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## Article

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## MANAGEMENT | RESEARCH ARTICLE

# A decision model for prioritizing geographic regions for cellulosic renewable energy

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**Abstract:** This paper proposes a decision model for prioritizing geographic provinces in Iran to produce renewable energy from cellulosic materials by applying the Analytic Network Process (ANP). Biomass (forest residues, agricultural waste and wood) is a cellulosic material that can be used to produce thermal energy, electricity, and transportation fuels. The abundance, renewability, versatility, and carbon-neutrality make biomass a suitable feedstock for energy applications, and as an alternative for fossil fuels. Nine provinces in Iran are considered as possible locations for establishing renewable energy units. The ANP is used to synthesize and analyze the model. In different situations, all the decisions were affected by external factors; hence, the value-weighted competency model (benefits, costs, opportunities and risks) is calculated in the first stage with the influence of external factors on the competency model. Hierarchical designs of decisions are made for each of the competencies and their subsets. Paired comparison matrices associated with the degree of importance of each of the competencies were achieved in the second stage. In the final stage, subsets of competencies' weighting values and their sub-options are identified through combination of the competencies and the best location is obtained. Finally, a sensitivity analysis of the model is performed and evaluated.



Majid Azizi

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### PUBLIC INTEREST STATEMENT

Consumption of energy is fast growing in the future accordingly finding proper alternative renewable energy instead of fossil energies is vital. Biomass is a kind of renewable energy which is produced from photosynthesis performance and is a suitable renewable energy resource. Agriculture, forests, and wood industries residues are main resources of biomass. Iran has favorite regions that have a wide range of mentioned resources. Perspective of the article describes prioritizing capable regions for establishment of new energy factory. It was found that the raw material factor has highest priority and has a key role to produce renewable energy; also Fars province is the best location to establish a factory in comparison with other provinces. Exploration of issues can also help governmental organizations to provide requirements of infrastructure and technology in the region.

A decision model for prioritizing geographic regions for cellulosic renewable energy.

**Subjects:** Development Studies, Environment, Social Work; Urban Studies; Alternative & Renewable Energy Industries

**Keywords:** biomass; renewable energy; prioritizing; ANP; benefits; costs; opportunities and risks

### 1. Introduction

Many experts believe that by utilizing clean energies such as solar, wind power, geothermal, hydrogen and biomass instead of fossil fuels energy, environmental pollution and the associated risks are avoided (Jacobson, 2009). Among various renewable energies, biomass is the fourth most-consumed energy resource on the planet and supplies fourteen percent of the world energy needs (FAO, 2007). The present cycle of energy is mostly based on using fossil fuels and creates complex ecological problems. Due to the industrial developments, growth of population, and the environmental pollution, the energy utilization from renewable resources has received much attention during the last decade in most of European, American and Asian countries (Dovetail News, 2009).

Biomass is a type of energy which is produced from photosynthesis performance and is a highly suitable renewable energy resource in forested and agricultural regions of the world. In addition, it is considered by many environmental advocates to be the most utilizable energy which has been considered by man in the past years (Hsu, Ladisch, & Tsao, 1980).

Much of the world's current production capacity for oil, gas, coal and electricity will need to be replaced by 2030. In addition, some of the new production capacity brought on stream in the early years of the projection period will need to be replaced before 2030 (International Energy Agency (IEA), 2008). Many power plants, electricity and gas transmission and distribution facilities, and oil refineries will also need to be replaced and refurbished. Total cumulative investment in renewable energy supply in 2007–2030 amounts to \$5.5 trillion. The greater part of this investment is for electricity generation (International Energy Agency (IEA), 2008). Renewables account for just under half of the total projected investment in electricity generation. Biomass is expected to remain by far the single most important primary source of renewable energy for decades to come (International Energy Agency (IEA), 2008). An estimated 60% of current biomass use is in the form of traditional biomass such as scavenged fuelwood, dried animal dung and agricultural residues used on open fires and in crude, low efficiency stoves to provide basic cooking and heating services. By 2030, most of the biomass consumed will still come from agricultural and forest residues, but a growing share will come from purpose—grown energy crop—primarily for making biofuels (Zubrin, 2007). A growing share is also projected to fuel combined heat and power (CHP) plants (Ray et al., 2014). Among all renewable energy sources, biomass is the largest contributor to global primary energy supply (International Energy Agency (IEA), 2008).

Of the major biomass sources, for lignocellulosic materials such as wood, grass, and crop residues, methanol synthesis appears to be the least expensive and nearest term option for producing liquid fuels. The bioenergy conversion processes that would be most efficient in displacing large quantities of oil are direct combustion and gasification for process heat and steam and home heat (Princeton University working group, 1980).

In the last three decades, the world needs for energy have increased rapidly. World energy consumption was 3.3 giga tons of carbon in 1930 and this amount increased to 8.8 giga tons by 1960. At this annual growth rate of 3.3%, global energy consumption will be 13 and 14 giga tons in 2010 and by 2020, respectively. Hence, the amount of world energy consumption will be high and increasing in the next century and production of alternative energy streams is vital. Different countries, especially developing countries, are interested in exploiting alternative renewable energies (SANA, 2009).

Scientists understand that the need to produce energy is a very important and effective factor in exploitation of resources and the resulting environmental changes (Kanagawa & Nakata, 2006). For instance, a prioritization of renewable energies has been done in Turkey using the Analytic Hierarchy Process (AHP) (Kahraman, Kaya, & Cebi, 2009). Major criteria considered in this study were the economy, environment, society, policy and technology. Biomass was considered against alternative energy sources water power, geothermal heating, wind generation and solar power. The results showed biomass to be a superior alternative to the alternatives.

Level of energy consumption can be an important factor to illustrate the development of human communities in social and economic situations (Sayin, Nisa Mencet, & Ozkan, 2005). For instance, the conversion of oil, coal, and propane thermal heating systems to wood-fired systems has traditionally been undertaken in rural, forested areas where availability of woody biomass is high and inexpensive. However, the best opportunity for future bioenergy projects may be in highly populated areas that have an abundance of commercial and industrial development and are fairly near to abundant sources of woody biomass (Ray et al., 2014).

Agricultural activities are the primary source from which cellulosic materials such as forest residues, agricultural waste, and wood and wood chips are produced. According to Iranian agriculture statistics (The statistics & IT office of The Ministry of Jihad-e-Agriculture, 2011), there is a wide range of cultivation and various resources of cellulosic waste in Iran (Zavare & Alizade, 2011). Thus, the use of cellulosic biomass as sources for energy production may be an under-utilized opportunity. Thirty-one percent of the area of Iran, equivalent to 51 million hectares, is acceptable for agricultural activities; sixty-four percent of that area, equivalent to 33 million hectares, has yet to be productively developed. These statistics and the favorable geography of Iran indicate a strong potential for production of cellulosic renewable energy which could supplement the country's total energy production.

### 1.1. Usable raw materials in producing energy from biomass

In many countries, biomass is produced in wood farming systems to supply small-diameter, high-production woody biomass. This type of biomass farming system is not common today in Iran. The mass of residues of Iran's agricultural products are sugarcane, wheat, rice, barley and corn, estimated as 24,827,000 tons annually (Table 1).

With respect to production amount of residues of Iran agricultural products, wheat, barley and rice have highest priority. Bagasse, wheat, straw of rice and corn are some residues which have high capacity to produce energy in the country (Golestan, 2005)

Unfortunately for national and regional planning purposes, the sheer size and classification of various wood use categories, diversity of biomass-based energy technologies, incompatibility and incompleteness of state and regional forest products flow databases, and different regional policies toward energy production, emission controls, and forest management make it extremely

**Table 1. Production amount of residues of Iran agricultural products, 2007–2008 (Reference: Ministry of Agriculture (2009))**

Product	Residue	Area of farming (hectare)	Product amount (1,000 ton)	Accessible amount of residue (1,000 ton)
Wheat	Stem and straw	7,222,311	15,886	17,900
Barley	Stem and straw	1,641,829	3,104	3,497
Rice	Stem and straw	630,561	26,120	2,220
Corn	Stem	307,015	2,361	578
Sugarcane	Bagass	61,178	5,315	632
Total	–	9,862,894	52,786	24,827

challenging to develop a comprehensive view of the woody biomass energy potential of the country within a defined framework. Without such an overview, policy planning and progress will be disjointed, inconsistent, and perhaps disincentivizing to potential wood energy utilization.

