Multi-Criteria Decision Aid for Sustainable Energy Prioritization Using Fuzzy Axiomatic Design

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ABSTRACT

Sustainability has gained tremendous importance and has been an important issue both for policy makers and practitioners. Realizing that the resources on the earth are limited, renewable energy alternatives have flourished and started to replace the conventional energy alternatives. Energy planning using different energy alternatives, for the long term becomes a vital decision. In this study, fuzzy multi criteria decision- making methodologies, axiomatic design (AD) and analytic hierarchy process (AHP) are utilized for ranking both renewable and conventional energy alternatives. In the first phase AHP is utilized to determine the importance of the criteria and in the second phase fuzzy AD is used to evaluate the experts' assessments. In the case study, both conventional and renewable energy alternatives are evaluated according to technical, economical, air quality and site selection perspectives. The case study results show that the renewable energy alternatives (biomass, geothermal power and wind) perform better than the conventional energy resources.

Keywords: *Analytic Hierarchy Process (AHP), Axiomatic Design, Fuzzy Sets, Multi Criteria Decision Making (MCDM), Sustainable Energy Planning*

1. INTRODUCTION

In the last few years, one of the key energy issues that have gained tremendous importance is the environment. Thanks to the increased concern over sustainability, both policy makers and practitioners started to consider that issue in their related researches. Recent studies pursue this trend. As the world's resources are limited, meeting the needs of the present without compromising the ability of further generations to meet their own needs has become a vital area of concern. Nowadays, the focus on global environmental protection drives MCDM aid in energy systems since MCDM methods provide better understanding of complex features of energy planning problem. Energy planning requires incorporation of environmental and

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social considerations resulted in the increasing use of multi-criteria approaches.

Another specification of energy planning that it has a complex structure that includes both quantitative and qualitative attributes. The evaluation of the qualitative criteria makes the modeling structure harder so this situation gives a birth to fuzzy numbers which is suitable and flexible to express experts' opinions about the desired goal and criteria.

Come to the point of why fuzzy numbers are useful for energy planning, fuzzy sets are able to manage in a better way with linguistic variables.

This paper is organized as follows. The next chapter includes the literature review on sustainable energy, energy types, MCDM in sustainable planning, fuzzy energy planning. The conducted criteria are described in the Evaluation Criteria chapter. The fourth chapter describes the methodology that consists of fuzzy sets, fuzzy AHP, and fuzzy axiomatic design.

An illustrative case study chapter stands for identifying the importance of criteria, ranking alternatives, and calculation results. Finally, review of the whole paper and further suggestions are described in the Conclusion section.

2. LITERATURE REVIEW

2.1. Sustainable Energy

According to the Brundtlandt Commission report (1983) that defined sustainable development as a process meeting "the needs of the present without compromising the ability of further generations to meet their own needs", the importance of "sustainability" become a noteworthy area of concern (Carrera & Mack, 2010).

Although the necessity of any kind of energy resources in order to improve the quality of life is indisputable, the usage of some resources have negative effects on the ecosystems such as the emission of the greenhouse gases and this requires a shift away from the current fossil fuel-based energy paradigm to sustainable energy technologies.

The sustainable development has been the subject of wide- ranging discussion and debate within government, non-government and academic community (Bilgen et al., 2008; Omer, 2008; Hofman & Li, 2009; Pereira et al., 2008; Jovanovic et al., 2009).

Sustainability can be seen as the final goal: a balance of social and economic activities and the environment (Hofman & Li, 2009).

Energy systems of today are largely driven by the combustion of fossil fuels. The emissions of greenhouse gases (GHG), the depletion of natural resources and the risks on the security of energy supply are the major consequences of the demand of fossil fuels (Neves & Leal, 2010). So this situation causes to arise a "selection problem of energy resource".

2.2. Energy Options/Types

According to the report of International Energy Agency that was released in 2010, the distribution of the world total primary energy supply in 2008 reveals that Oil has the biggest portion of the total production (Figure 1). Also the Renewable energy resources (Solid-Liquid Biomass and Biogas) have only 10%. Wind, Solar, Geothermal, Tide-Wave and Ocean Energy, Electricity and Heat are grouped under the label of "Other", although this label includes eight different type of energy resources, it gets only 0,7% which is the lowest share of the world energy supply.

The literature on energy planning heavily focuses on renewable and sustainable energy resources. Come to the point of the differences between renewable energy resources and sustainable energy resources, the former one is the energy that is generated from natural resources (sunlight, wind, rain, tides, waves, ocean and geothermal heat). The latter one includes all renewable sources, besides it covers energy resources that generate energy efficiency. The researches about energy planning mostly cover these two main energy classes. Sustainable energy resources are the most commonly analyzed topic within this area (Wang et al., 2009; Neves & Leal, 2010; Begic & Afgan,