European Journal of Operational Research 227 (2013) 227–238

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

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

Invited Review

# Modelling of linguistic variables in multicriteria energy policy support

Haris Doukas *

*National Technical University of Athens, School of Electrical and Computer Engineering, Decision Support Systems Lab (EPU-NTUA), 9, Iroon Polytechniou Str., 15773 Athens, Greece*

ARTICLE INFO

*Article history:*
Received 9 June 2011
Accepted 18 November 2012
Available online 27 November 2012

*Keywords:*
Decision support
Multicriteria analysis
Linguistic variables
Energy policy
Sustainable development

ABSTRACT

The climate change and the increasing complexity of the energy sector along with the prerequisite for sustainability have broadened the energy policy shaping field by bringing out new challenges. Decision support tools and methods, such as Multicriteria Decision Aid (MCDA), are necessary for energy policy, in the pursuit of appropriate approaches necessary to support the restructuring of the energy sector, concerning patterns of energy extraction, generation, transformation and use, from unsustainable to sustainable forms of development. Papers devoted to the investigation of MCDA models using linguistic variables for energy policy support seem to be not available in the international literature. The scope of this paper is to explore different linguistic representation and computational models in MCDA that are or can be applied to energy policy support and to establish a clear linkage between them. This paper argues that MCDA methodologies with direct computation on linguistic variables can support energy policy frameworks, bridging the gap between energy policy makers thinking, reasoning, representation and computing. Finally, current trends, open questions and prospects in this topic are pointed out.



## 1. Introduction

In previous decades it was highlighted that "the energy policy is not in the forefront" (Bloom, 1982) and the energy constitutes secondary priority of countries, which does not lead the economical developments but is guided from them. In addition to this, governments must pose suitable environmental and economical policies and the free market must impose the necessary energy changes. The examination of the future role of energy policy should be based on the comparison between the failure of policy and the choice of "do nothing policy", based on economic and other criteria (David and Zhao, 1989). The energy policy constituted a field, which even if it was supported by scientific practices, the related decisions constituted for many years a kind of "black box" in all the process of energy analysis. As it was reported "... what matters most is not what the ministry writes in its decrees, but what the minister says in his telephone calls" (Ammons and McGinnis, 1985).

Nowadays, the energy policy is at the heart of related discussions among policy and decision makers and is considered to be a matter of high priority, listed in the top of their agenda. This is particularly true, taking also into consideration the growing global energy demand, the corresponding security of supply issues and the prevailing fuel price fluctuations.

Moreover, the climate change and the increasing complexity of the energy sector along with the prerequisite for sustainability have broadened the energy application field by bringing out new challenges, with the emphasis laid on the integrated use of energy resources, both from the supply and demand side. In addition to the above, over the last decade the impact of "sustainability" on the development of national and international policy has increased (Cornelissen et al., 2001). Growing environmental concerns, the efforts for the mitigation of climate change effect and limitations in the exploitation of conventional energy resources have given new impulse in alternative technologies, such as energy efficiency, renewable energy (RE) and hydrogen. Such options will play a greater role in the future energy mix in order to achieve low-carbon intensive energy systems.

The European Union (EU), aiming to be a frontrunner in the international efforts towards energy sustainability, has adopted an integrated approach to combat climate change and increase the EU's energy security while strengthening its competitiveness and sustainability (Commission of the European Communities, 2007). The EU Heads of State and Government set a series of demanding climate and energy targets to be met by 2020, known as the "20–20–20" targets, committing Europe to transforming itself into a highly energy-efficient, low carbon and sustainable economy (Commission of the European Communities, 2008). Energy planning processes are being elaborated in this respect, so as to formulate action plans to sufficiently meet the ambitious targets, resulting in possible developments of the energy sector and scenarios–roadmaps on the expected impacts (Diakoulaki et al., 2005).

Researchers and practitioners have responded to abovementioned challenges with ever-increasing realistic problem formulations, models and adequate methods to tackle the diversity of operational and planning problems arising. Indeed, recent years

* Tel.: +30 210 7722083.
*E-mail address:* h_doukas@epu.ntua.gr

0377-2217/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2012.11.026

have seen a growth in the development and applications of new energy modelling methods, with the emphasis placed on the use of modern Operational Research/Management Science (OR/MS) techniques for assessing energy, environmental and sustainability performance of energy projects at various levels. Analytical and sophisticated energy models support the processes of energy planning and provide abundance of analytical data to decision makers (Antunes and Gomes, 2009; Diakoulaki et al., 2005; Wang et al., 2009b; White and Lee, 2009). This fact creates immediately the question in what way these results can be used more effectively, since analytic data and information do not constitute energy policy (Doukas et al., 2008b). The modern energy policy provides the objectives and the priorities in which energy planning should be based on, as well as the basic parameters of analysis. Methodological frameworks are necessary for modern energy policy support in this respect, sufficiently incorporating the energy policy triangle of objectives, constituting of the security of supply, the competitiveness of the energy sector and the environmental protection.