### 1.2. Analytic hierarchy process and analytic network process

The Analytic Hierarchy Process (AHP) developed by Saaty (2000) determines the relative importance of a set of activities in a multi-criteria decision problem. The process makes it possible to concurrently incorporate judgments on intangible qualitative criteria with tangible quantitative criteria into an analysis of alternatives. The AHP method is based on three steps: model structure; comparative judgment of the alternatives and criteria; and synthesis of the priorities. In the literature, the main developments in AHP have been widely used to solve many complicated decision-making problems (Ishizaka & Labib, 2011).

In the first step, a complex decision problem is structured as a hierarchy. AHP initially breaks down a complex multi-criteria decision-making problem into a hierarchy of interrelated decision elements (criteria, decision alternatives). The objectives, criteria and alternatives are then arranged in a hierarchical structure similar to a family tree. This hierarchy has at least three levels, with the overall goal of the problem at the top, multiple criteria that define the solution alternatives in the middle and decision alternatives at the bottom (Albayrak & Erensal, 2004).

The second step is the comparison of the alternatives and criteria. Once the problem has been decomposed and the hierarchy is constructed, a prioritization procedure is conducted to determine the relative importance of the criteria within each level. The pair-wise judgment starts at the second level and finishes with the lowest level alternatives. In each level, the criteria are compared pair-wise according to their levels of influence and based on the specified criteria in the higher level. In AHP, multiple pair-wise comparisons are based on a standardized comparison scale of nine levels.

Let  $C = \{C_j \mid j = 1, 2, \dots, n\}$  be the set of criteria. The result of the pair-wise comparison on  $n$  criteria can be summarized in an  $(n \times n)$  evaluation matrix  $A$  in which every element  $a_{ij}$  ( $i, j = 1, 2, \dots, n$ ) is the quotient of weights of the criteria, as shown in Equation (1):

$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} a_{ii} = 1, a_{ij} = 1/a_{ji} \quad (1)$$

where  $a_{ij}$  represents the comparison between element  $i$  and element  $j$ .

At the final step, the mathematical process commences to normalize and identify the relative weights for each matrix. The relative weights are given as the eigenvector ( $W$ ) corresponding to the largest eigenvalue ( $\lambda_{\max}$ ), as

$$A \cdot W = \lambda_{\max} \cdot W \quad (2)$$

where  $\lambda_{\max}$  = the maximum eigenvalue and  $W$  = eigenvector corresponding to  $\lambda_{\max}$ .

If the pair-wise comparisons are consistent, the matrix  $A$  has rank  $n$  and  $\lambda_{\max} = n$ . In this case, weights can be obtained by normalizing any of the rows or columns of  $A$ .

The analytic network process (ANP) is a mathematically similar, but more generalized form of the AHP methodology in which criteria are structured as a network rather than a hierarchy of independent elements (Saaty, 2006). In ANP, the elements can be considered with levels of interdependence, which is the case in energy policy considerations. The specifics of the ANP as used in this study will be explained more fully in Section 2 of the paper.

### **1.3. Strengths and weaknesses of AHP and ANP over other methods**

AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales (Saaty, 2008). It is one of the more popular methods of multi-criteria decision-making (MCDM) and has many advantages, as well as disadvantages. One of its advantages is its ease of use. Its use of pairwise comparisons allows decision-makers to weight coefficients and compare alternatives with relative ease. It is scalable, and can easily adjust in size to accommodate decision-making problems due to its hierarchical structure. However, AHP requires enough data to properly perform pairwise comparisons, and it has been shown to experience problems of interdependence between criteria and alternatives. Due to the approach of pairwise comparisons, it can also be subject to inconsistencies in judgment and ranking criteria and it “does not allow individuals to grade one instrument in isolation, but in comparison with the rest, without identifying weaknesses and strengths” (Konidari & Mavrakis, 2007).

The advantages of AHP over other multi-criteria methods are its flexibility, intuitive appeal to the decision makers and its ability to check inconsistencies (Ramanathan, 2001). Generally, users find the pairwise comparison form of data input straightforward and convenient. Additionally, the AHP method has the distinct advantage that it decomposes a decision problem into its constituent parts and builds hierarchies of criteria. Here, the importance of each element (criterion) becomes clear (Macharis, Springael, De Brucker, & Verbeke, 2004). The AHP method supports group decision-making through consensus by calculating the geometric mean of the individual pairwise comparisons (Zahir, 1999). AHP is uniquely positioned to help model situations of uncertainty and risk since it is capable of deriving scales where measures ordinarily do not exist (Millet & Wedley, 2002).

The widespread use of AHP may be assigned to its simplicity and flexibility. According to the literature review, it has been realized that AHP has been recently employed along with other methods like mathematical programming to consider not only quantitative and qualitative factors, but also limitations similar to real world (Nassar, Thabet, & Beliveau, 2003). Integrated AHP presents more promising and reliable results. Therefore, integrated AHP has been the focus of a significant amount of studies in recent years. The reason of integrating AHP with different tools may be assigned to the wide application and success in the decision-making (Nassar et al., 2003).

One of its biggest criticisms is that the general form of AHP is susceptible to rank reversal. Due to the nature of comparisons for rankings, the addition of alternatives at the end of the process could cause the final rankings to flip or reverse. AHP has seen much use in performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning. Resource management problems minimize the disadvantage of rank reversal by having a limited number of alternatives to begin with. AHP's ability to handle larger problems makes it ideal to handle problems that compare performance among alternatives. However, problems where alternatives are commonly added post-analysis are not ideal for AHP application.

ANP can be considered the general form of AHP (Saaty, 2006) and is more concerned with network structure. In terms of advantages, it allows for dependence and includes independence. It has the ability to prioritize groups or clusters of elements. It can better handle interdependence than AHP and “can support a complex, networked decision-making with various intangible criteria” (Tsai, Leu, Liu, Lin, & Shaw, 2010). Its major disadvantage, in addition to those associated with AHP, is that “it ignores the different effects among clusters” (Wang, 2012). ANP is often utilized in project selection, product planning, green supply chain management, and optimal scheduling problems. Many of these problems have the interdependence among criteria that AHP normally does not handle well. It can also prioritize the groupings involved in project selection and scheduling problems.

Taliscali and Ercan (2006) and Alves, Simões, and Neyra (2008) show as fundamental advantages of AHP/ANP, in comparison with other MCDM methods, its ease of use for topical experts and the application of qualitative and quantitative factors together in the evaluation. The basic difference between them is ANP has a network structure that allows the analysis of dependence among



elements of the model. This makes ANP more powerful in situations with complex levels of uncertainty, and allows the analysis to more closely model reality.

ANP models have been used for locating facilities strategically (Partovi, 2006), selection of the appropriate energy policy for Turkey (Ulutaş, 2005), and for product mix planning in semiconductor fabrication (Chung, Lee, & Pearn, 2005). ANP was also used to determine the best alternative raw material mix for Iranian facial tissue plants; results showed using virgin pulp mixed with rejected paper makes the production more efficient. Furthermore, long fibers of the pulp prevent harming the environment, and benefits and costs are more sensitive than opportunities and risks in this study (Azizi & Modarres, 2010).

#### 1.4. Study objective

The aim of this study is to propose and test an ANP decision model for prioritizing capable provinces and policies that have the most potential for success in the production of renewable biomass energy in Iran.

## 2. Methodology

### 2.1. Questionnaire preparation

In order to analyze the study criteria for production of renewable energy from cellulosic materials and identify the preferred ones, the initial step was to identify the criteria. A comprehensive list of factors was prepared, and a questionnaire was designed to evaluate their contribution to a decision process as it might be applied in the case of Iran. This questionnaire was distributed among 13 experts in environmental science and policy, wood industries, agriculture and forest policy, foreign academic members and the Iranian new energies organization (SANA). The final set of attributes was concluded via a Delphi method (Linstone & Turoff, 1975).

