the case of industry sector (subfigure 4a) the results reveal that the BAU and TAR20 scenario have identical efficiency distributions[6]. Furthermore, it appears that there is a bimodal distribution of efficiencies with a first peak around the 45% level of efficiency and a second peak around the 75%. The bimodality is also reported for TAR30 and Green scenarios. Again for both scenarios there is a first peak at the 45% level of EREP whereas the second peak for the TAR30 is around the 87% and for the Green scenario is around 100%. For the case of transport (subfigure 4b) the twin-peak is observed only for the Green scenario with one peak around 70% of efficiency and the second peak around 100%.

Under the BAU scenario the distribution of the efficiencies of the renewable energy policies over the examined period is platykurtic. This indicates that the efficiency estimates are highly dispersed and their distribution is less clustered around the mean than in a leptokurtic distribution. Similar results can be also viewed for the efficiencies of TAR20 and TAR30. Finally, subfigure 4c presents the distribution of efficiency estimates for the Greek energy sector. It appears that under the BAU scenario the efficiency distribution has three peaks one around 35%, a second one around 40% and a third one around 55%. Under the TAR20 and TAR30 the distribution is bimodal with a first peak around 38% and a second peak of 45% for TAR20 and 50% for TAR30.

Similarly, under the Green scenario the distribution of efficiency is platykurtic. Figure 5 presents the efficiency estimates under the four scenarios for the three sectors under examination. When analysing the industry (subfigure 5a) we realise that the efficiency of the renewable energy policies adopted under the BAU and TAR 20 (same line) will decrease over the years. That is their ability to decrease

[6]This is due to the fact that the Greek government under the law of L3851/2010 has decided to commit on energy investments from RES only for the sectors of transport, energy, industry and households. As a result the BAU energy scenario is identical with the TAR20.

GHG emissions over the examined period will be weak. As a result this indicates that the commitments made by the Greek government especially for TAR20 and BAU will be not sufficient to tackle the increased GHG emissions. Under the TAR30 it appears that the EREP will increase after 2024, whereas only under the Green scenario the efficiency of the Greek policy scenarios will be efficient on reducing the projected GHG emissions.

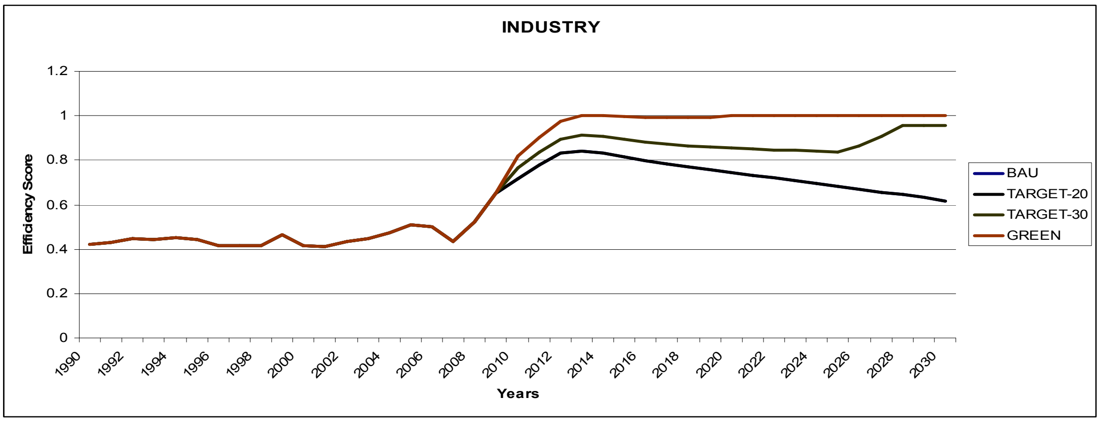
Moreover, subfigure 5b represents the efficiency levels for the Greek transport sector. It appears that under the BAU and TAR20 the EREP will decrease over the examined period indicating that under these two scenarios the Greek government will not succeed on reducing efficiently the GHG emission in the sector of transport. Under the TAR30 the efficiency will increase after 2022 whereas under the Green scenario the efficiency will increase after 2015. In these lines and for the energy sector it appears that only the Green scenario the efficiency will increase. Under the BAU scenario the efficiency will decrease whereas under theTAR20 and TAR30 the efficiencies are in similar efficiency levels.

