Fuel 106 (2013) 212–218

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Strategic planning in the electricity generation sector through the development of an integrated Delphi-based multi-criteria evaluation model

John K. Kaldellis [a,*], Alexandros Anestis [a], Irene Koronaki [b]

[a] Lab of Soft Energy Applications & Environmental Protection, TEI of Piraeus, Greece
[b] School of Mechanical Engineers, National Technical University of Athens, PO Box 41046, Athens 12201, Greece

HIGHLIGHTS

- ▶ Decision making in the electricity generation sector comprises a complex process.
- ▶ Evaluation of technologies to support power generation is based on several criteria.
- ▶ Delphi method is used to determine importance of criteria based on experts' opinion.
- ▶ A multi-criteria analysis is then developed to provide ranking of technologies.
- ▶ Developed methodology is then applied using as a case study the island of Crete.

ARTICLE INFO

Article history:
Received 6 November 2011
Received in revised form 25 November 2012
Accepted 26 November 2012
Available online 19 December 2012

Keywords:
Electricity generation technologies
Decision making
Weight factors
Crete

ABSTRACT

Decision making process in selecting the most suitable technological solutions for electricity power generation in terms of strategic planning comprises a rather complex procedure with several contradicting factors involved. In this context, development of an appropriate evaluation methodology that will provide decision makers with a useful tool is the aim of the specific study. To achieve this, the Delphi method is used in order to compare a number of alternative technologies with respect to several characteristics, e.g. cost, environmental impacts, social impacts and technological status. According to this method, a properly formed questionnaire is sent to a number of experts, currently related to the power generation sector. After the evaluation of results, weight factors are determined, so that the different technologies can be ranked according to both their scoring in each criterion category and their global scoring, independently of categories, on the basis of a multi-criteria analysis. Emphasis is currently given on the electricity generation sector of Greece, with application of the developed methodology carried out for Crete, i.e. the biggest Greek island.

1. Introduction

National gross electricity consumption of Greece may be determined by a long-term annual increase rate in the order of 3.3% since the early 90s (see also Fig. 1), although according to the latest official data [1] a small decrease has been recently noted (2008–2009), mainly owed to the impacts of economic recession. At the same time, reliance of the Greek electricity generation sector mainly on the local lignite deposits [2] as well as on imported fossil fuels (i.e. oil and natural gas (NG)), implies electrical energy dependence at the levels of 35–40% [3] along with considerable production of greenhouse gas (GHG) emissions [4]. Electricity demand throughout this long period of study has been satisfied mainly on the basis of thermal power plants (Fig. 2), while contribution of large hydropower units should also be taken into account [5] (serving however as peak power plants). In the meantime, contribution of the rest of renewable energy sources (RESs) is relatively restricted [6,7] (given that the RES potential of the entire Greek region is of medium–high quality), with the wind and PV power shares only recently exceeding the capacity of 1.7 GW [8] and 1.0 GW respectively [7].

By acknowledging issues such as excess GHG emissions (considering Greece's commitment to decrease the corresponding emissions in 2020 by 4% in comparison to the 2005 levels [9]), high levels of energy dependence (a long-term, primary energy dependence of around 70% must be considered), gradual retirement of already existing power stations and finally urgency of meeting RES targets adopted at the country level (e.g. 20% and 40% of RES contribution to the national gross energy and electricity consumption

* Corresponding author. Tel.: +30 210 5381237; fax: +30 210 5381467.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).
URL: http://www.sealab.gr (J.K. Kaldellis).

0016-2361/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2012.11.073

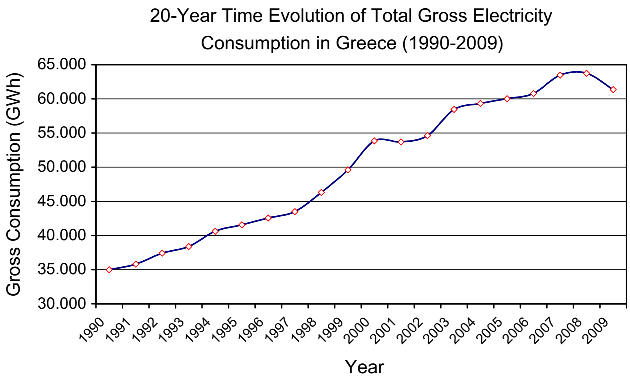

Fig. 1. Time evolution of gross electricity consumption in Greece.

