Evaluation methods for energy production in the province of Yazd, Using Analytic Hierarchy Process (AHP)

Abstract
One of the most important problems for planners and policy makers in the field of energy is selection of a source for energy production in various regions due to the potential, the geographical and climatic conditions of each region. This issue in Yazd (One of the economical provinces in Iran), due to potentials such as intensity of solar radiation, existence sunny days in year and the process of growing solar energy technologies, which has led selection between the method based on solar energy with fossil fuel-based methods and determining each of these methods be the most important component of research programs and units which are responsible for electricity production in Yazd. In this study, using multi criteria analysis, comparison of methods of producing energy (electricity) and their priority has determined. Five ways of energy production are considered in this study: Generate electricity using photovoltaic solar power plant, photovoltaic domestic packages, solar thermal power plants, wind and gas. According to the results and activists and scholars ideas of Yazd province’s energy field, priorities in energy production options include: 1) photovoltaic domestic packages 2) gas power plant 3) solar photovoltaic power plant 4) solar thermal power plant, 5) wind power plant

Keywords: Analytic Hierarchy Process (AHP), Gas power, Renewable energy, Solar photovoltaic power plant

1. Introduction
With the recent increase in environmental awareness and macro trends such as global warming, the environmental impact of energy production processes has become a major concern in drafting of environmental policies, especially in developing countries. The main cause of global warming and climate change has been determined to be an increase in carbon dioxide in the biosphere due to the excess consumption of fossil fuels (Nel and Cooper, 2009). For this reason, renewable energies like wind and solar energy have been replacing fossil fuels (Boyd and Ibarraran, 2002; Korhonen and Savolainen, 1999). Despite all the advances in environmental awareness, we still face difficulties in assessing these energy production processes due to conflicts in core concepts especially affecting the decision making mechanisms in environmental risk and impact assessment methodologies.

As it is valid for environmental management systems, the decision making involved in energy production process is a mechanism characterized by complexity and uncertainty (Lee et al., 2007). Additionally, energy policies are inevitably a balancing act of many diverse factors such as social, economic, political, legal,
technical and scientific issues. In fact, environmental policies are also a combination of all of these factors. As a solution, multiple criteria analyses (MCA) can reduce uncertain ties by quantifying the factors for comparison of available energy production process options. The analyses can help decision makers (DM), as well as scientists, stakeholders and society to systematically consider and apply their judgments to come up with a strategic choice of energy alternatives (Georgopoulou et al., 2003).

As a whole, one of the most common problems of energy planning is to choose among various alternative energy sources and technologies to be promoted. Technologies based on solar energy, wind energy, hydraulic energy, biomass, animal manure, geothermal energy, energy saving in residential and industry sectors and wave energy are among the most popular alternatives (Dicorato et al., 2008; Krukanont et al., 2007; Tsoutsos et al., 2009).

In this way, the main objective of this work is to identify a priority schedule within the framework of the global environment and energy policies to assist decision makers in the selection of energy production options. To achieve this aim, an approach based on comparisons of five basic energy production options (e.g. photovoltaic domestic packages, solar photovoltaic power plant, solar thermal power plant, gas power plant and wind power plant) has been implemented. Main factors such as economic, technical, social, investment tendency and environmental impacts for energy production options are hierarchically assigned within AHP method. Finally, the comparison of the options is performed by converting the subjective variables to numerical values and priority values are obtained.

The rest of the paper is organized as follows: In Section 2, a literature review on multi criteria energy production decision making is briefly given. In Section 3, AHP methodology is presented. In Section 4, following the determination of the selection criteria and alternatives, the proposed methodology and research model are applied to a renewable energy planning problem for decision makers in Yazd province. In Section 5 research methodology are presented and finally concluding remarks are given.