In addition to this, a series of uncertainties have to be included in energy policy support frameworks, such as:

- Fossil fuel price uncertainty, environmental regulations uncertainty, demand uncertainty, supply uncertainty, initial capital cost and technological uncertainty, market structure uncertainty (Venetsanos et al., 2002). For instance, the current crisis in Europe and its impacts associated with unemployment, decreasing of demand and industrial production reveal these sources of uncertainty on energy modelling and policies associated with the economic situation.
- Energy sustainability uncertainty, since it is an inherently vague and complex concept and its implications as a policy objective are difficult to be defined or measured (Phillis and Andriantiatsaholiniaina, 2001).

Indeed, assessing energy options, in the framework of designing national/regional/international energy policies, is inevitably a very complex process, taking into consideration the, usually, incomplete and uncertain information as well as its qualitative, in many cases, nature. Decision support tools are necessary in this new era, in the pursuit of appropriate approaches necessary to restructuring energy sector from unsustainable to sustainable forms of development. Multicriteria Decision Aid (MCDA) can provide the flexibility and capacity to assess the examined alternatives' implications to the economical, environmental and social framework.

Conventional energy technologies, although still dominant in the energy system, were increasingly disputed on environmental grounds. Cost, although still being the market's driving force, was no longer enough to reflect the society's multiple, incommensurate and often conflicting concerns. Conventional methods of microeconomic analysis can lead to significant limitations, since one criterion can be used (namely net economic benefits). Many of the key attributes of alternative energy, which are not market-valued and concern the social and environmental dimension of sustainable development, are often excluded from the analysis. In this respect, MCDA models are needed to analyze all the multiple facets of the examined options, with respect to a much wider range of evaluation criteria under conditions of a higher uncertainty (see Figueira et al. (2005) for a complete state of art survey on MCDA). Classical decision theory provides probabilistic models to manage uncertainty in decision problems. As previously noted, in real energy policy decision situations, these uncertainties have a non-probabilistic character since they are related to imprecision and vagueness of meanings. In these cases, linguistic descriptors are used by energy policy experts to assess examined energy policy options. Zadeh (1975) introduced the concept of linguistic variable as "a variable whose values are not numbers but words or sentences in a natural or artificial language". A linguistic value is less precise than a number but it is closer to human cognitive processes used to solve successfully problems dealing with uncertainty (Martínez et al., 2010).

Papers devoted to the investigation of MCDA models using linguistic variables for energy policy support seem to be not available in the international literature. Consequently, the aim of this paper is to explore different linguistic representation and computational models in MCDA that are or can be applied to energy policy support and to establish a clear linkage between them. This paper argues that MCDA methodologies with direct computation on linguistic variables can support energy policy frameworks, bridging the gap between energy policy makers thinking, reasoning, representation and computing. Finally, current trends, open questions and prospects in this topic are pointed out.

The paper is structured along seven sections. Apart from the introduction, a taxonomy of MCDA applications for energy policy is presented, using ordinal scale and fuzzy numbers for modelling linguistic variables, in Section 2, including the related "pros" and "cons" and outlining the need for direct and transparent frameworks and methods, bridging the gap between energy policy makers thinking, reasoning, representation and computing. Linguistic variables representation and computational models for energy policy are presented in Sections 3 and 4 correspondingly, as well as energy policy applications of MCDA with direct computation on linguistic variables. An analysis of the modelling options of linguistic variables in multicriteria energy policy support and related discussion is presented in Section 5 and current research trends and prospects are identified and categorized in Section 6. The last Section 7 summarizes the main points drawn up from the previous analysis.

## 2. A taxonomy of MCDA applications for energy policy: the need for direct computation on linguistic variables

Most multicriteria methods try to model human thinking and insert the results of this modelling into their procedures (cf. Figueira et al., 2005). Indeed, the multicriteria methods can be an important supportive tool in the policy making, providing the flexibility and capacity to assess the technologies' implications to the economy, the environment and the social framework (Salo et al., 2003). The social and environmental dimensions of sustainability are frequently the motivation for the use of MCDA models and methods in energy policy and planning, taking into consideration that many of the related key attributes of energy technologies are not market-valued and are often excluded from other decision support methods' analysis (Van den Bergh et al., 2000).

In this respect, MCDA concepts and methodologies have been widely used for the design of energy and environmental policies (Greening and Bernow, 2004) as well as for sustainable energy planning (Pohekar and Ramachandran, 2004). In the following sections, a taxonomy of related MCDA applications for energy policy support is presented, with the emphasis laid on the modelling options of the linguistic variables to be incorporated in the methods, namely with ordinal scale and with fuzzy numbers. Such taxonomy, linking MCDA methods and energy policy application areas, using ordinal scale (Table 1) and using fuzzy numbers (Table 2) for modelling linguistic variables, is not available in the international literature.

A concise discussion of these modelling alternatives is also analyzed, including the related "pros" and "cons" and outlining the need for direct and transparent frameworks and methods, bridging the gap between energy policy makers thinking, reasoning, representation and computing.