

Evaluating the Best Renewable Energy Technology for Sustainable Energy Planning

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ABSTRACT: Energy is one of the main factors that must be considered in the discussions of sustainable development. The basic dimensions of sustainability of energy production are environmentally, technically, economically and socially sustainable supply of energy resources that, in the long term, is reliable, adequate and affordable. Renewable, clean and cost effective energy sources are preferred but unfortunately no one of the alternative energy sources can meet these demands solely. So, the problem of determining the sustainable energy planning is a strategic tool for the development. In this dissertation, the aim of this study is to determine the best renewable energy technology for sustainable energy planning. For this aim, we used AHP methodology, which is a multi-criteria decision making (MDCM) method. In the proposed method, the weights of the selection criteria are determined by pairwise comparison matrices of the AHP. Results indicate that wind energy is the most appropriate renewable energy option in this study. Future researches could be conducted based on different multi-criteria decision-making techniques such as ANP, fuzzy ELECTRE or fuzzy TOPSIS for comparative purposes.

Keywords: Renewable Energy; Sustainable Energy Planning; AHP; Multi-Criteria Decision Making

JEL Classifications: Q0; Q2; Q4

1. Introduction

Energy, which is important in economical, political, social and environmental aspects, has become one of the most discussed issues globally. The industrialization of the world and technological developments brought a higher energy need for the entire world. However, the amounts of reserves of traditional energy resources differ from one country to another. Thus, this has resulted in major environmental concerns, serious political conflicts, unavoidable economical dependency and important social consequences. The existing situation and the future estimations for energy requirements make people to find alternative energy resources. Moreover, current and future possible environmental, economical, political and social negative consequences also force the countries to incline towards to renewable energy resources. In this respect, renewable energy has become the answer for sustainable energy planning.

Sustainable development is the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987). In the light of this definition, sustainability is used to characterize the desired balance between economical growth and environmental preservation (Köne and Büke, 2007). Energy is one of the main factors that must be considered in the discussions of sustainable development. Energy planning involves finding a set of sources so as to meet the energy requirements in an optimal manner (Hiremath et al., 2007). Also

energy planning decision involves a process of balancing environmental, technical, economical and social aspects over space and time. This balance is critical to the survival of nature. It was shown that the electricity consumption of the world will reach up to 24,400 billion kWh by the year 2020 by the new estimations. To select the primary energy resources needed to supply this consumption, the most important parameters will be economical and environmental, since 85% of greenhouse gas emissions worldwide are sourced by the energy sector today (Ozgur, 2008).

Renewable, clean and cost effective energy sources are preferred but unfortunately none of the alternative energy sources can meet these demands solely. So, determining the appropriate energy policy problem can be viewed as a multiple criteria decision making (MCDM) problem and it is a long range and strategic process (Ulutaş, 2005; Samouilidis and Mitropoulos, 1982; Pohekar and Ramachandran, 2004).

A lot of factors (quantitative/qualitative) involve in decision making process. As the complexity of decisions increases, it becomes more difficult for decision makers to determine an alternative which fulfil or maximizes the needs. Energy evaluating's must deal with attributes difficult to define and components that may involve both quantitative and qualitative factors. The evaluating should cover technical, economical or environmental problems which may not be easily identifiable, and also socio-economic factors that affect various interest groups or stakeholders needs. In the view of these difficulties, AHP method may be useful in undertaking difficult assessment procedures (Zadeh, 1965).

There is some evaluation criteria used in MCDM studies conducted on energy issues. These are technical (efficiency, primary energy ratio, safety, reliability, maturity, etc.); economical (investment cost, operation and maintenance cost, fuel cost, net present value, payback period, service life, equivalent annual cost, etc.); environmental (CO₂ emission, NO_x emission, SO₂ emission, particles emission, land use, noise, etc.); social (social acceptability, job creation, social benefits, etc.) (Kaya and Kahraman, 2010).