2. literature

Energy planning using multi criteria analysis has attracted the attention of decision makers for a long time. During the 1970s, dealing with energy problems by single criterion approaches which aimed at identifying the most efficient supply options at a low cost was popular. However, in the 1980s, growing environmental awareness modified the above decision framework. The need to incorporate environmental and social considerations in energy planning resulted in the increasing usage of multi criteria approaches (Meier and Mubayi, 1983; Pohekar and Ramachandran, 2004; Samouilidis and Mitropoulos, 1982).

There is a vast multi criteria decision making literature on energy issues. Keeney et al. structured a hierarchical representation of criteria and then aggregated them into a combined ‘value tree’ in order to evaluate future energy systems of West Germany (Keeney et al., 1987). Hamalainen and Karjalainen utilized AHP to determine the relative weights of the evaluation criteria of Finland’s energy policies (Hamalainen and Karjalainen, 1992). Mirasgedis and Diakoulaki compared the external costs of power plants which used different energy sources by a multi criteria analysis (Mirasgedis and Diakoulaki, 1997).
Polatidis and Haralamopoulos proposed a new methodological framework of multi-participatory and multi criteria decision making to evaluate renewable energy options in Greece (Polatidis and Haralam, 2004). Önüt et al. employed analytic network process (ANP) to solve an energy resource selection problem for the manufacturing industry (Onüt et al., 2008).

Olfat and Torkestani use a methodological framework of multi criteria decision making to evaluate renewable energy sources in Iran. The result of their research shows that the solar photovoltaic power planet is the best renewable energy alternative for considering in future decision making. The next alternatives are determined as wind energy, solar thermal power planet and hydrogen energy. (Olfat and Torkestani, 2006).

Wang et al.’s literature review on the application of the MCDM techniques to the energy issues shows that evaluation criteria for energy source and site selection problems can be grouped into four main categories: Technical, economic, environmental, and social (Wang et al., 2009).

Talinli et al. present a comparative analysis of three different energy production process (EPP) scenarios for Turkey. The most important goal of their study is to incorporate the prioritization criteria for the assessment of various energy policies for power alternatives, and evaluating these policies against these criteria. The main factors such as economic, technical, social and environmental impacts for EPP options are hierarchically assigned within AHP method. Their study concludes that Turkey’s existing thermal power stations should gradually be substituted by renewable energy options according to a schedule of Turkish energy policies in future (Talinli et al., 2010).

Kaya and Kahraman determine the best renewable energy alternative for Istanbul by using an integrated VIKOR-AHP methodology then propose a selection among alternative energy production sites in this city is made using the same approach. In the proposed VIKOR-AHP methodology, the weights of the selection criteria are determined by pair wise comparison matrices of AHP. It is found that wind energy is the most appropriate renewable energy option and Çatalca district is the best area among the alternatives for establishing wind turbines in Istanbul (Kaya and Kahraman, 2010).

Heo et al. established the criteria and factors and assessed the importance of each factor using the fuzzy analytical hierarchy process (AHP) method. Five criteria-technological, market related, economic, environmental, and policy-related and a total of seventeen factors were established. From the weights estimation results, they derived four major conclusions regarding the importance of economic feasibility, the advancement of the target technology in the global market, the disagreement between the policymaker and the specialist group, and the application of the results (Heo et al., 2010)

3. Analytic Hierarchy Process (AHP)

AHP is a tool used for setting priorities in a complex, uncertain multi-criteria problematic situation and has been broadly used in MCDM research. In the AHP, the calculation method proposed by Saaty was based on crisp judgment. The AHP enables the decision makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environment in confliction (Saaty, 1980).

The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. The entries of final weight
coefficients vector reflect the relative importance of each alternative with respect to
the goal stated at the top in the hierarchy (Pohekar and Ramachandran, 2004). A
decision maker may use this vector according to his particular needs and interests.
In a pair wise comparison, the decision maker examines two alternatives by
considering one criterion and indicates a preference. These comparisons are made
using a preference scale, which assigns numerical values to different levels of
preference (Taha, 2003). The standard preference scale used for AHP is 1–9 scale,
which lies between “equal importance” and “extreme importance” where sometimes
different evaluation scales can be used such as 1–5. In the pair wise comparison
matrix, the value of 9 indicates that one factor is extremely more important than the
other; the value of 1/9 indicates that one factor is extremely less important than the
other, and the value of 1 indicates equal importance (Sarkis and Talluri, 2004).