Benefits, opportunities, costs and risks (BOCR) were ranked with the same method with respect to overall factors (Table 2).

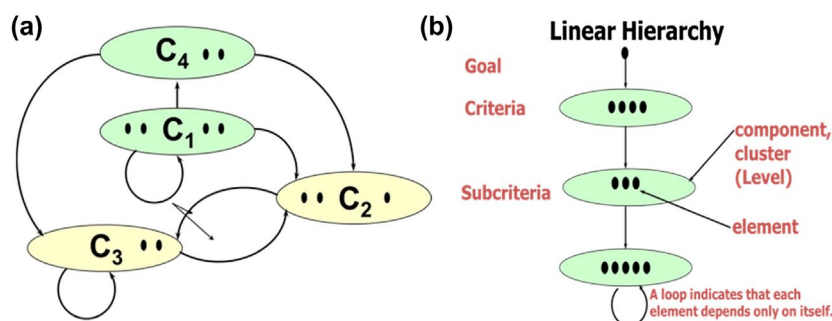
There are two basic variations of hierarchical AHP personal decision models:

- (1) Relative model: Pairwise comparison of the alternatives against the criteria.
- (2) Rating model: Establishing standards for each criterion and rating the alternatives one at a time according to how they perform on the standards. In the rating model, there is a set of intensity levels (or categories) that serves as a base to evaluate the performance of the alternatives in terms of each criterion and/or sub-criterion. The categories that form the ratings must be clearly defined, in the least ambiguous way possible, to adequately describe the criterion/sub-criteria.

**Table 2. Priority rating for the merits: Benefits, costs, opportunities and risks (BOCR): Very high (1), high (0.51), medium (0.252), low (0.124), very low (0.065)**

	Benefits	Costs	Opportunities	Risks	
	Benefits	Costs	Opportunities	Risks	
Economic (0.488)	Very high	High	Very high	Low	
Politic (0.222)	Passive defense	High	Medium	Medium	Medium
	Governmental rules	Medium	Medium	Very high	Very high
Technological (0.134)	Very high	High	Very high	High	
Environmental (0.078)	Agricultural farming	Medium	Very low	Low	Very low
	Environmental pollution	Medium	Low	Low	Medium
	Supporting of forests	Medium	Medium	Low	Medium
Cultural & social (0.078)	Population growth (0.5)	High	Medium	Medium	Medium
	Literacy level (0.5)	Very high	Very high	High	Medium
Overall priorities	0.364	0.192	0.316	0.128	

**Figure 1. How a hierarchy compares to a network.**



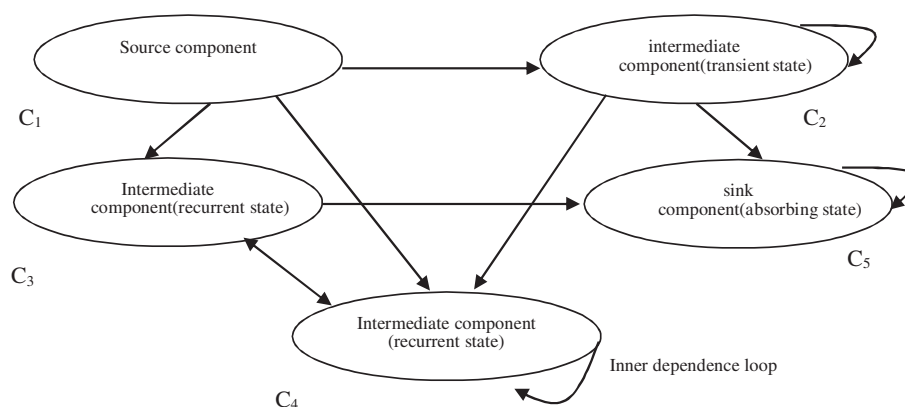
In this study, the Rating Model methodology was utilized, and categories were established as shown in Table 2. Categories selected are *Very High, High, Medium, Low, and Very Low*. The rating was selected by industry decision-makers who considered these levels an appropriate segregation of alternatives. In Table 2, criteria are overall factors and alternatives are benefits, costs, opportunities and risks. The evaluation is performed by intensity levels (categories) attributed to each sub-criteria related to each alternative, instead of evaluating the alternatives by pairwise comparisons (Saaty & Cho, 2001).

## 2.2. Analytic network process

The analytical network process (ANP), a generalization of the AHP method for multi-criteria decision-making, provides a broader framework for decision-making in complicated environments. The advantage of this theory over the AHP (Analytic Hierarchy Process) is its ability to extend to the cases of dependence and feedback and generalization of the super-matrix approach. It allows interactions and feedback within clusters (inner dependence) and between clusters (outer dependence). The ANP is a coupling of two parts. The first consists of a control hierarchy or network of criteria and sub-criteria that control the interactions in the system under study. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a super-matrix of limiting influence is computed for each control criterion. Finally, each of these super-matrices is weighted by the priority of its control criterion and the results are synthesized through addition for all the control criteria.

The different between a hierarchy and a network is illustrated in Figure 1. A hierarchy has a goal or a source node or cluster. It also has a sink node or cluster known in probability theory as an absorbing state that represents the alternatives of the decision. It is a linear top-down structure with no feedback from lower to higher levels. However, it does have a loop at the bottom level to indicate that each alternative in that level only depends on itself and thus the elements are considered to be independent from each other. That is the case for any cluster or collection of elements that influences another group (by convention an arrow is directed toward it as in a hierarchy) but is not influenced by any other group; such a cluster is known as a source. A cluster of elements also has a loop if its

**Figure 2. Connections in a network.**





elements were to depend on each other resulting in dependence known as inner dependence. Unlike a hierarchy, a network spreads out in all directions and its clusters of elements are not arranged in a particular order. In addition, a network allows influence to be transmitted from a cluster to another one (outer dependence) and back either directly from the second cluster or by transiting through intermediate clusters along a path which sometimes can return to the original cluster forming a cycle. The alternatives' cluster of a network may or may not have feedback to other clusters.

Figure 2 characterizes the clusters of a system and their connections in greater detail. A system may be generated from a hierarchy by increasing its connections gradually, so that pairs of components are connected as desired and some components have an inner dependence loop. In Figure 2, no arrow feeds into a source component, no arrow leaves a sink component, and arrows feed into and leave a transient component. A recurrent component falls on a cycle. Loops as in C2, C4 and C5 feed back into the component itself. Each priority vector is derived and introduced in the appropriate position as a column vector in a super matrix of impacts with respect to one control criterion (Saaty, 2005).

Assume that we have a system of  $N$  clusters or components, whereby the elements in each component interact or have an impact on or are themselves influenced by some or all of the elements of that component or of another component with respect to a property governing the interactions of the entire system, such as energy, capital or political influence. Assume that component  $h$ , denoted by  $C_h$ ,  $h = 1, \dots, N$ , has  $n_h$  elements, that we denote by  $e_{h1}, e_{h2}, \dots, e_{hn_h}$ . A priority vector derived from paired comparison in the usual way represents the impact of a given set of elements in a component on another element in the system. When an element has no influence on another element, its influence priority is assigned (not derived) as zero. The priority vectors derived from pairwise comparison matrices are each entered as a part of some column of a super matrix. The super matrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix. A super matrix along with an example of one of its general entry  $i, j$  block are shown in Figure 3. The component  $C_i$  alongside the super matrix includes all the priority vectors derived for nodes that are "parent" nodes in the  $C_i$  cluster (Saaty, 2005).