For sustainable development in both national and global scale, different middle and long-term alternatives which enable to increase energy source variations and decrease the dependence on the foreign supply must be considered. The native and renewable energy sources have to be evaluated in a sensitive way and they must be promoted from an environmental point of view. In this dissertation, the aim of this study is to determine the best renewable energy technology for sustainable energy planning. For this aim, we used AHP methodology in order to make a multi-criteria selection among alternative renewable energy options.

This article is organized in four main sections. First, a review of the literature on sustainability and energy are presented, followed by the development of the model. Second, the research method is discussed in detail. Third, an analysis of the field study data is presented along with the discussion of the results in relation to the literature. Finally, strengths and weakness, research implications and future research recommendations are given.

2. Literature Review

Sustainability and Energy

Sustainability is economically and environmentally improving quality of life over the long term in a way that can be sustained and must be supported by the institutional structure of the country.

The term includes improving social and economical well-being, industrial and commercial wealth generation, relieving poverty, improving human welfare and raising living standards and energy central to these processes (Bishop et al, 2008; IAEA et al, 2005). Hennicke et al. (2004) suggest that sustainable energy systems should deliver affordable services while raising the population's standard of living. In order to make the system sustainable, diversification and localization of energy sources is needed together with ensuring that the impact of using each source is within environmental limits (Lior, 2010). Delivering affordable energy services while raising the living standard of the global population by increasing energy efficiency and deployment of renewable is the goal of sustainable energy systems (Bishop et al., 2010).

Sustainability Indicators for Energy

Most of the sustainability issues and human activities are closely related to energy use. Therefore the energy system is a reliable framework for providing lead indicators for sustainable development (Kemmler and Speng, 2007). The determination of indicators is the first step in sustainable development, design and monitoring. The investigated systems are very large and complex and they include technical, economical, environmental and social components (Lior, 2010). Indicators are tools for communicating energy issues related to sustainable development and for promoting institutional dialogue. The aspects or consequences of the production and use of energy were expressed by a set of indicators. They must give the picture of the whole system, including interlinkages and trade-offs among various dimensions of sustainable development, and they must give the longer-term implications of current decisions and behavior (IAEA et al, 2005). The indicators must also reflect the wholeness of the system as well as the interaction of its subsystems; otherwise they cannot cope up with the complexity of sustainability related issues for different systems (Afgan et al., 2000).

There are a lot of verbal studies found in the literature that make assessment of sustainability indicators, sustainable development strategies or show the possible paths to the future. But, few studies that contains mathematical model for energy sustainability among the existing publications are found. For example, Afgan et al. (2000) and Begic and Afgan (2007) selected energy indicators with respect to the energy systems' actual values and they calculated these variables under different weighting scenarios. Also, there is a vast multi-criteria decision making applications in the literature on energy issues. Zhou et al. (2006) emphasized that the importance of multiple criteria decision making methods and energy-related environmental studies have increased substantially since 1995. Wang et al. (2006) grouped energy source problems into four main categories such as technical, economical, environmental, and social factors. Burton and Hubacek (2007) compared the perceived social, economical, and environmental cost of small-scale energy technologies to larger-scale alternatives. Afgan et al. (2007) evaluated the potential natural gas usage in energy sector. Önüt et al. (2008) employed analytic network process (ANP) to solve an energy resource selection problem for the manufacturing industry. Kahraman et al. (2009) used axiomatic design (AD) and AHP for the selection of the best renewable energy alternative under fuzzy environment. Kaya and Kahraman (2010) used fuzzy AHP and VIKOR methodology to determine renewable energy planning. Cristobal (2011) used fuzzy VIKOR in selection of a renewable energy project. Based on the above literature, the indicators of sustainable energy planning have considered four dimensions in this study (see Table 1).