4. Project alternatives and criteria
To establish the criteria and factors, we first reviewed the papers and factors for
evaluating the value of the energy production processes. Making an energy planning
decision involves a process of balancing diverse ecological, social, technical, and
economic aspects over space and time. This balance is critical to the survival of
nature and to the prosperity of energy dependent nations (Kaya and Kahraman,
2010). In this study we choose five factors for assessing energy production process.
These factors listed as follows:

1. Economic factors: Capital cost (initial investment cost), fuel cost and unit
   price of electricity produced are usually considered to be sub-factors of
economic factors for energy production processes. Also, payments resulting
   from the CO2 emissions for a fossil fuel plant must be taken into
   consideration in economic factors (i.e. emission trading) (WWEA, 2009).
2. Social facotrs: Social factors, such as prosperity, community values, and
   availability of health care, may affect the susceptibility of an individual or a
definable group to risks from a particular stressor. Decision making for
   sustainable energy future requires methods that allow for evaluating the
   complexities of social factors (Kowalski et al., 2009). Occupational and
   public health and public acceptance have become increasingly popular sub-
   factors of social factors in decision making analysis about energy issues
3. Technical properties: Include technological aspects such as R&D activity,
   automation, technology incentives and the rate of technological change,
capacity per unit for energy production, efficiency and availability.
4. Environmental factor: Environmental risk, impacts and waste-emissions
   are set as sub-factors in hierarchy in order to assess environmental
   consequences of EPPs. Potential dangers that may lead to big damages such
   as environmental disasters are taken into consideration within the
   environmental risk factors. Estimation of adverse effects on the environment
   or calculated environmental consequence index(Arunraj and Maiti, 2008), the
   amount of solar radiation provides evaluation of environmental impact factors.
5. Investment tendency: Such as return of capital (economic justification), the
   amount of capital required, the government granted facilities and legal
   incentives, access to technological resources and technical knowledge.

The energy alternatives considered in this study are: photovoltaic packages, gas
power planet, solar photovoltaic power planet, solar thermal power planet and wind
energy. Photovoltaic refers to a technology which uses a device (usually a solar panel) to produce free electrons when exposed to light, resulting in the production of an electric current. Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Solar technology or photovoltaic energy does not release any greenhouse gases into our atmosphere when in use, as the process absorbs light energy as opposed to the burning of a fuel in order to generate the output of electricity (CEI, 2011).

Wind energy does not pollute the air like thermal power plants that rely on combustion of fossil fuels such as coal or natural gas. Wind turbines do not produce atmospheric emissions that cause acid rain or greenhouse gases (Saidur et al., 2011). Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. Any effects on the environment are generally less problematic than those from other power sources (Fthenakis and Kim, 2009).

Wind energy is considered as a green power technology because it has only minor negative impacts on the environment. The energy consumed to manufacture and transport the materials used to build a wind power plant is equal to the new energy produced by the plant within a few months of operation. Garrett Gross, a scientist from UMKC in Kansas City, Missouri, states, “The impact made on the environment is very little when compared to what is gained” (EEWP, 2012).

Gas power plants are still using in our country. One of the reasons for the growth and development of gas power plants is Combined-Cycle Power Plants that combined with thermal.

The structure of the renewable energy planning decision making formulated in this study is presented in Figure 1.

![Comparison of Energy Production Processes](image)

**Figure 1: The hierarchical structure for the selection of the energy production processes**

### 5. Methodology

In order to provide input data, a questionnaire was used to gather the respondents’ pair wise comparison judgments for the two levels in the hierarchy (see Figure 1). This questionnaire designed in AHP framework. With the abovementioned criteria and alternatives, a survey for calculating the weights of each factor was implemented among the experts in this field. The results of the calculation are
presented in the next chapter. In order to determine the importance of each criterion, the experts employed a nine point scale given in Table 1.

