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An energy source policy assessment using analytical hierarchy process

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ABSTRACT

Energy resource planning for a district in the built environment is a challenging issue for the authorities. They have to take many criteria into account in order to derive sustainable, robust, and long-term energy policies. Among these criteria authorities have to look at the alternatives from different point of views, such as the environmentalists, industry, local community, and local authorities of that district. In this study, an Analytical Hierarchy Process (AHP) method was developed in order to facilitate energy resource planning activities. This method was applied to the district of Aydin in Turkey. Hypothetical results showed that solar energy investments has the highest priority and can be realized by local residents and government, while industry and government can make investments for geothermal power plants and de-centralized lignite power plants using clean technology.

1. Introduction

Long-term planning for rational, efficient, sustainable, environmentally safe, and economic allocation and utilization of various forms of energy resources in the built environment like a city or a district is one of the biggest challenges and responsibilities faced by the decision makers. They have to take many conflicting criteria into account in order to develop the optimum energy and exergy allocation policies for minimum waste, exergy destruction, and harmful emissions without conflicting energy, environment, economy, and human welfare. In order to make decisions including all of these criteria multi-criteria decision making (MCDM) processes are used. Pohekar and Ramachandran [1] and Wang et al. [2] has made a review of the application these multi-criteria methods in sustainable energy planning. Also Løken [3] has studied the selection and classification of MCDM processes in energy problems. Many of these methods can be used in the energy planning such as Topsis [4], Electre [5,6], Promethee [7,8], Vikor [9,10] and SWOT [11]. In analyzing many criteria associated with energy policy making processes authorities have to incorporate different perspectives and opinions of the community like environmentalists, industry, industrialists, inhabitants, and local authorities of the district. Ribeiro et al. has studied the social aspects in energy planning [12]. In this article an Analytical Hierarchy Process (AHP) method was developed in order to derive an energy resource allocation plan that encompasses different perspectives in the city of Aydin in Turkey. In the assessment process, thirteen criteria were accounted and seven different energy sources were rated from five different points of view. Then the importance weights of these point of views were rated by using six factors. By the help of these importance weight matrices a common policy was defined among these seven energy sources. AHP technique and its variations were applied for different energy policy assessments in the past. Hämäläinen and Seppäläinen [13] applied AHP technique to the energy decision problems. Akash et al. [14] made a comparison of electricity power production options in Jordan by using AHP. Schweickardt and Miranda [15] combined AHP with Fuzzy Dynamic Programming and made a two stage model to evaluate the distribution system dynamic de-adaptation respecting its planning for a given period of tariff control for San Carlos de Bariloche. A renewable energy R&D policy assessment for the Republic of Korea was made by Heo et al. [16]. They made a fuzzy AHP application which uses 17 factors and five criteria, in which some of the factors that they mention in their paper was also be used in this study. A clean energy source assessment was made by Daim et al. by using this technique [17]. They made a selection of clean power generation in the Pacific Northwest between wind and clean burning coal energy technologies. Another AHP application made on Korea was made by Shin et al. [18]. In their study, they propose an evaluation process of the national nuclear R&D projects. Also another nuclear technology assessment plan was made by using AHP by Lee and Lee [19]. They made a decision support process for selecting promising nuclear technology from the exportability point of view. AHP was used to make decision other than nuclear energy. Nixon et al. applied this method to select a proper solar thermal collection technology in north-west India [20]. They used this technique to select a solar thermal technology from parabolic troughs, heliostat fields, linear Fresnel reflectors, parabolic dishes, compound parabolic concentrators and linear Fresnel lenses. Chatzimoratidis

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et al. used AHP to select power plant from ten different power plants by using nine end node criteria [21]. The framework of this study is similar to the study made by Ramanathan [22]. In the determination process of the energy source policy, importance views for different energy sources from different parts of the society and importance views of these parts were determined. They are business people, environmentalists, local residents, academicians, and public authorities. Importance weights of these points of view would be determined in the first step and the importance of energy sources for each part of the society would be determined in the next step. By using these importance weights a final decision would be made by using the decisions of the whole society.