The technical indicator is used to assess the availability and adequacy of the institutional framework to support effective and efficient energy system. The effect of the use and production patterns of energy and quality of energy services on the progress of economical development is measured by economical indicators. They also measure the improvement that the status of energy sector and its trends might made on the chances for economical development to have a sustainability. The third indicator is environmental indicators which used to measure the impact of energy systems on the overall environment, positive or negative trends in land, water (fresh and marine), and air quality. Energy service availability has impact on poverty, employment opportunities, education, community development and culture, demographic transition, indoor pollution and health (UNDESA, 2007). So, the social indicators are used to measure the impact of energy systems on human well-being.

Table 1. List of evaluation criteria for sustainable energy planning

Indicator	Criteria
Technical	Energy Production Capacity
	Technological Maturity
	Reliability
	Safety
Economical	Investment Cost
	Operation and Maintenance Cost
	Service Life
	Payback Period
Environmental	Impact on Ecosystem
	CO ₂ Emission
Social	Social Benefits
	Social Acceptability

Renewable Energy Sources

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 geothermal energy, solar energy, wind energy, hydropower energy and biomass are among the most popular alternatives (Beccali et al, 1998; Krukanont and Tezuka, 2007; Dicorato et al, 2008; Tsoutsos et al, 2009).

Geothermal energy is the heat of the earth. It has been discovered on the earth's surface in the forms of fumaroles, geysers, volcanoes and hot springs. With another words, geothermal energy refers to the energy stored in the form of heat beneath the earth's surface. In addition, geothermal energy has large theoretical potential, which is widely dispersed in the world, and it is available everywhere in the upper 10 km of the earth's crust, with a mean temperature gradient of 20 to 30°C/km depth (Kruger, 2006).

Solar energy has huge theoretical potential. The sun provides the energy of life on Earth. It continuously operates as a fusion reactor which radiates energy throughout the solar system. According to Kruger (2006) the usable forms of solar energy are direct beam (thermal) radiation which can be focused to a collector, diffuse (thermal) radiation that scattered from clouds and cannot be focused and secondary forms converted to biomass, wind energy and hydropower. The amount of solar radiation intercepted by the Earth is much higher than annual global energy use worldwide. The availability of solar energy depends on the geographic position of the region, land availability and

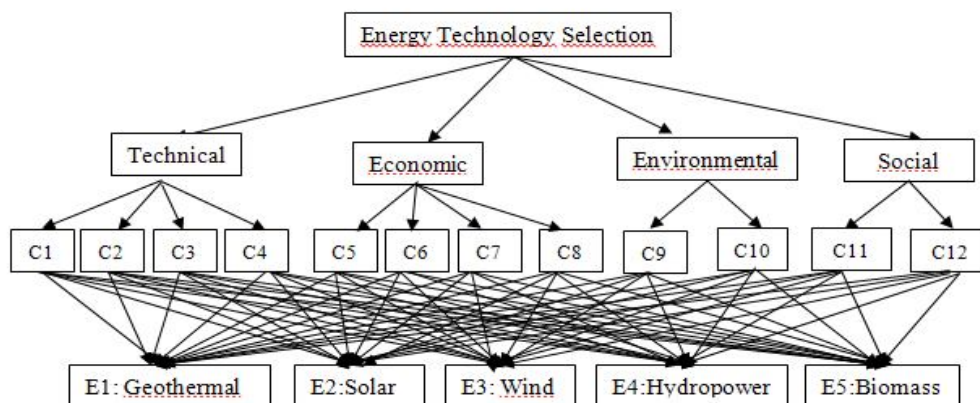
weather conditions (Assmann et al., 2006). In addition, from environmental perspective, solar power, with its all forms, is extraordinarily clean (Lehman and Nierderle, 2006).