Figure 3. The super matrix of a network and detail of matrix in it.

$$W = \begin{matrix} & \begin{matrix} C_1 & C_2 & \dots & C_N \end{matrix} \\ \begin{matrix} C_1 \\ e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \\ C_2 \\ e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \\ \vdots \\ C_N \\ e_{N1} \\ e_{N2} \\ \vdots \\ e_{Nn_N} \end{matrix} & \begin{bmatrix} e_{11}e_{11} \dots e_{1n_1} & e_{21}e_{22} \dots e_{2n_2} & \dots & e_{N1}e_{N2} \dots e_{Nn_N} \\ W_{11} & W_{12} & \dots & W_{1N} \\ W_{21} & W_{22} & \dots & W_{2N} \\ \vdots & \vdots & \dots & \vdots \\ W_{N1} & W_{N2} & \dots & W_{NN} \end{bmatrix} \end{matrix}$$

where

$$W_{ij} = \begin{bmatrix} W_{i1}^{(j_1)} & W_{i1}^{(j_2)} & \dots & W_{i1}^{(j_1)} \\ W_{i2}^{(j_1)} & W_{i2}^{(j_2)} & \dots & W_{i2}^{(j_1)} \\ \vdots & \vdots & \dots & \vdots \\ W_{in_i}^{(j_1)} & W_{in_i}^{(j_2)} & \dots & W_{in_i}^{(j_1)} \end{bmatrix}$$

## 2.3. Hypothesis and alternatives

### 2.3.1. Hypothesis

Northern, northwestern, and southern provinces of Iran have favorable potential for establishing facilities of production of renewable energy from forest residues, agricultural waste, and wood.

There are nine potential alternatives or Iran provinces:

A1: Western Azerbaijan, A2: Eastern Azerbaijan, A3: Fars, A4: Gilan, A5: Golestan, A6: Khorasan Razavi, A7: Khuzestan, A8: Mazandaran, A9: Zanzan

## 2.4. Overall factors

In this research, the merits of benefits, costs, opportunities, and risks are weighted by five general factors, assignable to one of the following broad categories:

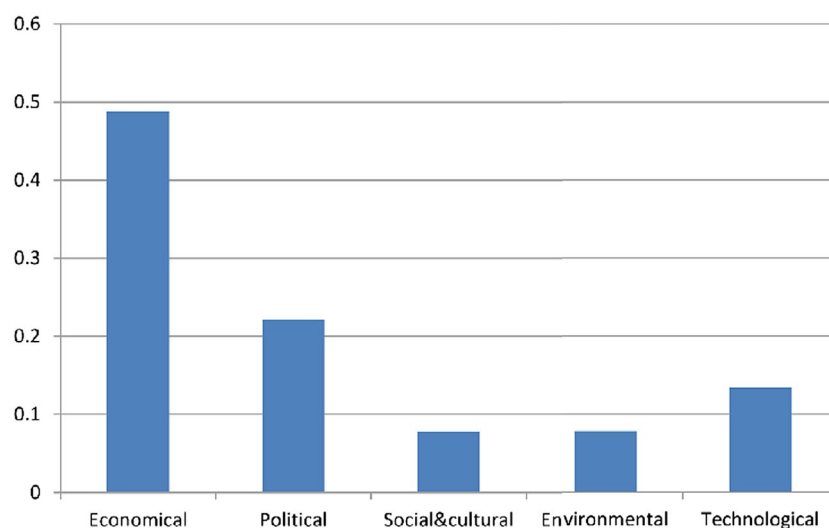
- (1) Environmental factors: Related to the production process issues—three subsections: Wood agricultural farming, environmental pollution, supporting of forests
- (2) Cultural and social factors: Divided into two subsections: Literacy and culture level, Population growth
- (3) Economic factors: Related to economic condition
- (4) Politic factors: Related to the two subsections: Passive defense, governmental rules
- (5) Technological factors: Related to technology condition

Ratings of general factors are done by pairwise comparison of the lower level factors and summing up for the main factors at the top level. Priorities of the factors were calculated and results of the calculations are shown in Figure 4 (Section 3, Results). Figure 4 shows the economic factor has highest priority in comparison with other overall factors.

## 2.5. Description of the criteria

To study criteria identification for production of renewable energy from cellulose materials and identify the preferred alternatives, the best approach is to categorize the criteria into favorable and unfavorable categories. The decision-maker considers the favorable criteria as Benefits and the unfavorable criteria as Costs. The possible events are also divided into Opportunities and Risks criteria, depending whether they are considered to be positive or negative (Saaty, 2001a). A factor table of the criteria has been presented in Table 3. Abbreviations of sub-criteria have been listed in this table for reference in the Results section of this paper.

**Figure 4. The priority of overall factors (inconsistency rate, 0.01).**



### 2.5.1. The indices related to benefits

The desirable certain indices show benefits that will deliver positive impact in the future. The benefits are divided into four main criteria: Skilled job creation, raw material production, creation of infrastructure, and financial database development.

- (1) Skilled job creation—Production of raw material for energy production results in an increase in native income and skill development of the native workforce. It is divided into two sub-criteria (see factor table, Table 3):
  - a. Increased appeal native skilled workforce (BCIW)—Due to decreasing costs of energy production factory, most of local skillful workforce are employed in the factory,
  - b. To increase native income (BCII)—To increase employment, improvement of new economy, to increase farmer's income etc. include increased native income
- (2) Raw material—Required raw materials supply from wood industries, farming fields, forests and wood plantation are the most important precondition for establishment of production of renewable energy. Raw material has three sub-criteria:
  - a. Expansion of farming fields—Because of top needs regarding raw material in facilities, the necessary expansion of wood farming, plantation of rapid trees and agricultural products, necessary to increase the supply of raw material requirements is considered. It has two sub criteria:
    - i. Increase in wood farming (BREI)—Wood farming as one of the supply resources of raw material can play an important role in decreasing pressure over natural resources and supply of raw material in industry.
    - ii. Expansion of plantation of agricultural products (BREE)—Due to the predominance of agriculture fields with the resulting wastage like straw, wheat, rice, maize stem, bagasse cane sugar, etc., these plantations can be used for biomass energy raw material.
  - b. The use of outputs of low value forests: This criterion divided into two sub criteria:
    - i. Clearance of forest fields (BRUC)—With wastage resulting from harvest of existing forest trees, by-products like bark, timber, branches, dead trees, etc. can compensate a portion of raw material.
    - ii. Increase in sales for low value woods (BRUI)—The selling of sections of woods that are not currently used by traditional wood-using industries.
  - c. Increase in facilities income of wood industries: This criterion has two sub criteria:
    - i. Residues sale (BRIR) - By selling mill wastes like sawdust, shavings, and bark as a raw material for energy generating facilities, additional income is created for existing wood facilities.
    - ii. Decrease in wastes disposal cost (BRID)—By selling wastes, the cost of land-filling and burning wastes is avoided.
- (3) Infrastructure (BIIF)—Creation of infrastructures like transportation, energy, communications, needed water in farming etc., accelerates with respect to energy facility requirements in areas to be developed.
- (4) Financial Database Development—Creation of database of raw material financing that includes wood industry mills, farming wood and forests situation and farming fields. Financier criterion is divided in three sub criteria:

**Table 3. Factor table**

	Sub criteria		Abbreviation
Main criteria of benefits			
Create a job	Increased appeal native skilled workforce		BCIW
	Increase native income		BCII
Raw material	Expansion of farming fields	Increase in wood farming	BREI
		Expansion of plantation of agricultural products	BREE
	Use of outputs of low value forests	Clearance of forest fields	BRUC
		Increase in sales for low value woods	BRUI
	Increase wood industries income	Residues sale	BRIR
		Decrease in wastes disposal cost	BRID
Financier	Wastes	Farming wastage	BFWF
		Wastes of wood industrials mills	BFWW
	Amounts of trees resulting from farming wood		BFAW
	Forests position		BFFP
Infrastructure	Infrastructure		BIIF
Main criteria of costs			
Economic	Cost of land		CECL
	Cost of transportation		CECT
	The cost of forest road construction		CECC
	Operation cost	Cost of manpower	CEOC
		Purchase of raw material	CEOP
Social & cultural	Social and cultural		CSCL
Main criteria of opportunities			
Development	Local economy development		ODLD
	Wood industries development in the area		ODWA
	Farming fields development		ODFD
Possibility of parallel production and sale of heat, electricity and fuel	Parallel production and sale of heat, electricity and fuel		OPPF
Future investment	Future investment		OFFI
Improvement of systems of reform in forest management	Improvement of systems of reform in forest management		OIIM
Increase in governmental supports	Granted facilities (foreign exchange & rial)		OIGF
	Exemptions from taxation		OIET
Main criteria of risks			
Unsure of constant raw material supply	Unsure of constant raw material supply		RUUS
Creation of problems from government and its associated organization	Lack of financial supports		RCLS
	Non constancy of government-tal rules	Tax rules	RCNT
		Decrease in harvest from forest resources	RCND
Environmental problems	Decrease of fields using		REDU
	Change in forest management regimes		RECR
	Damage of the forests		REDF