2. What is AHP?

The Analytical Hierarchy Process (AHP) is a structured technique for dealing with complex decisions. Instead of making a decision, AHP gives a result, which is the best suitable answer for the problem's needs. The idea of this process was introduced by Myers and Alpert and modeled by Saaty [23,24]. In his paper Yaralioğlu gave a brief explanation of this method [25]. While it can be used by individuals working on straightforward decisions, the Analytic Hierarchy Process (AHP) is most useful where teams of people are working on complex problems, especially those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions [26]. In this study, the steps that Yaralioğlu [25] used in his work were used, which gives the following steps of AHP;

- Defining the problem.
- Development of comparison matrix.
- Percentage distribution of the factors.
- Consistency of factors that are calculated.
- For each factor, calculation of percentage importance weight distribution for the *m*th decision point.
- Calculation of the result distribution of the decision points.

The most important part for the user is to determine the comparison matrices for the factors and decision points. In the AHP method, importance weights should get values between 1 and 9. In order to establish a comparison between the two factors, their explanations are given in Table 1.

In the case if the 2nd factor is more important than the 1st factor, then the importance value is given as the inverse of the importance value (e.g. 1/7). In this study, for each point of view different factor comparison matrices were formed, while the comparison matrix among the energy sources for each factor remained the same.

Table 1
Importance values and explanations that are used in AHP [25].

Importance weight value	Value explanation
1	Two objectives are equal in importance
3	1st Factor is weakly more important than the 2nd factor
5	1st Factor is strongly more important than the 2nd factor
7	1st Factor is very strongly more important than the 2nd factor
9	1st Factor has an absolute more important than the 2nd factor
2, 4, 6, 8	Intermediate values

3. Definition of the problem

A case study of this planning subject was carried out for the district of Aydin in this paper. Aydin has sufficient local resources of lignite and geothermal reservoirs of very high enthalpy. Also Menderes River may have some potential of hydroelectric or hydrokinetic energy. The region is not rich in solar and wind energy. Although it is not locally available, natural gas can also be used. This resource is important, because of the pay-or-buy agreements in effect between Turkey and the natural gas exporting countries. According to these agreements made in the past, Turkey has to imports more natural gas than its demand. A careful planning is essential among these resources:

- **Ease of Access to the Source (EAS):** How far and easy to transport the source to the power plant?
- **Source Durability (SD)** [16]**:** For how long the source can be used by the power plant? Can the plant use the source for its lifetime or will the source be depleted before the lifetime of the power plant?
- **Source Sustainability (SS):** Can the source supply energy to the power plant constantly and sufficiently or does this source needs supplementary sources in order to fulfill the demand of the power plant.
- **Additional Investments (AI):** Does the source needs additional investments in order to produce electricity? Coal storage area for a thermal power plant, waste nuclear fuel storage facilities for a nuclear power plant or purification facilities can be examples of this factor. This factor has a negative effect and the level of the need for extra investments will be defined with negative value of the importance.
- **Superiority of Technology (ST)** [16]**:** Is the energy supply technology innovative and hardly imitated by competitors? Can this technology be accepted by the world?
- **Completeness of Technology (CT)** [16]**:** How long does the scientists and engineers work on the technology? The more mature the technology, the safer and more efficient the power plant is.
- **Reliability of Technology and Operation (RTO)** [16]**:** Is this technology reliable and does not require frequent maintenance?
- **Possibility of Acquiring Original Technology (POT)** [16]**:** Is it possible to obtain the "know how" of the technology? By acquiring the original technology, it can be modified according to the problems of the country, can be sold to the third countries or new technologies can be developed from this independently.
- **Carbon Footprint (CF):** What is the carbon footprint of the power plant? This is one of the most important questions that should be asked before building a power plant. This factor includes not only the carbon footprint in the operation, but also in the construction of the power plant.
- **Requirement of Resources (RR)** [16]**:** Does the power production require additional natural resources, such as water, and rare metals? This factor has also a negative impact like the additional investments factor.
- **Effect of the Technology to the Environment (ETE):** What is the effect of the technology to the environment? This factor is not only related with carbon footprint of the technology, but also the waste management, effects of the source preparation from raw materials, etc.
- **Acceptability by Local Resident (ALR)** [16]**:** What are the impacts of the technology on the local residents' health, economy? Can the facilities that will be built produce employment?
- **Supplementary Usage of the Resources (SUR):** Can the source be used other than electricity generation? For example, can the waste heat of the source be used in building heating?

These factors would be used from the following point of views: