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Optimal design of the renewable energy map of Greece using weighted goal-programming and data envelopment analysis

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ABSTRACT

Renewable energy forms have been widely used in the past decades highlighting a “green” shift in energy production. An actual reason behind this turn to renewable energy production is EU directives which set the Union's targets for energy production from renewable sources, greenhouse gas emissions and increase in energy efficiency. All member countries are obligated to apply harmonized legislation and practices and restructure their energy production networks in order to meet EU targets. Towards the fulfillment of 20–20–20 EU targets, in Greece a specific strategy which promotes the construction of large scale Renewable Energy Source plants is promoted. In this paper, we present an optimal design of the Greek renewable energy production network applying a 0–1 Weighted Goal Programming model, considering social, environmental and economic criteria. In the absence of a panel of experts Data Envelopment Analysis (DEA) approach is used in order to filter the best out of the possible network structures, seeking for the maximum technical efficiency. Super-Efficiency DEA model is also used in order to reduce the solutions and find the best out of all the possible. The results showed that in order to achieve maximum efficiency, the social and environmental criteria must be weighted more than the economic ones.

1. Introduction

The design of a country's energy map and the investment proposals for making it complete and responsive to national needs, are subjects that need interdisciplinary approach. This is because investing in energy incorporates not only energy production and consumption but it also has social, economic and environmental aspects. Investing in the energy sector and in energy plants in particular is not only financially evaluated; other criteria such as environmental pollution, gas emissions, social acceptance and the economic effects are considered important too. Sometimes making the trade off among them is also a point of conflict.

In European Union, both energy and environment are subjects of great importance and there are plenty of directives to promote the competitive, sustainable and secure energy but in a tight environmental framework policy that adapts Kyoto protocol in terms of greenhouse emissions' reduction. The EU Directive 2009/28/EC EU [1] ‘*Promotion of the use of energy from renewable sources*’ subsequently repealing the EU Directive 2001/77/EC [2] and EU Directive 2009/29/EC [3], incorporates the basic principles for the use of renewable sources in the energy production, aiming to limit greenhouse gas emissions, like CO_2 and NO_x, and encourages the deployment of national energy plans including renewable energy sources. Furthermore, in this direction each European member state has a target of renewable energy production to gross final consumption ratio for 2020, which is included in the overall 20–20–20 Community's goals. Additionally, in the pursuit of the EU climate targets, greenhouse gas emissions should be reduced by 20% and an increase in energy efficiency by 20% should be achieved.

In Greece, due to the Greek Legislation (Law no. 4001/2011) every month an imprinting of the fundamentals of Renewable Energy Sources (RES) and of High Performance Stations which cogenerate Electricity and Heat is conducted. As it is stated in the recent reports so far for 2014, the total national installed capacity of renewable energy plants is 4.482 MW and the total energy production of renewable energy plants is 682 GWh. At the same time the 2014 goal for the total national installed capacity of renewable energy plants is 9.520 MW and for 2020 is 13.950 MW (Renewable Energy Sources and High Performance Electricity and Heat Stations Report, 2014). The deviation from the goals is approximately 300%. At the same time CO_2 levels from fossil fuel

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Nomenclature

Index/Set

$i \in I$	renewable energy plant
$j \in J$	prefecture
Ω	all possible combinations (alternatives and prefectures)
S	selected alternatives and prefectures

Binary variables

X_{ij}	1 if renewable plant i will be installed in prefecture j, 0 otherwise

Nonnegative variables

d_{PP}^{+}	over achievement of the Power Production goal
d_{PP}^{-}	under achievement of the Power Production goal
$d_{CO_2}^{+}$	over achievement of the CO_2 goal
$d_{CO_2}^{-}$	under achievement of the CO_2 goal
d_{INV}^{+}	over achievement of the Investment Ratio goal
d_{INV}^{-}	under achievement of the Investment Ratio goal
d_{OM}^{+}	over achievement of the Operations & Maintenance Cost goal
d_{OM}^{-}	under achievement of the Operations & Maintenance Cost goal
d_{OH}^{+}	over achievement of the Operating Hours goal
d_{OH}^{-}	under achievement of the Operating Hours goal
d_{JOB}^{+}	over achievement of the Job goal
d_{JOB}^{-}	under achievement of the Job goal
${}^{UMP}d_j^{+}$	over achievement of the Unemployment goal for each prefecture j
${}^{UMP}d_j^{-}$	under achievement of the Unemployment goal for each prefecture j
${}^{GDP}d_j^{+}$	over achievement of the GDP goal for each prefecture j
${}^{GDP}d_j^{-}$	under achievement of the GDP for each prefecture j

Parameters

PP_i	power produced by renewable plant i
$CO2_i$	tones of CO_2 avoided of renewable plant$i$
INV_i	Investment Ratio for renewable plant i
OM_i	Operations and Maintenance cost for renewable plant i
OH_i	Operating Hours for renewable plant i
JOB_i	Jobs created by installation of renewable plant i
UMP_j	Unemployment percentage at prefecture j
GDP_j	GDP at prefecture j
G^{PP}	Goal for Power Production
G^{CO2}	Goal for tones of CO_2 avoided
G^{INV}	Goal for Investment Ratio
G^{OM}	Goal for Operations and Maintenance
G^{OH}	Goal for Operating Hours
G^{JOB}	Goal for Jobs created
G_j^{UMP}	Goal for Unemployment percentage for prefecture j
G_j^{GDP}	Goal for GDP for prefecture j

from 2012 to 2013 decreased approximately 10.2% (from 85.268 to 76.614 thousand tonnes) based on Eurostat reports of year 2014.

The Greek national energy plan for achieving 20% in renewable energy production to gross final consumption ratio, includes investments in renewable energy plans in the sector of electrical energy production, in household's heating and cooling and the use of biofuels in transportation. Furthermore, it is estimated that the overall investments needed in the energy sector are approximately 22.2 billion euro for the 10-year period 2010–2020 from which 74.32% will be invested in Renewable Energy Sources. More specifically, the plan promotes the construction of large scale RES plants, such as wind farms, hydro plants and Concentrating Solar Power (CSP) plants, in conjunction to medium and small scale RES plants, including photovoltaic, small hydro, biogas, geothermal plants, biomass and co-generation and RES applications for electricity generation in the residential and tertiary sector buildings according to Ministry of Environment, Energy and Climate Change.

Nevertheless, recent studies give Greece a really low score of Climate Change Performance Index concluding that Greece has almost totally abandoned all climate policies under the effects of the economic crisis and Troika's economic control [4]. These facts point the interest to promote the national strategy of Renewable Energy Planning proposing radical and applicable policies considering energy, economic, environmental and social factors.

However, restructuring the energy production network of the country in order to meet EU targets, affects the country in a variety of ways including social, environmental and economic. This is the main reason why choices such as selecting among the different types of RES plants and selecting the place of their installation, should be made considering not only the financial effectiveness, the produced energy and the levels of GHG emissions, but also the social acceptance and the impacts on local and national economy in terms of unemployment and GDP. The data for unemployment and GDP for the Greek prefectures have been retrieved from Hellenic Statistical Authority (EL.STAT) for the fiscal year 2013.

Towards this direction, in the current work we present the optimal design of the Greek renewable energy production network applying a 0–1 weighted Goal Programming model. In our approach we take into consideration energy, economic, environmental and social factors and we finally present the different structures of the network when the importance of these factors alters. The proposed method scans through all the possible combinations of weights assigned to each criterion, providing an objective analysis in the absence of a panel of experts that would provide weights or a relative importance table with the application of AHP. Each combination is examined in terms of pre-set inputs and outputs taken from the slack variables and Data Envelopment Analysis (DEA) technique is applied.

The concept of constructing the renewable energy map of Greece using a 0–1 Weighted Goal Programming model and utilizing DEA models as a filter to select the best out of multiple solutions, has not been proposed before.

The paper is structured as follows. In Section 2, we present the related literature review. In Section 3 we present the proposed modeling framework. In Section 4 we present and analyze the results of the analysis. Finally, a summary of the proposed approach is demonstrated in Section 5 while Conclusions are presented in Section 6.

2. Literature review

The use of goal programming has so far become popular with numerous applications to the energy sector, by solving problems related to energy production and consumption, gas emissions and other subproducts of the related procedures, economic and public