Wind is becoming an important contributor to the world energy production. Although each country in the world has been affected by the global financial crisis more or less, according to the data from BP Statistical Review of World Energy (2010), the performance of wind is a success story. There are several factors that allowed wind power to become even more dominant as an investment inflow sector (Cristobal, 2011). One of the developments that strengthened wind is the financial go ahead for a number of large offshore wind farms; another factor is that, in uncertain economical and financial circumstances, many investors including venture capitalists and private equity firms have seen wind as a relatively mature, lower risk, sub sector of green energy than other renewable energy resources (Saygin and Çetin, 2010). Also, electricity is generated through wind energy without the CO₂, SO₂, NO_x, particulate matter and mercury air pollutants that conventional power plant emit in huge quantities (Lund, 2009).

Hydropower energy is the most expanded renewable energy over the world. It represents almost 94% of the renewable energy production and 20% of worldwide energetic needs. In fact, this is due to high power hydroelectric stations, each of them producing several hundreds of megawatts, which have been built for approximately one century. Nowadays, it is nearly no more possible to settle such a plant in many countries because of suitable site rareness and environmental concerns. Nevertheless small-scale hydropower has a quite large potential of development because of the increasing interest in renewable energies and dispersed electrical generation. (Ansel and Robyns, 2006). Modern hydro turbines can convert as much as 90% of the available energy into electricity. The best fossil fuel plants have only about 50% efficiency. Hydro resources are also widely distributed compared with fossil and nuclear fuels and can help provide energy independence for countries without fossil fuel resources. (Yüksek et al., 2006).

Biomass, derived from forestry, agricultural, and municipal residues as well as from a small share of crops grown specifically as fuel, is available in solid (e.g., straw or wood chips), liquid (e.g., vegetable oils animal slurries that can be converted to biogas), and gaseous (biogas) forms (Sastresa et al, 2010). Biomass provides already 14% of the world-wide primary energy production and it includes all organic matter that is available on a renewable basis: energy crops and all kinds of organic wastes. Now and in the near future waste products from agriculture and forestry, easy and cheap to collect, will dominate as source for bio-energy (Velden et al, 2008).

Figure 1. The hierarchical structure for the selection of the renewable energy technology.



From the above mentioned indicators, criteria and renewable energy sources, the model for sustainable energy planning in this study is established as in Figure 1.

3. Methodology

Research Goal

The aim of this study is to determine the best renewable energy technology for sustainable energy planning.

Sample and Data Collection

The indicators are taken from the literature and the criteria under these indicators are chosen by 10-management personnel who belong to technical departments, research and development (R&D) departments in the energy sector. The interviews are made by face to face. After constituting the criteria, a second interview is made by the same people. At the second interview, we wanted them to compare the criteria one-to-one using the comparing scale (see Table 2). Then, the AHP methodology is being performed.

Table 2. Analytic Hierarchy Measurement Scale (Saaty, 1980)

Reciprocal Measure of Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Moderate importance	Experience and judgment strongly favor one activity over another
7	Strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocal of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

