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Evaluation of future sustainable electricity generation alternatives: The case of a Greek island

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ABSTRACT

The decision-making process regarding the choice of alternative energy technologies is multidimensional, made up of a number of aspects at different levels, economic, technical, environmental and social. This paper uses a multicriteria decision making model, PROMETHEE II, to determine the best fuel mix for electricity generation in an isolated Greek island, Lesvos. Having analyzed the energy profile of the island, a set of 7 energy policy scenarios are determined and assessed against economic, technical, environmental and social criteria. The energy policy scenarios include the use of conventional fuels, wind energy and natural gas, in its liquid form, liquefied natural gas (LNG). Weighting of criteria is carried out according to three different perspectives, each one focusing on sustainability, economic and environmental/social benefits. Two sensitivity analyses are performed taking into account the fluctuations of the electricity demand and the fluctuations of the fuel prices.

1. Introduction

Sustainable development means the satisfaction of present needs without compromising the quality of life of future generations. Sustainable development has a dominant role in energy planning. Energy planning is the process of developing long-range policies for the future of a regional, national or even global energy system. It takes into consideration technical, political, social and environmental aspects and is carried out collecting the historical data of previous energy plans of the under examination region [1,2]. One of the most common problems of energy planning is to choose among various alternative energy sources and technologies in order to cover the energy demand. In some cases, decision makers face the dilemma of choosing among current and future conflicting goals of sustainable development, such as environmental degradation and energy security. This need to incorporate various aspects in energy planning, resulted in the increasing use of multicriteria approaches. Strantzali and Aravossis [3] showed in their literature review that the majority (almost 38% of the examined papers) of decision support papers, cover the application area of power generation technologies evaluation in regional and national energy planning. The classical outranking methods PROMETHEE and ELECTRE dominate in the preferences of decision makers in the research field of energy planning.

Energy planning in an island environment is complex and requires rigorous planning and appropriate tools of evaluation to aid in decision making. The important aspects are security of supply, economic viability, social acceptability and environmental protection. Specifically, in decentralized energy planning, the increasing interest in the utilization of models within the multicriteria analysis, indicates that these models provide better results during the energy supply systems planning process. Islands face specific problems, constraining their energy policies summarized by the following [4]:

- Connection to mainland production sources is impossible in the majority of cases, and the infrastructure for mainland interconnection is extremely expensive in other cases.
- A high level of dependence on imported fuel makes most islands highly vulnerable to fuel price fluctuations.
- There are numerous considerable demand fluctuations due to seasonal tourism.

Considering these limits, this paper uses a multicriteria decision making model, to determine the best fuel mix for electricity generation in a Greek island, Lesvos. It was found that the PROMETHEE II method is well adapted to this problem, since its flexibility enables the decision maker to express precisely his preferences and stable results can be easily obtained by sensitivity analysis. Greek islands cover their electricity needs mainly by heavy fuel oil (HFO) and light fuel oil (LFO),

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Nomenclature

LNG	Liquefied Natural Gas
NG	Natural Gas
HFO	Heavy Fuel Oil
LFO	Light Fuel Oil
APS	Autonomous Power Station
PPC	Public Power Corporation
$\Phi(X)$	Net flow of an alternative action X
Φ^+	Leaving flow
Φ^-	Entering flow
V_i	Values for criterion i
$V_{i\ max}$	Maximum value for criterion i
$V_{i\ min}$	Minimum value for criterion i
f_i	Preference function for criterion i
D_i	Difference function for criterion i
p_i	Preference threshold for criterion i
n	Number of alternative actions-scenarios
SCn	Scenario n
C	Criteria
LCOE	Levelised Cost of Electricity
$Investment_t$	Investment expenditure in year t
$O\&M_t$	Operation and Maintenance cost in year t
$Fuel_t$	Fuel expenditure in year t
$Electricity_t$	Electricity generation in year t
r	Discount rate
N	Number of criteria
W	Weight of criteria
$\overline{W}$	Average Weight
w	Relative Weight

with a small contribution of renewable energy plants (wind farms and photovoltaics). For the majority of isolated Greek islands, the interconnection to the mainland is challenging, due to the long distance from the mainland and the depth of the sea, whereas at the same time, their electricity demand faces fluctuations. It is expected that conventional fuels will keep their dominant role in their autonomous insular system, unless natural gas could replace them. The main scope of this paper is to investigate the possibility of natural gas penetration in the insular energy system of Lesvos as it is an alternative that researchers have not considered until now, and in parallel it is attempted an increase in the exploitation of renewable energy sources (RES).