<table>
<thead>
<tr>
<th>Judgment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal importance</td>
<td>1</td>
</tr>
<tr>
<td>Weak importance</td>
<td>2</td>
</tr>
<tr>
<td>Moderate importance</td>
<td>3</td>
</tr>
<tr>
<td>Moderate plus</td>
<td>4</td>
</tr>
<tr>
<td>Strong importance</td>
<td>5</td>
</tr>
<tr>
<td>Strong plus</td>
<td>6</td>
</tr>
<tr>
<td>Very strong</td>
<td>7</td>
</tr>
<tr>
<td>Very, very strong</td>
<td>8</td>
</tr>
<tr>
<td>Extreme importance</td>
<td>9</td>
</tr>
</tbody>
</table>

After the respondents’ judgments had been obtained, it was necessary to check the consistency of each respondent’s tradeoff judgments. This was measured by a consistency index (denoted as CI). A consistency index was derived by Saaty (1980) to check for any inconsistent judgments. For example, if a respondent prefers A to B, and B to C, that respondent cannot prefer C to A. The CI index should be low, so that the ratings will not be affected (Saaty, 1980). In this study, consistency index was 0.02, which means the respondents’ pair wise comparison judgments are consistent.

6. conclusion

Iran is a developing country which is extensively dependent on energy imports. Our study focused on the selection of the most appropriate renewable energy investment in Yazd because this city has some potentials such as intensity of solar radiation, the most sunny days and the process of growing solar energy technologies. A selection among the renewable energy alternatives has been made using AHP methodology. Results of this analysis can help decision makers while they are orienting energy policy of Yazd province.

We established five alternatives (photovoltaic domestic packages, gas power planet, solar photovoltaic power planet, solar thermal power planet and wind energy) and a total of five factors (social, technical, economic, environmental, and investment tendency) using AHP in order to formulate an effective dissemination program and appraise it.

In this study, Expert Choice software was used for pair wise comparisons data were collected from the questionnaire. The results of the multi criteria decision analysis suggest that the photovoltaic domestic packages is the best renewable energy alternative for this region. The ranking of the other alternatives in descending order is determined as gas power planet, solar photovoltaic power planet, solar thermal power planet and wind energy, that shows in table 2.
Table 2: Priority of the energy production options

<table>
<thead>
<tr>
<th>Priority</th>
<th>Alternatives</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Photovoltaic packages</td>
<td>0.271</td>
</tr>
<tr>
<td>2</td>
<td>Gas power planet</td>
<td>0.216</td>
</tr>
<tr>
<td>3</td>
<td>Solar photovoltaic</td>
<td>0.206</td>
</tr>
<tr>
<td>4</td>
<td>Solar thermal</td>
<td>0.204</td>
</tr>
<tr>
<td>5</td>
<td>Wind energy</td>
<td>0.103</td>
</tr>
</tbody>
</table>

The rank order of factors from the best to the worst is obtained as investment tendency, environmental factors, social factors, economical and technical factors. The priority numbers are calculated as summarized in Table 3.

Table 3: Priority of factors

<table>
<thead>
<tr>
<th>Priority</th>
<th>Factors</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Investment tendency</td>
<td>0.242</td>
</tr>
<tr>
<td>2</td>
<td>Environmental</td>
<td>0.227</td>
</tr>
<tr>
<td>3</td>
<td>Social</td>
<td>0.192</td>
</tr>
<tr>
<td>4</td>
<td>Economical</td>
<td>0.189</td>
</tr>
<tr>
<td>5</td>
<td>Technical</td>
<td>0.15</td>
</tr>
</tbody>
</table>

In the future research, similar studies can be conducted based on different multi criteria decision making techniques such as PROMETHEE, ELECTRE or fuzzy AHP.

References