**5. Concluding remarks**

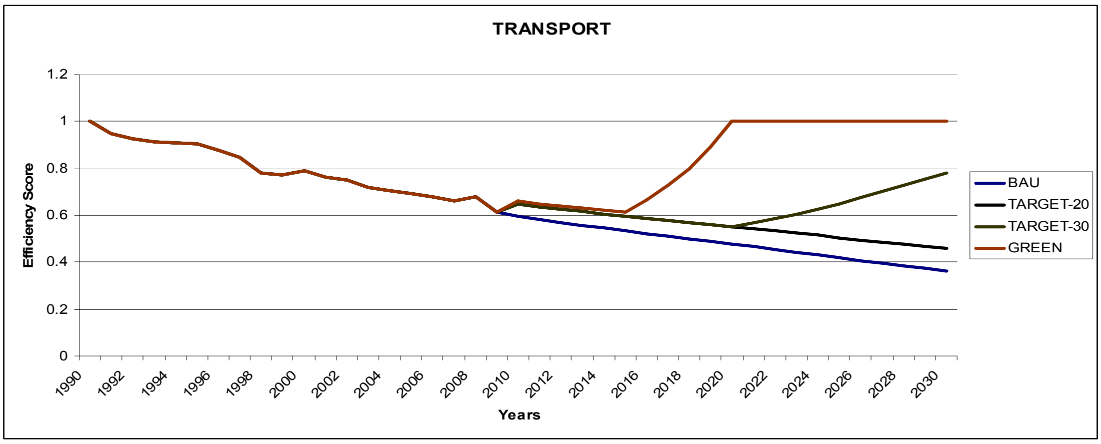
The paper analyses four long term renewable energy scenarios by using LEAP software for three Greek sectors. We present the energy consumption estimates from RES and the GHG emissions generated over the period of 1990-2030 for the sectors of industry, transport and energy. In a second stage analysis we use DEA methodology in order to evaluate the efficiency of renewable energy commitments on decreasing GHG emissions. The results reveal that the efficiency of renewable energy commitments set by the Greek government under the Law 3851/2010 will not be sufficient to decrease systematically the generated GHG emissions over the examined period. In order for the Greek government to have more significant results should increase the share of energy consumption produced from renewable resources at least up to 27% by 2020 this in turn will decrease significantly more the generated GHG emissions compared to the energy policies which are based on the original commitments set by the Law 3851/2010.

**Figure 5**: Efficiency plots based on the four scenarios

a




b

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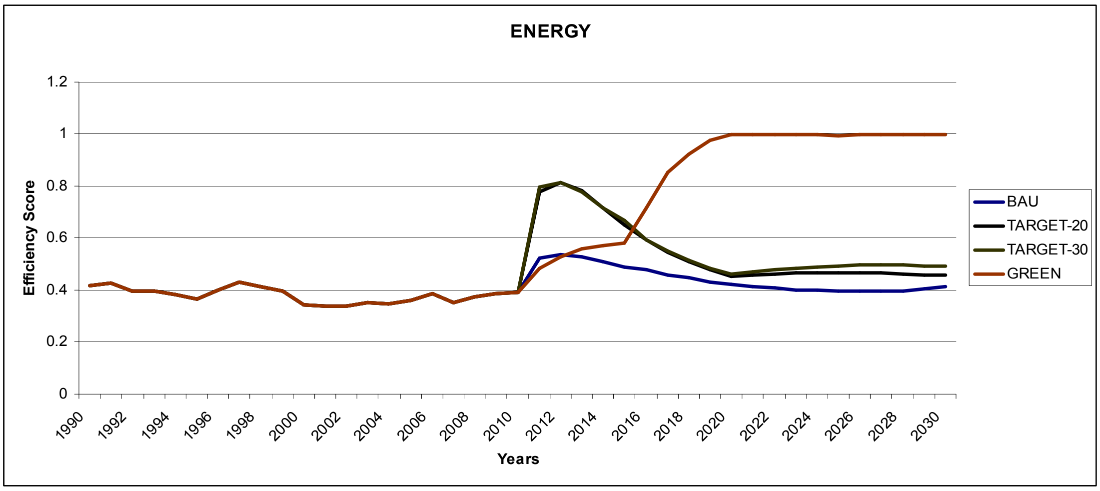

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