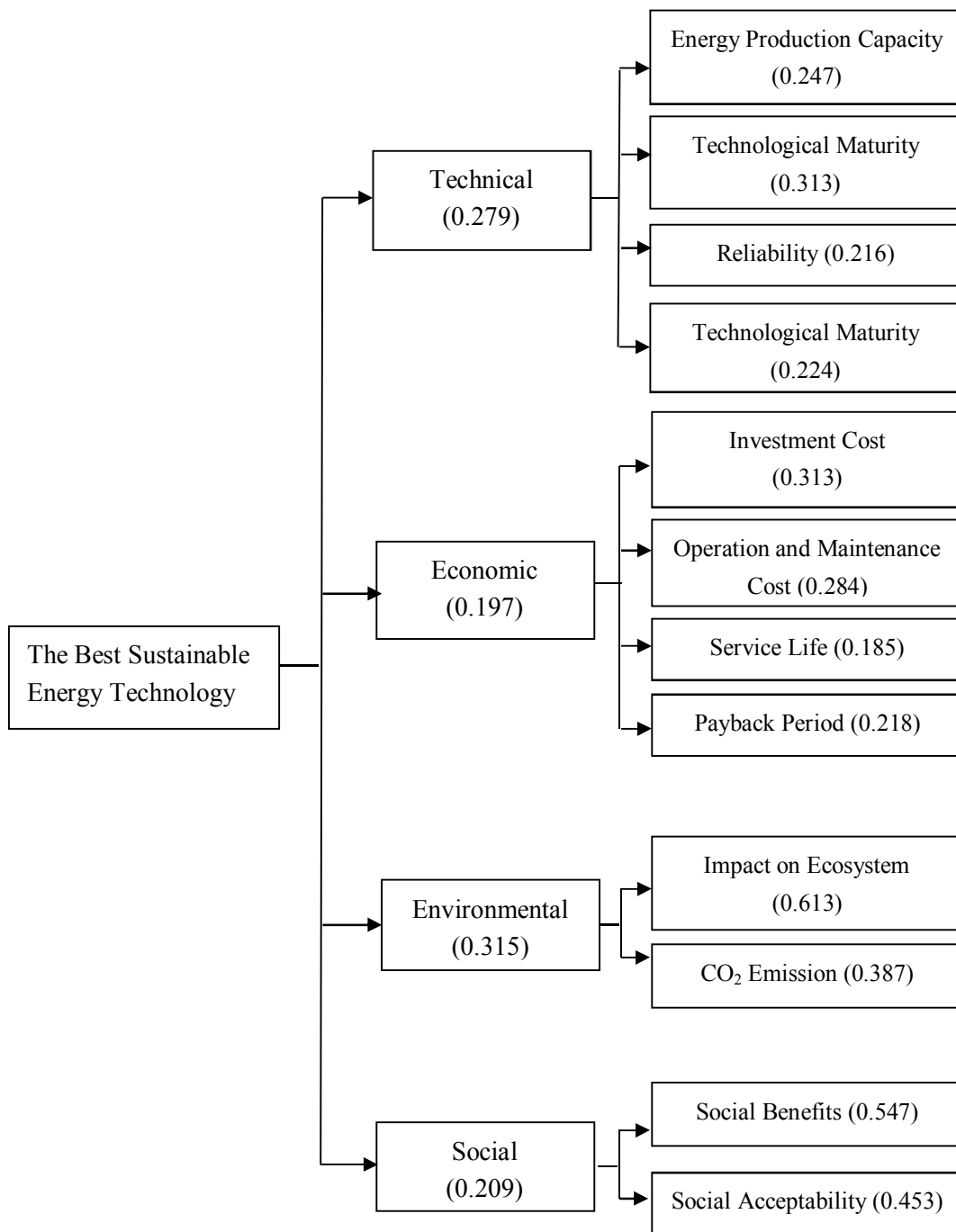
4. Results

AHP methodology steps can be defined as (Saaty, 1980);

- Stating the problem;
- Broadening the objectives of the problem;
- Identifying the criteria that influence the behavior;
- Structuring the problem in a hierarchy (criteria, sub-criteria and alternatives);
- Comparing each element in the corresponding level with 1-9 scale;
- Performing calculations to find the max. eigen value, consistency index (CI), consistency ratio (CR), and normalized values for each criteria;
- Finally, if the max. eigen value, CI and CR are satisfactory, decision is taken, else the procedure is repeated until reaching the desired range.

Analyses were made following the completion of pairwise comparisons. The first of analyses is to check the consistency of judgments. In the AHP method, the consistency of matrixes in a pairwise comparison should be ensured. If the matrix is inconsistent, evaluations must be made until a consistency is achieved. The consistency ratio (CR) wanted to be smaller than 0.10, (according to some reports in the literature, it should be smaller than 0.20) (Soma, 2003; Cox et al., 2000). The consistency ratios in our study varied between {0 and 0.1}. The second stage of analysis is to calculate relative weights of both main criteria and sub-criteria. Final relative weights of main and sub-criteria that were considered in determination of renewable energy technology as in Figure 2.