- a. Waste, which includes two sub criteria:
  - i. Wastes of wood industry mills (BFWW)—Wastes of wood industry mills received as a raw material financial resource.
  - ii. Farming wastage (BFWF)—Farming wastage supply as an energy financial resource.
- b. Amounts of trees resulting from farming wood (BFAW)—Estimation of amount of land under plantation, the specific tree inventories and identification of farmers who plant these plantations.
- c. Forests position (BFFP)—Determination of annual forest harvest to be considered according to annual raw material demand of energy production facilities from forest wastes.

#### 2.5.2. The indices related to costs

The undesirable certain indices show costs; these indices will deliver negative impact in the future. The costs are divided into two main criteria:

- (1) Economic—This criterion includes some sub-criteria which are related to costs like land, transportation, construction and operation costs. It has four sub-criteria:
  - a. Cost of land (CECL)—The average cost is price of one square meter of land in area which is paid by established industry facilities.
  - b. Cost of transportation (CECT)—This expense includes raw material transportation from supplying location like forest, wood industry mills, farming wood and farming land to energy facility.
  - c. The cost of forest road construction (CECC)—This expense includes forest road construction which is necessary for exit of wastes of farming lands and forest harvests.
  - d. Operation cost: It divided into two sub criteria:
    - i. Cost of manpower (CEOC)—This cost includes salary, wage and other employee costs (like housing, hygiene, food and welfare) in energy facility.
    - ii. Purchase of raw material (CEOP)—This cost includes purchase of forest wastes, farm crop wastes, the wood that is cut from tree plantations, and wastes of wood industry mills.
- (2) Social & cultural (CSCL)—Planning to monitor impacts and address public concerns for societal health and economic impact, climate and ecological impact, and cultural impact.

#### 2.5.3. The indices related to opportunities

The favorite uncertain indices show opportunities that will deliver positive impact in the future. The opportunities contain five main criteria:

- (1) Development includes three sub-criteria:
  - a. Local economy development (ODLD)—Impact depends on the area of established factory, and the extent of improvement to the economy of the area with measurables like job creation, farm productivity improvement, and increasing farm incomes.
  - b. Wood industries development in the area (ODWA)—Impact of increasing wood industry production and density for productive raw material supply with favorable logistics.
  - c. Farming fields development (ODFD)—Identification of potential methods of using farming wastes for producing energy causes increase of farm area under planting for specific bio-mass products.

- (2) Potential for parallel production and sale of heat, electricity and fuel (OPPF)—The extent to which multiple, parallel energy products can be developed, produced and marketed with available biomass supplies.
- (3) Future investment (OFFI)—The extent to which future investment in complementary industry or development is encouraged and enhanced by new biomass facilities.
- (4) Improvement of systems of reform in forest management (OIIM)—The development and deployment of a management system to ensure sustainable development of forest resources and supervisory systems for effective supply of suitable, sustainable raw material.
- (5) Increase in governmental supports: These supports divided into two sub criteria:
  - a. Granted facilities (foreign exchange & rail) (OIGF)—These include ease of access to banking and other infrastructure resources necessary for development of the biomass industry.
  - b. Exemptions from taxation (OIET)—These exemptions should include industrial activities like exemption of taxation in the beginning of operation.

#### 2.5.4. The indices related to risks

The undesired, uncertain indices that indicate a level of negative risk potential in the future. The risks are divided into three main criteria:

- (1) Uncertainty of constant raw material supply (RUUS)—Demand for raw material (like short rotation tree harvests, forest wastes and farming wastes) will increase due to starting new biomass energy units, so future markets and supply of raw material will be difficult to predict in future time periods.
- (2) Creation of problems from government and its associated organization: The criterion has two sub criteria:
  - a. Lack of financial supports (RCLS)—Lack of certainty in receiving and supply of financial resources in complementary time frame to meet requirements of new operational needs.
  - b. Non-constancy of governmental rules—Monetary rules and their unpredictability causes many problems in factory activities. This criterion has two sub criteria:
    - i. Tax rules (RCNT)—Changes in taxation rules, specifically tax increases, generate significant problems for the facilities.
    - ii. Regulatory constraint in harvest level of forest resources (RCND)—Decrease in harvest of forest resources due to environmental regulation increase unit costs of the operations and make them less competitive with other energy sources, particularly foreign fossil fuels.
- (3) Environmental problems—These problems are divided into three sub-criteria:
  - a. Decrease of food production (REDU)—Farm transition from food production to biomass crops due to increase in farmer's income which have negative impact on local food cost and availability.
  - b. Change in forest management regimes (RECR)—Loss of soil fertilization, decrease in biodiversity and soil erosion that appear with removal of forest wastes.
  - c. Damage of the forests (REDF)—Lack of attention to ecological system of the forests and implementation of transient forest management situation resulting in possible deforestation and decrease in value of the forest resource.



### 3. Results

#### 3.1. Prioritizing overall factors

Based on the results of Figure 4, Economic criterion (0.488) is the most important overall factor on BOCR. The political (0.222); social and cultural factors (0.078); environmental (0.078); and technological (0.134) are other factors, respectively.

Since BOCR are not equally important, it is necessary to prioritize them. Five possible ratings ranging from “very high” to “very low” are used. The results of the influence of the overall factors on the merits of benefits, costs, opportunities, risks, and the priority of the above mentioned merits are reported in Table 2.

**Table 4. Synthesized priorities of the criteria and sub criteria see Table 3 (factor table)**

Merits	Criteria	Sub criteria		
Benefits (0.364)	Create a job (0.174)	BCIW (0.293)		
		BCII (0.706)		
	Raw material (0.67)	Farming fields (0.652)	BREI (0.4402)	
			BREE (0.559)	
		Output forests (0.222)	BRUC (0.665)	
			BRUI (0.334)	
		Income wood industry (0.125)	BRIR (0.404)	
			BRID (0.595)	
	BIIF (0.061)			
	Financier (0.094)	Wastes (0.599)	BFWW (0.309)	
			BFWF (0.69)	
BFAW (0.266)				
BFFP (0.134)				
Opportunities (0.316)	Development (0.469)	ODLD (0.625)		
		ODWA (0.109)		
		ODFD (0.265)		
	OPPF (0.234)			
	OFFI (0.126)			
	OIIM (0.055)			
	Governmental support (0.114)	OIET (0.588)		
		OIGF (0.411)		
	Costs (0.192)	Economic (0.662)	CECL (0.101)	
			CECT (0.509)	
CECC (0.068)				
Operation cost (0.32)			CEOC (0.238)	
		CEOP (0.761)		
CSCL (0.338)				
Risks (0.128)	RUUS (0.644)			
	Creation of problems from government and its associated organization (0.241)	RCLS (0.637)		
		Non constancy of government rules (0.362)	RCNT (0.743)	
			RCND (0.256)	
	Environmental problems (0.114)	REDU (0.508)		
		RECR (0.337)		
		REDF (0.154)		

With respect to the influence of the overall factors on BOCR, benefits, costs, risks, and opportunities have the weighing values of 0.364, 0.192, 0.316, and 0.128 respectively.