The main steps relating to the formulation of the multicriteria problem for the sustainable energy planning in Lesvos, are outlined in Fig. 1.

The rest of the paper is organized as follows: Section 2 presents a literature review for energy planning studies in Greek islands, an overview of the background of the electricity system of the islands (and for Lesvos) and the current situation of natural gas penetration in Greece. Section 3 refers to the method used for the multicriteria analysis. Section 4 introduces the proposed sustainable energy policy scenarios for the island. Section 5 analyzes the criteria used and determines their values. In Section 6, the results from the application of the model are presented followed by Section 7 with the paper's conclusions.

2. Determination of the current energy system framework

2.1. Energy planning in Greek islands

One of the principal barriers that Greek islands face, is the energy balance of small capacity grids and the variable nature of power production, which does not necessarily correspond to the seasonal demands. The multidimensional problem of sustainable energy planning in Greek islands tried to face researchers in Table 1 using multicriteria analysis.

Kaldellis and Zafirakis [11] presented the current and future prospects of electricity generation in the Aegean Archipelago islands. Annual electricity consumption, peak power demand, capacity factor and specific fuel consumption are recorded for the years 1975 until 2005. It is, also, estimated the contribution of RES in the energy demand and the alternative of their interconnection with the mainland. Oikonomou et al. [12] studied the wind potential in the Dodecanese islands and identified the technological, environmental, social, economic and legislative barriers that face the RES projects. Georgiou et al. [13] examined the feasibility and the consequences of the interconnection of the Greek islands to the mainland grid. Various cost indicators (such as annualized investment cost, fixed and variable operation and maintenance cost, fuel cost, greenhouse gas (GHG) emissions, the cost of imported electricity and the cost of interconnections' development) have been considered. The study of the alternative power plants included different technologies: conventional and integrated gasification combined cycle (IGCC) lignite power stations, HFO conventional power station, LFO gas turbine power plant, HFO and LFO internal combustion engines (ICE), natural gas turbine power station, natural gas combined cycle (NGCC) power plant, mini, small and large hydroelectric stations, wind farms, photovoltaics (PV) parks and geothermal power plants plus biogas combined heat and power (CHP) plant.

2.2. Greek islands' electricity system

The Greek power sector consists of two subsystems, the main interconnected electric grid, that covers the mainland demand, and the insular power systems of Aegean islands. The Aegean Sea includes several hundreds of islands.

The majority of Aegean islands, with an exception for a few of them that are connected to the nearest mainland electrical network, are not connected to the mainland electricity grid. The electricity demand is covered almost exclusively by the existing Autonomous Power Stations (APS), based on internal combustion engines (running on Heavy Fuel Oil – HFO) and gas turbines (running on Light Diesel Oil), which owned from the Greek Public Power Corporation (PPC). Almost all the islands have high RES potential: wind, solar, biomass and geothermal [8].

In islands, the stability of the electrical system is sensitive to rapid variations of the peak loads, while at the same time the importance of self-reliance is evidently higher in comparison with a large connected system. These conditions limit the maximum load provided by energy

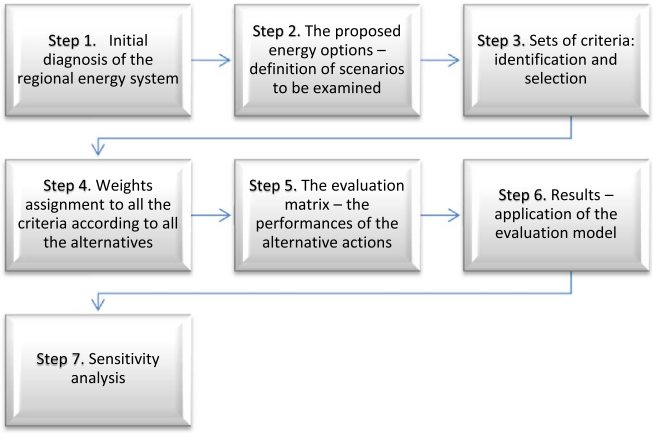

Fig. 1. The steps of the formulation of the problem.