Figure 2. Final relative weights respect to the main and sub-criteria in the hierarchical structure



With respect to these weights, environmental criteria seemed to be the most important criteria in determination of the alternatives. The criterion with the least significance seems to be the economical criteria. The third stage of analysis is to determine importance values for alternatives. The importance values for the five technology alternatives dealt with in the study have been determined and presented in Table 3.

Table 3. Importance values and ranks for alternatives

Technology	Importance Value	Rank
Geothermal	0.184	3
Solar	0.175	4
Wind	0.298	1
Hydropower	0.145	5
Biomass	0.198	2

As seen from the above table, "Wind Energy" seems to be the best technology for sustainable energy planning according to the AHP methodology.

5. Discussion

Because of wind energy's potential abundance and lower need costs, much more importance is given to this energy technology. While projecting a wind energy technology, cost effectivity and the amount of wind are vital inputs. Researches on this subject show that wind energy is and will be one of the most emphasized energy sources. Because of some technological and economical consequences, renewable energy sources do not have wide applications in the world. Due to a number of regions with relatively high wind speeds, proper sites for wind energy utilization should be investigated and wind-power plants should be installed. For the countries which have abundant wind power, wind energy may play a critical role in strengthening their energy security, decreasing their energy dependency, avoiding greenhouse gas emissions on a large scale and supporting hundreds of thousands of jobs. Since wind energy technology is developed rapidly, the cost of wind energy farm installation is decreasing. Thus, those countries which have a desire to promote their wind energy have to provide efficient investment environment for the potential investors. Setting realistic and encouraging targets, developing wind energy maps and implementing attractive incentives are the major actions that successful countries in wind energy generation should take.

6. Conclusion

Renewable energy is produced from natural resources such as wind, sunlight and geothermal heat. By providing the energy needs, creating new businesses and employment, energy technologies have demonstrated that renewable energy sources could make significant contributions to the economies. Considering the future needs, this study focused on the determination of the best renewable energy technology. A selection among the renewable energy alternatives has been made using AHP methodology.

Analytic Hierarchy Process, which developed for solving the multi-criteria decision making problem, is a widely used method in determining the best alternative. In the first step twelve evaluation criteria were taken into consideration according to the given literature (Wang et al., 2006;

Kaya and Kahraman 2010; Lior, 2010). The results of the multi-criteria decision analyses suggest that the wind energy is the best renewable energy alternative. The ranking of the other alternatives in descending order is determined as biomass, geothermal, solar and hydropower. Also, the evaluation of criteria indicates that environmental effects are more important in this problem of technology selection.

Strengths and Weaknesses

This study has several notable strengths. First, in this study the qualitative factor in decision making process transformed to quantitative factors. Second, the survey is made by face to face to reduce questionnaire mistakes. Finally, this study advances the energy literature by selecting the best energy technology using multi-criteria decision making.

Also, this study has several limitations. First, data are taken from a small group in energy sector. So, the results in this study cannot be generalized. Second, the results in this study are just ranking of alternatives. These results must be taken in to account with capacity and budgetary scenarios to optimize sustainable energy planning.

Future Researches

Future researches can be conducted based on different multi-criteria decision making techniques such as ANP, fuzzy ELECTRE or fuzzy TOPSIS for comparative purposes. In addition, it is to be emphasized that the public has to be provided with the necessary information as to the pros and cons of renewable energy sources, about recent developments in technology (about the decreasing costs and increasing efficiency), and the renewable energy projects have to be designed carefully. Otherwise, huge economic potential of the country for renewable sources cannot be realized even if there is the political will and support, and even if the public is right now demanding a “time for change” in the energy investment decisions of the government towards a stronger reliance on renewable energy sources.

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