### **3.2. Prioritizing criteria and reaching outcome**

After pairwise comparisons between sub-criteria for benefits, costs, opportunities and risks by ANP as well as pair-wise comparisons of the criteria and choices against each other and also by following the above-mentioned merits, the resulting weights are reported in Table 4. As Table 4 shows, Agricultural products (BREE) (0.559), Local economy (ODLD) (0.625), Social & cultural (CSCL) (0.338) and Uncertainty of constant raw material supply (RUUS) (0.644) have the highest priority in terms of benefits, opportunities, costs and risks criteria, respectively.

Table 5 shows both the assigned priority of alternatives, as well as the final outcome of the analysis. Fars (A3) has the highest priority with respect to benefits (0.1592) and opportunities (0.2136). Western Azerbaijan (A1) has highest priority with respect to costs (0.2416) and risks (0.2464).

The resulting Final Outcome Additive column of Table 5 shows that Fars province has the highest priority (0.1801), and is the most suitable choice for establishing factory of new energy production from biomass in Iran.

## **4. Analysis and discussion**

In most energy industry analyses, raw material criterion has the highest priority; the same was confirmed in this research for the biomass potential in Iran. Existence of sufficient, sustainable and cost-effective raw material is vital to establish productive energy facilities. Wastes of agricultural lands, wood farming, forestland remnant wood and by-products of wood industries facilities are the main resources which can be utilized to produce bioenergy. Approximately half of the population of the world utilizes biomass resources to supplement energy needs.

### **4.1. Analysis of benefits**

Synthesizing benefits criteria indicated agricultural products (BREE) (0.559) has the highest priority. These products are the main resources of new energy in other countries and have a key role to produce energy (Mahdavi, 2001). In European countries and United States of America, agricultural wastes are applied to produce energy such as ethanol and methanol (Plieninger, Thiel, & Bens, 2009). Wood farming (BREI) (0.440) has the second priority with respect to benefits (see Table 4).

### **4.2. Analysis of costs**

With respect to overall synthesis of weights, social and cultural criterion (CSCL) (0.338) has the highest priority. The growth of trees depends on nitrate absorption. Based on investigations of UN-Energy (2007), exploitation of agricultural wastes and forest residues causes decreased nitrate absorption, and extraction of forest residues gives rise to soil erosion and a decrease in soil fertility. Therefore, scientific solutions from researchers and scientists to decrease pressure on the lands will play an important role in the reduction of the anxiety of the public with regards to environmental impact of increased biomass harvesting and utilization (see Table 4).

### **4.3. Analysis of opportunities**

Local economy criterion (ODLD) (0.625) has the highest priority with respect to opportunities. Dovetail LLC (2009) states that for American renewable biomass delivery and utilization systems, the economical transportation radius in United States is fifty miles or less for transferring cutting residual and seventy miles with respect to wood and agricultural wastes transfer. Accordingly, if similar transportation parameters are assumed and achieved in Iran, it will be possible to both increase local income and reduce wood wastes firing and evacuation costs through utilization of forests wastes and low quality woods. In addition, employment of local work forces for cutting, harvest, transportation, chipping and fuel transfer are possible by utilizing accessible biomass resources provided from local resources owners. Likewise, local community skilled jobs are created for energy production, along with increased economic activity, local economic development and increased value of agricultural products (see Table 4).

#### 4.4. Analysis of risks

Regarding risks, the uncertainty of constant raw material supply criterion (RUUS) (0.644) has the highest priority. Wyman (2003) believes that the most important factor to uninterrupted operation of energy producer's facilities is a continuous raw material supply in sufficient volume. In addition, Coleman and Stanturf (2006) suggest that the most effective factor in starting and maintaining energy facilities is having sufficient and appropriate raw material (see Table 4).

#### 4.5. Highest priority analysis and discussion

As shown in Table 5, Fars province (A3) with the highest priority (0.1801) is the most suitable province for establishing the factory for the production of new energy from biomass in Iran. Regarding the benefits and opportunities, the results are also shown in Table 5. Fars province (A3) has the highest priority (0.1592, 0.2136).

With respect to the influence of the overall factors on the merits of: Benefits, costs, opportunities, risks (Table 2), etc., the benefits (0.364) are considered as the most important factors in decision-making. Therefore, to increase the value of benefits in the future, the investors and manufacturers should uphold and support Fars province (A3) as the best location to establish a facility for the production of new energy from biomass.

Table 6, the synthesized priorities of the alternatives, shows that Fars province (A3) has the highest priority regarding the criteria of Benefits in comparison with other provinces in cases such as: Agricultural products (BREE) (0.331), Infrastructure (BIIF) (0.199), Skilled workforce (BCIW) (0.246), Farming waste (BFWF) (0.33) and increased Native income (BCII) (0.256). Fars province has temperate climate, adequate rainfall, and high capability to successfully farm agricultural products like wheat, barley, rice, corn and fast growing trees. As evidence of its suitability, Fars has the highest rate of producing agronomic products in recent years, having obtained the first place among Iran provinces in agricultural production (<http://fars.mrud.ir/Portal>).

Table 6 also shows that among other provinces, Fars province (A3) has the lowest priority in terms of Costs; hence, the criteria of costs will have least effect on this province. All criteria of costs have the lowest negative effect on Fars province, meaning the selection of Fars province as the factory location for producing new energy from biomass would incur the lowest costs.

**Table 5. Final outcome for priorities of the alternatives**

Mer	Benefits (0.364)	Opportunities (0.316)	Costs (0.192)	Risks (0.128)	Final outcome additive	Ranking
Alter						
Western Azar-A1	0.0402	0.0333	0.0305	0.0329	0.0265	9
Eastern Azar-A2	0.0767	0.0576	0.0489	0.0589	0.0731	7
Fars-A3	0.1592	0.2136	0.262	0.237	0.1801	1
Gilan-A4	0.1062	0.0846	0.073	0.087	0.1050	6
Golestan-A5	0.1322	0.1508	0.142	0.145	0.1454	3
Khorasane. raz-A6	0.1205	0.0919	0.072	0.0803	0.1120	5
Khuzestan-A7	0.1265	0.1805	0.217	0.211	0.1556	2
Mazandaran-A8	0.1207	0.1470	0.121	0.108	0.1362	4
Zanjan-A9	0.1178	0.0408	0.0319	0.0372	0.0662	8

**Table 6. Synthesized priorities of the alternatives with respect to benefits, costs, opportunities, and risks criteria (see Table 3, factor table)**