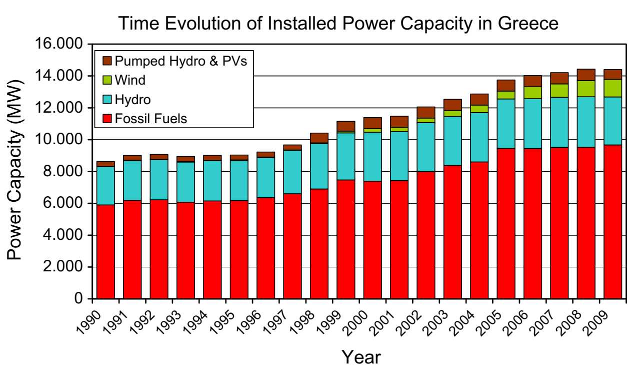

Fig. 2. Time evolution of electrical power capacity mix in Greece.

respectively by 2020) [10], a strategic plan concerning operation of new power stations needs to be configured.

At the same time, decision making concerning configuration of the optimum electrical power mix at the national level is a complicated process, depending on numerous and in most cases contradicting factors. For example, persisting in the operation of new thermal power plants using lignite may seem attractive for Greece on the basis of exploiting indigenous energy resources, avoiding at the same time costly energy imports. On the other hand, combustion of lignite leads to higher CO_2 emissions in comparison to other fuels – on top of pollutants' emission (e.g. NO_x, SO_3, TSP) – which could alter the status quo [11] in the future and encourage the government to purchase emission allowances from other participants in the EU emission trading scheme [12] instead of auctioning. Similarly, investment in wind power may be effective up to a certain point [13,14], where large scale penetration starts jeopardizing demand satisfaction and thus requires additional backup power or energy storage. Furthermore, investment in NG plants, although ensuring less GHG emissions in comparison to e.g. lignite, increases energy dependence on a price-volatile fuel [15].

Considering the above, strong contradictions arising become apparent. For this reason, the use of a multi-criteria decision tool, taking into consideration the consequences that implementation of each different technology may induce on many different levels, is thought to be a useful tool that may enhance strategic planning in the field of electricity generation as well [16,17]. In this context, special emphasis is given in the current study in order to determine criteria involved in such an evaluation process and most importantly in assigning to each of them an appropriate weight factor that will adequately reflect their importance.

2. Proposed solution

Decision making problems are often related to optimization and are therefore based on the maximization or minimization of an objective function, i.e. the so called optimization criterion. During this process, a set of constraints expressing the bounds of the problem variables and the relationships/laws governing the problem are all considered. On the other hand, what should be underlined is that in many cases, one single optimization criterion cannot express or completely reflect the underlying objectives of a problem. For example, in energy planning, the decision making problem of selecting the optimum mix of energy supply sources cannot be based on a financial objective alone, such as minimum costs or maximum profits, since additional factors like environmental performance of each technology and accruing energy dependence levels also need to be taken into account. As already implied, one efficient way to deal with such problems, determined by various – possibly conflicting – objectives, is to define multiple alternative decision criteria under the umbrella of a multi-criteria analysis.

More specifically, multi-criteria analysis is a term used to describe techniques that use more than one criterion to evaluate and judge performance [18]. Multi-criteria decision support techniques typically involve weighing of the criteria to reflect the relative importance attributed to each of them, with examples of such techniques ranging from simplistic "rate and weight" to rigorous multi-objective optimization. Overall, the scope of such analyses is to assign each alternative solution with a rate against each of the criteria (within a predetermined range of values), after assigning a weight factor to each of the criteria, adding up to 100%. In fact, it is these weight factors that configure the final output of such an evaluation process and thus determination of the former requires profound investigation on the basis of established methodologies.

In this context, after the selection of criteria to be involved in the analysis, the Delphi method [19] can be used so as to estimate the respective weight factors in a more objective way. Delphi comprises a qualitative evaluating approach that is able to achieve a structured anonymous interaction between carefully selected experts. More precisely, what Delphi does is that it uses the opinion of experts on the basis of collecting primary data through questionnaires that are properly formed and managed through controlled feedback. Acknowledging this, an effort is currently undertaken so as to adapt the Delphi methodology in the problem of evaluating different technologies for the support of the electricity generation sector.

3. Developed evaluation methodology

Considering the above, development of a multi-criteria analysis for the support of decision making concerning strategic planning in the Greek electricity power sector is currently based on the following steps:

(1) Selection of evaluation criteria to be involved in the analysis.
(2) Estimation of weight factors showing the importance of each criterion, as given by the experts (Delphi method).
(3) Determination of numerical values expressing the compliance of each electricity generation technology to each criterion.
(4) Calculation of the overall score/rate for each technology.

Furthermore, a bundle of criteria currently selected (see also Table 1) may be categorized in the following four thematic areas/categories, i.e.:

(1) Environmental impacts (air pollution, solid waste, etc.).
(2) Social impacts (potential health problems, employment rates, etc.).