	A1	A2	A3	A4	A5	A6	A7	A8	A9
BREE	0.035	0.043	0.331	0.046	0.103	0.103	0.231	0.078	0.03
BREI	0.044	0.144	0.035	0.054	0.108	0.212	0.03	0.054	0.319
BCII	0.03	0.058	0.256	0.07	0.133	0.091	0.182	0.145	0.036
BRUC	0.043	0.045	0.104	0.17	0.18	0.082	0.106	0.238	0.032
BIIF	0.03	0.039	0.199	0.112	0.135	0.083	0.177	0.176	0.049
BCIW	0.056	0.06	0.246	0.057	0.132	0.109	0.22	0.085	0.034
BRUI	0.044	0.045	0.078	0.165	0.195	0.078	0.083	0.27	0.41
BRID	0.032	0.084	0.046	0.287	0.182	0.042	0.054	0.21	0.063
BFWF	0.035	0.043	0.33	0.045	0.105	0.105	0.223	0.079	0.034
BRIR	0.032	0.086	0.047	0.285	0.176	0.043	0.056	0.205	0.069
BFAW	0.045	0.138	0.038	0.055	0.114	0.204	0.03	0.057	0.319
BFWW	0.033	0.092	0.051	0.291	0.169	0.044	0.055	0.197	0.068
BFFP	0.047	0.042	0.104	0.194	0.146	0.085	0.101	0.251	0.03
Benefits synthesized	0.0402	0.0767	0.1592	0.1062	0.1322	0.1205	0.1265	0.1207	0.1178
CSCL	0.221	0.147	0.031	0.097	0.057	0.111	0.037	0.068	0.232
CECT	0.257	0.151	0.026	0.098	0.049	0.103	0.031	0.054	0.231
CEOP	0.251	0.151	0.025	0.123	0.044	0.092	0.032	0.059	0.222
CECL	0.227	0.163	0.026	0.105	0.044	0.084	0.29	0.058	0.263
CEOC	0.244	0.142	0.039	0.076	0.076	0.099	0.045	0.075	0.204
CECC	0.268	0.139	0.027	0.078	0.047	0.109	0.032	0.061	0.241
Costs synthesized	0.2416	0.1496	0.0281	0.1004	0.0520	0.1026	0.0339	0.0609	0.2310
Costs reciprocal	0.0305	0.0489	0.262	0.073	0.142	0.072	0.217	0.121	0.0319
ODLD	0.03	0.06	0.247	0.054	0.159	0.097	0.168	0.145	0.04
OPPF	0.031	0.062	0.187	0.104	0.135	0.062	0.22	0.158	0.042
OFFI	0.039	0.06	0.183	0.075	0.177	0.063	0.183	0.179	0.04
ODFD	0.035	0.042	0.336	0.039	0.125	0.108	0.209	0.075	0.033
OIET	0.03	0.049	0.19	0.094	0.155	0.094	0.201	0.139	0.049
OIIM	0.047	0.041	0.116	0.187	0.14	0.084	0.107	0.248	0.031
ODWA	0.045	0.06	0.07	0.18	0.2	0.087	0.089	0.196	0.073
OIGF	0.026	0.086	0.21	0.087	0.134	0.14	0.227	0.06	0.031
Opportunities synthesized	0.0333	0.0576	0.2136	0.0846	0.1508	0.0919	0.1805	0.1470	0.0408
RUUS	0.257	0.143	0.029	0.085	0.049	0.114	0.034	0.067	0.222
RCLS	0.275	0.107	0.031	0.094	0.05	0.058	0.035	0.078	0.271
RCNT	0.281	0.18	0.044	0.081	0.054	0.085	0.043	0.06	0.172
REDU	0.2	0.149	0.023	0.173	0.058	0.104	0.034	0.079	0.181
RECR	0.174	0.191	0.065	0.044	0.05	0.106	0.07	0.033	0.268
RCND	0.05	0.046	0.095	0.176	0.196	0.076	0.095	0.226	0.041
REDF	0.042	0.044	0.103	0.165	0.178	0.078	0.105	0.251	0.034
Risks synthesized	0.2464	0.1379	0.0342	0.0934	0.0558	0.1011	0.0384	0.0747	0.2181
Risks reciprocal	0.0329	0.0589	0.237	0.087	0.145	0.0803	0.211	0.108	0.0372

As for Opportunities, Fars (A3) has the highest priority according to the criterion of development of farming fields (ODFD); as a result this province provides the best condition for developing facilities for the production of new energy from biomass. And regarding the criteria of future investment (OFFI), production and sale of heat, electricity and fuel simultaneously (OPPF) and local economy development (ODLD), Fars enjoys the maximum priority in comparison with other provinces due to having vaster area of agricultural lands and high capability of farming cellulosic materials.

With respect to Risks, Fars (A3) has the lowest risks (0.0342) associated with factory establishment. Lack of assurance about constant raw material supply (RUUS) is among the most important criterion risks; Fars province has the lowest priority (0.029) among other provinces. Other risk criteria like lack of financial support (RCLS), tax rules (RCNT) and decrease of land use (REDU) have the least effect on Fars of any province in Iran. The risk of inconsistent raw material supply in Fars is low, because the area of agricultural lands in the province is vast and provides constant raw material supply.

Khuzestan province (A7) has second highest priority for establishment of bioenergy production. Regarding opportunities criteria, Khuzestan has highest priority with respect to sub-criteria including local economy development (ODLD), parallel production and sale of heat, electricity and fuel (OPPF), future investment (OFFI) and farming fields development (ODFD).

The availability of cellulosic by-product in Khuzestan province results in decreased costs of wastes destruction and negative environmental impacts, increased farmer's income due to wastes sale, and improved occupation situation due to development of agricultural lands (ODFD), which will result in development of local economy (ODLD) and increase investment rate (OFFI). With regard to raw material supply (RUUS), there is low risk in Khuzestan province due to existence of cheap and plentiful waste resources and high priority of risks such as lack of financial supports (RCLS), tax rules (RCNT) and decrease of fields using (REDU).

Golestan province (A5) has third highest priority for establishment of a bioenergy production facility. Golestan has high capabilities regarding agricultural products (BREE), forest areas and high progress in wood plantation (BREI). Golestan has an advantageous situation with respect to clearance of forest fields (BRUC), use of outputs of low value forests and decrease in wastes disposal cost (BRID) criteria. There are some problems in the province, such as regulation by environmental protection authorities to forbid residue and waste utilization from the forest and prevailing segmentation of agricultural fields with its negative influence on transportation cost due to non-existence of proper roads for related activities. These problems create a decreased production capacity of the province with respect to agricultural products, waste product utilization and increased prices. Potentially, through integration and development of the agricultural fields, there will possibly be some opportunities such as local economy development (ODLD), production of multiple energy sources (OPPF) and increased investment attraction (OFFI) in the province. Golestan province has low risk with regard to raw material supply (RUUS) due to having high capacities of agricultural products.

Mazandaran province (A8) has fourth highest priority after Fars, Khuzestan and Golestan provinces, to establish energy production facilities. Mazandaran has highest capability in field of raw material supply for energy production but there are certain limitations in Golestan province which decrease capabilities of the province. Despite these limitations, Mazandaran has unique characteristics of climate, desirable lands and abundant water which make it a potentially productive place for establishment of bioenergy facilities.

An empirical cross-check was also performed for confirming the validity of the ANP results, and the results indicate that Fars is, in fact, a suitable location for the establishment of new energy facility. Statistical reports of the Ministry of Agriculture (2009) shows that Fars is the most active province in agricultural products in Iran, with high amounts of agricultural residues annually. Unfortunately, there is no plan to use them. The necessary raw material for bioenergy production could be supplied from these agricultural residues. In this way, current environmental problems of the accumulation

of residues in the region could be lessened. Studies by the Fars Organization of Forest and Ranges ([www.fars.frw.org.ir](http://www.fars.frw.org.ir)) suggest that Fars province is highly capable of developing fast growing tree plantations due to its temperate climate and productive soil. In Fars province, transportation costs are low because agricultural lands are uniform, the distance of agriculture lands is close and there are connective roads between the farms. Low transportation costs contribute to acceptable profit potential for industrial production.

Most of the required raw material for the new bioenergy industry will be supplied by agricultural wastes. Traditionally, landholders and farmers of Fars burn these agricultural and forest wastes. Buying and using the wastes in comparison with other provinces will be done at relatively low costs ([www.fars.agri-jahad.ir](http://www.fars.agri-jahad.ir)). Statistics of Fars Agriculture Organization ([www.fars.agri-jahad.ir](http://www.fars.agri-jahad.ir)) show that in spite of high activity of the province in farming agricultural products, the province does not use all of its capabilities to plant agricultural products or wood, and as much as half of the lands have good potential for fast growing trees which have been left intact. High rate of the wastes is one of the reasons that cause decrease in farming agricultural lands. If the wastes could be used in a new bioenergy industry, the rate of planting agricultural products as well as the amount of available raw materials would increase. This bilateral cooperation can adequately supply the needs of both activities.

### 5. Sensitivity analysis

It can be shown that by increasing or decreasing the weight of one criterion, the ratios of the weights of other three criteria (with respect to each other) remain unchanged, although the sum of their weights changes accordingly [Equation (3)]. For example, if the weight of benefit increases from 0.364 to 0.5, then the new weights of costs, opportunities and risks will be 0.151, 0.248, and 0.1, respectively. Although the sum of these weights is decreased to 0.5, they are proportional to the previous ones, that is, 0.192, 0.316, and 0.128 (see Table 2).

Example: Recalculating Total Weight of Cost Criteria with Change in Weight of Benefits

$$C + O + R = 0.636 \quad (3)$$

where, C: Costs, O: Opportunities, R: Risks from original formulation (Table 2), then

$$\frac{C}{0.636} = 0.302$$

$$0.302 = \frac{C'}{0.636}$$

$$C' = 0.151$$

where C': New weight of costs

Since there may be different judgments about the comparison of priority rates of benefits, opportunities, costs, and risks or their sub-criteria, to achieve stability and compatibility of the analysis, we apply sensitivity analysis (see Saaty, 2001b). To perform sensitivity analysis, we apply the software developed by Saaty and Cho (2001). Results of sensitivity analysis of benefits, costs, opportunities and risks with respects to alternatives are illustrated in Figure 5.

Figure 5(a) indicates there are two changes of priority of alternatives with respect to changes of weighted value of benefits. If we change the basic value of benefits from 0.346 to 0.757 and 0.842, priority of A5, A7, A9 and A4 will change. Figure 5(b) shows two changes of priority of alternatives with respect to changes of weighted value of costs. Change of basic value of costs from 0.192 to 0.864 and 0.071 give rise to change of priority of A4, A6, A2 and A9. Figure 5(c) shows there is not any change of priority of alternatives with respect to change of weighted value of opportunities.



**Figure 5. Sensitivity analysis of benefits, costs, opportunities, and risks.**

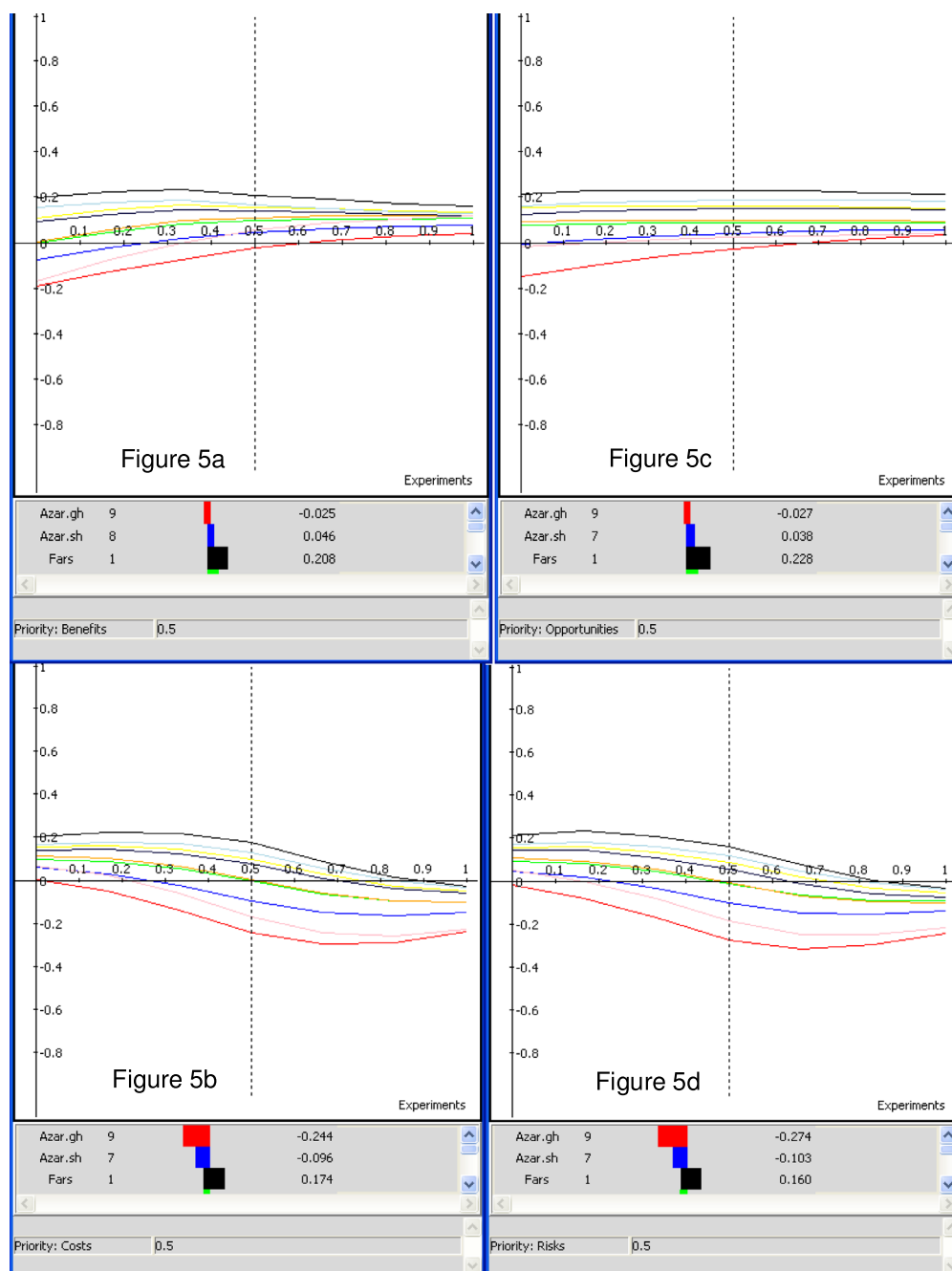


Figure 5(d) indicates two changes of priority of alternatives with respect to changes of weighted value of risks. If we change basic value of risks from 0.267 to 0.607 and 0.01, priority of A4, A6, A9 and A2 will change.

Some cases of weights changes are presented in Table 7. From Table 5, the priorities are A3-A7-A5-A8-A6-A4-A2-A9-A1. After changing the weights of one criterion, the priorities also change, as shown in Table 7. Table 7 illustrates that benefits, costs and risks are more sensitive than opportunities.

**Table 7. The results of sensitivity analysis (Basic priority: A3>A7>A5>A8>A6>A4>A2>A9>A1)**

Criterion	Basic weight	New weight	Number of changes	New priorities
Benefits	0.346	0.757	2	A3-A5-A7-A8-A6-A4-A9-A2-A1
		0.842		A3-A5-A7-A8-A6-A9-A4-A2-A1
Opportunities	0.309	–	0	
Costs	0.192	0.864	2	A3-A7-A5-A8-A4-A6-A2-A9-A1
		0.071		A3-A7-A5-A8-A6-A4-A9-A2-A1
Risks	0.267	0.607	2	A3-A7-A5-A8-A4-A6-A2-A9-A1
		0.01		A3-A7-A5-A8-A6-A4-A9-A2-A1

## 6. Conclusion

Potential locations for establishment of new bioenergy facilities in Iran were analyzed. Nine provinces are capable of establishing new bioenergy production facilities. These nine provinces were analyzed through a combination of multi-criteria decision techniques.

In the first stage, the overall strategic factors were identified, and based on those factors, the weighting values of BOCR (benefits, opportunities, costs, and risks) were determined. Weighting values of the criteria of BOCR were derived by applying the Analytic Hierarchy Process (AHP) in the second stage. In the third stage, the weighted values of the provinces derived in the prior stages were synthesized using the ANP and Super Decision software.

The conclusion of this application of AHP/ANP techniques shows that the Fars province of Iran has the highest capability for establishment of new bioenergy production facilities, and is the preferred solution with respect to Benefits, Opportunities, Costs and Risks.

As for benefits, Fars has the best situation regarding agricultural products, infrastructure, skilled workforce, farming waste and increased native income. In addition, it has temperate climates, good rainfall, particular natural condition, and high capability to farm agricultural products like wheat, barley, rice, corn, and fast growing trees. With respect to opportunities, Fars has the highest priority according to the criterion of development of farming fields. Selection of Fars has the lowest costs and risks in comparison with other provinces to establish new energies production facilities.

Results of sensitivity analysis revealed that benefits, costs, and risks are more sensitive than opportunities but the resulting two changes in priorities do not change the conclusion of Fars province (A3) as the best location.

Future study may be conducted to investigate in more detail the capabilities of the Fars province. Specifically, more detailed levels of agricultural products and their wastes with respect to availability of raw material; requirements of technology with respect to the cost of human resources and also employment generation; and requirements of infrastructure and market demand could be examined in more detail. In addition, project feasibility studies could be performed in chosen locations of the favored provinces, in order to validate the assumptions of this study and to refine expert opinion for future surveys.

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