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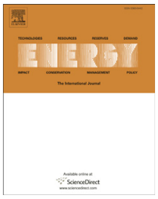

Corn cultivation location selection for bioethanol production: An application of BWM and extended PROMETHEE II

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ABSTRACT

The purpose of this paper is to streamline the supply of corn, one of the key ingredients in the production of bioethanol. Using a comprehensive sustainable framework of criteria (including social, economic, and environmental dimensions), the potential locations of corn cultivation in Iran are examined from a multi-criteria decision analysis perspective. To this end, we need to find the importance of the relevant evaluation criteria and a ranking method to rank the potential locations. Best worst method (BWM) is used to determine the weight of the criteria presented in the framework based on the opinion of a sample of Iranian experts, after which the 'preference ranking organization method for enrichment evaluations II' (PROMETHEE II) is applied to ranking the different provinces of Iran. To improve the ranking results, we extend the PROMETHEE II by employing a set of piecewise linear value functions, for which the performance of alternatives with respect to the criteria calculated by the piecewise linear value functions is used to determine the amount of deviation in the first step of PROMETHEE II. The results of the hybrid methodology indicate that the presence of water, land cost and air pollution are the most important factors determining the ranking of the alternatives, and that Kordestan is the best province for corn cultivation in Iran.

1. Introduction

Increasing air pollution, constantly rising oil prices and falling fossil fuel reserves are among the main challenges the world faces today [1]. Bioethanol offers a valuable alternative to fossil fuels [2]. By using bioethanol produced from cellulosic, starchy and sugar sources [3], not only are air pollution level, unemployment rates and our dependency on oil reduced, it can also provide an important boost to rural communities [4]. Despite these advantages, cultivating biomass for bioethanol production requires large areas of land, may compromise food security [5] and requires specialized knowledge.

Of all the resources used to produce bioethanol, corn cultivated in various weather conditions is an important one, because it can simultaneously provide starch and cellulosic materials [6]. Corn as a starchy crop with a high amount of fiber, proteins, and oil is considered as the primary source of the ethanol [7]. Bioethanol production from corn consists of three main subsequent steps including conversion of starchy feedstock's into fermentable sugars, metabolically fermentation of sugar by yeast and purification and generation of ethanol [8]. It is estimated that one bushel (i.e., 56 pounds) of corn approximately provides 2.8 gals of bioethanol [9]. In addition, corn plays a significant role in providing much of the food and feed being consumed in the world [10].

There is a direct relationship between the economic, social and environmental performance of cultivation areas and the efficiency of agricultural products [11]. As such, for the cultivation of corn, it is necessary to determine optimal cultivation areas based on the criteria outlined above. Reviewing existing literature shows that most studies focus on economic factors and tend to ignore social and environmental criteria. To remedy that situation, a comprehensive sustainable three-dimensional framework of criteria which affect the location selection of cultivation areas for agricultural crops, is suggested in this research. The framework, which is an

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extended version of Kheybari et al. [12] improves both the accuracy and duration of the evaluation of cultivation areas for different biomasses and products. As a first contribution of this research, the sustainable framework is employed to determine the corn cultivation areas in Iran. It is worth noting that, the aim of this research is not to find precise locations for corn cultivation which is a technical problem. In other words, considering the result of this research, we want to identify the regions (i.e., provinces of Iran) for corn which significantly help government and other policy-making organizations for long-term planning and developing strategies to support farmers.

The criteria in question are expected to have different levels of importance when it comes to identifying the most suitable cultivation area. To this end, the best-worst method (BWM) is employed to determine the weight of the individual criteria. BWM that is a structured pairwise comparison-based method (i) helps decision-makers conduct their evaluation in a systematic way, (ii) due to employing two pairwise comparison vectors, which are formed based on two opposite reference points, in a single optimization model, mitigates potential decision-maker's anchoring bias in the weighting process [13] (iii) requires an efficient number of data to reach conclusions, which, in turn, (v) produces consistent and reliable results [14—16]. Identifying the location of corn cultivation areas as a multi-criteria decision analysis (MCDA) problem and using BWM to solve that problem is the second contribution of this study.

To evaluate cultivation areas within the context of an MCDA model, the most important step involves calculating the performance of alternatives on different criteria. For this purpose, PROMETHEE II frequently used to solve location problems [17] is employed in this research. Depending on the nature of the criterion in question, PROMETHEE II uses increasing or decreasing linear functions. Although these functions simplify the evaluation process through PROMETHEE II, they could lead to improper results. To improve the evaluation result, the PROMETHEE II is extended using a set of piecewise linear value functions [18] employed the first step of PROMETHEE II. The use of that extended version of PROMETHEE II is the third contribution of this paper.

Iran has the fourth-largest oil reserves and the second-largest gas reserves all around the world, most of its energy consumption is dependent on fossil fuels [19]. In recent years, Iran has faced serious levels of air pollution [20], most of which caused by transportation, which accounts for about 24% of CO_2 [21]. The existence of this amount of CO_2 has adverse effects on both the air quality and biodiversity of the marine ecosystem [22]. Therefore, to alleviate the mentioned problems, it is necessary to replace a portion of fossil fuel with renewable-based resources in Iran. To deal with fossil fuels concerns, biofuels (such as bioethanol) which is obtained from waste management and agriculture [23], is one of the renewable energy resources for the transportation sector in Iran [24]. Bioethanol does not reduce air pollution to zero, but significantly reduces it [25]. Besides decreasing the emission of greenhouse gases, the utilization of agricultural and industrial waste are some other advantages of biofuels over fossil fuels. Since the distribution of population and industry is difference in different sectors of Iran, advantages of biofuel production may have non-identical impacts on the provinces of Iran.

According to Ghobadian [26], Ardebili [27], Kheybari et al. [28] and Ardebili and Khademalrasoul [29], Iran is a country with high potential for biomass production due to its land availability and diversity of climatic situations. It is claimed that for every 24.3 million tons of agricultural waste, 2.443 million liters of bioethanol is produced in Iran [27]. It is expected that the use of bioethanol could significantly help to solve the air pollution problem, which means that the production of the raw materials for bioethanol is a contributing factor [30].

The remainder of this paper is organized as follows. In Section 2, related studies involving the location of corn cultivation areas are discussed, while the methodology of our study is addressed in Section 3. The results of the criteria-weighting process and the conditions in the various provinces of Iran in terms of cultivating corn are discussed in Section 4. The result of the methodology is validated in Section 5. Section 6, finally, contains the conclusions and suggestions for future research.

2. Literature review

Generally speaking, based on the solution space, location selection problems are divided into two discrete and continuous categories [31]. For the problems with continuous space, there is no pre-option and the whole space is considered as an integral part. In this case, a set of criteria is specified to determine the appropriate locations. Using multi-criteria methods, spatial data are mathematically formulated, and appropriate decisions are determined accordingly. If the location space is defined by a specific set of alternatives such as the problem investigated in this research, we are dealing with a discrete location selection problem. In discrete models, first a set of criteria is selected and then, considering the criteria, the candidate alternatives are evaluated, and the best place (s) is determined.

To identify the criteria, in particular the social and environmental criteria, that are commonly used in determining where to cultivate agricultural products, we reviewed relevant studies on the subject, based on an extensive search in different library databases. The text and tables of the papers we reviewed were used to extract and categorize the criteria that could be used to identify optimal locations for the cultivation of agricultural products. The papers in question are discussed below.

Kihoro et al. [32] determined the proper location for rice cultivation in Kenya by using the geographic information system (GIS) and analytical hierarchy process (AHP). The alternatives were assessed based on topography, temperature, moisture and soil quality, and the results showed that temperature had the greatest effect on determining the optimal location. Zhang et al. [33] proposed a mixed integer linear programming (MILP) to design a supply chain network for bioethanol production in the USA. The factors involved in determining the optimal locations for switchgrass cultivation were annual rainfall, land costs and proximity to transportation network. In another study research by Osmani and Zhang [34], a MILP model was used to maximize the expected profit of a bioethanol production supply chain in the USA. The proposed model determined the best locations to cultivate raw materials, taking into account criteria like annual rainfall, the amount of land needed for cultivation and cultivation costs.

The aim of the study by Boruff et al. [35] was to identify the best location for microalgae cultivation in Australia. They used GIS and criteria like climate condition, land, CO_2 emission, infrastructure and the amount of water accessibility to evaluate different locations. Babazadeh et al. [36] applied data envelopment analysis (DEA) to select the optimal location for Jatropha curcas L. (JCL) cultivation in Iran, the main criteria being cultivation costs, human resource development, annual rainfall, average temperatures, water resources, cultivated area, amount of arid and semi-arid lands and population. In another study, Babazadeh et al. [37] examined the optimal location for JCL cultivation in Iran using fuzzy DEA, the main criteria being cultivation costs, human development index, annual rainfall, annual average of mean daily temperature, water resources, amount of arid and semi-arid lands, cultivated area of different gardens and population. Maddahi et al. [38] used a hybrid methodology that included AHP-GIS and 23 different criteria,

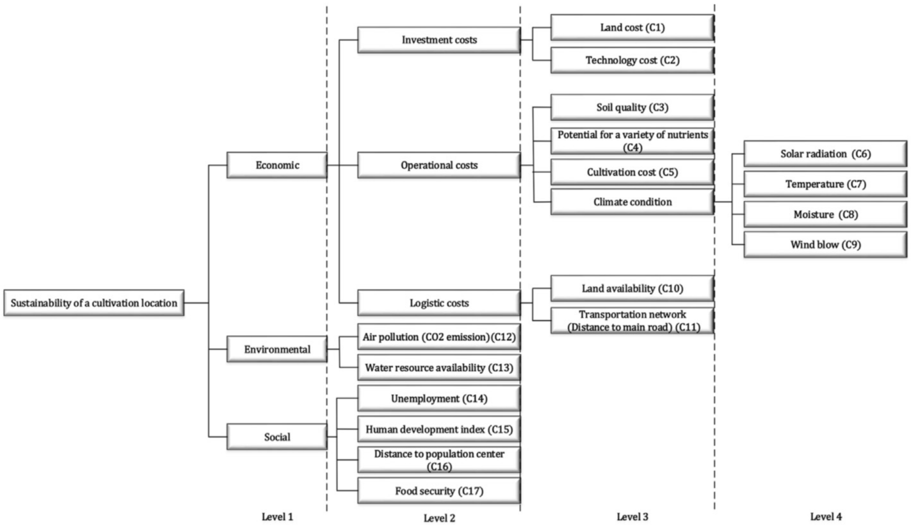

Fig. 1. The hierarchical tree for the criteria.

divided into soil properties, topography, climate condition and accessibility categories, to assess different locations for rice cultivation in Iran, the results indicating that slope, temperature, soil texture and distance to surface water are the most important criteria, related to topography, climate dimensions, soil properties and accessibility, respectively.

Lopez-Díaz et al. [39] used a MILP model to design a biofuel supply chain in Mexico. That model was used to determine the optimal location of cultivation sites, distribution center and bioenergy facility locations. The objective function in their study maximizes the total annual profit, which land required for cultivation, water costs and transportation costs being main criteria when it comes to selecting the best locations for cultivation. Khanjapanah et al. [11] used DEA to identify the best location for switchgrass cultivation in Iran, based on land costs, human deployment index, annual rainfall, annual average of mean daily temperature, water resources, amount of arid and semi-arid land, population, unemployment rate and fuel demand, while Babazadeh et al. [40] tried to determine the optimal location in Iran to cultivate algae, a potential ingredient for biodiesel production, also using DEA, and including human deployment index, annual rainfall, annual average of temperature, solar radiation, population, cultivation cost and the amount of wastewater as the main criteria used.

Anggraini et al. [41] used AHP and nine criteria divided among the categories into nutrients, water sources and technology cultivation, to identify the most suitable location for microalgae cultivation in Indonesia. The results of their study indicated that water resources, technology and nutrients have the greatest impact on the location of microalgae cultivation. Ghaderi et al. [42], using fuzzy DEA examined the optimal location for switchgrass cultivation based on sustainable development indicators in Iran. The amount of water resources, area of marginal land, amount of cultivated land area, rural population, unemployment rate and human development index are among the criteria they used to evaluate the candidate places. Mostafaeipour et al. [43] evaluated the potential of bioethanol production from agricultural residues such as rice straw, wheat straw, barley straw, rice hulls, maize fodder, sugarcane bagasse and cotton stalks in 13 major cities of province Mazandaran in the south of Caspian Sea in Iran using VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje). The results confirmed the potential of Mazandaran for bioethanol production from agricultural residues and Babol ranked as first place among the 13 alternatives. It is worth noting that we also reviewed other relevant studies such as nuclear power plant [44], photovoltaic [45], and wind/PV/hydrogen hybrid [46] centers to identify criteria contributed to the location selection issues investigated in this research.

Building on the result of the literature review above, we identified a comprehensive set of evaluation criteria, which we used to create a comprehensive framework of sustainable criteria for determining the optimal location for cultivation (see Fig. 1). To divide the criteria into economic, social and environmental dimensions, the framework proposed by Kheybari et al. [12] is extended and used in this research. We used the following approach to categorize the identified criteria into the three dimensions of sustainability [47]:[1]

- Criteria which are related to environmental protection are categorized under environmental dimension.
- Rules and regulations and all the issues related to people and government are categorized as social dimension.
- Cost and income are the factors categorized under economic dimension.

The proposed framework can be used to determine the optimal location for the cultivation of agricultural products. Note that the definition of criteria presented in Fig. 1 is summarized in Table A in Appendix.

As presented in the literature review, the combination of MCDA and GIS is popular to solve the locations selection problems of cultivation areas for agricultural crops. To use GIS, as a methodology, existing spatial data for alternatives in criteria which impact the location selection is necessary. But for many provinces of Iran considered as alternatives in this research, accessing to such data is impossible. In this regard, we employ a mix of MCDA and value functions as methodology to solve the problem in this research.

3. Research methodology

As presented in Fig. 2 this study consists of four steps. The first

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[1] Since "climate conditions" has effect on the yield of cultivated crop, we categorized it as an economic factor.

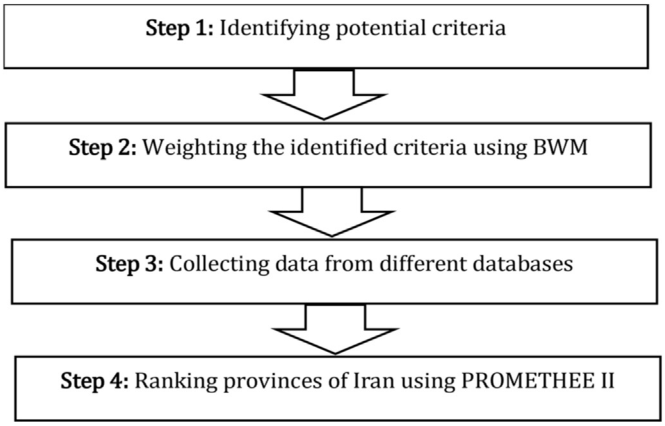


Fig. 2. Steps done in this research.

step is to identify potential criteria for the selection of optimal cultivation areas (presented in Fig. 1) based on a literature review. To determine the weight of the identified criteria, the opinions of 30 experts in the area of corn cultivation were collected through an online questionnaire. The Agriculture Organization of Khorasan Razavi, Agricultural Research, Education and Extension Organization (AREEO), and Department of Agronomy at the Ferdowsi University of Mashhad provided the most cooperation in the weighting process, with 11, 10 and 9 respondents, respectively. All experts were identified by their online profile and have conducted extensive studies into agriculture in Iran. Of the 30 respondents involved in this study, 12 (40%) were working as researchers in Ferdowsi University of Mashhad or AREEO, while the other 18 (60%) experts were employed as senior managers at the Agriculture Organization of Khorasan Razavi or AREEO. Their average work experience is about 18 years. It is worth nothing that due to the experts' experience and work condition they were familiar with, the importance of the criteria is categorized into the three dimensions of sustainability. After aggregating the experts' opinion using the geometric mean and collecting data from Statistical Center of Iran, Ministry of Petroleum, and the Ministry of Culture and Islamic Guidance, the performance of the provinces of Iran was calculated by piecewise linear value functions [18] in the third step. Finally, the provinces were ranked using PROMETHEE II. It is worth noting that, as a prequalification phase, 6 of the 31 provinces of Iran (Bushehr, Kerman, Sistan and Baluchestan, Fars, Khuzestan, and Yazd) were excluded from the evaluation process, because according to the report presented by the Ministry of Energy of Iran [48], they suffered from a severe water shortage problem, rendering them totally inappropriate for corn cultivation.

3.1. *Best-worst method*

The best-worst method (BWM) is a pairwise comparison-based weighting method that was developed by Rezaei [15]. It has been used successfully in a variety of studies into energy [49,50], sustainability [51], and location [12,47,52], among others. For a comprehensive list of applications, we refer the reader to Ref. [53]. The weighting process using BWM is divided into five steps as follows [16].

1. A set of decision-making criteria $\{c_1, c_2, \ldots, c_n\}$ is identified by experts or decision-makers.
2. The best (B) and worst (W) criteria are determined by the experts or decision-makers, based on the set identified in Step 1.
3. The preference of the best criterion over all the other criteria is determined by a number from 1 to 9 (where 1 is equally important and 9 is extremely more important) by the experts or decision-makers. Using the comparisons of best-to-others, the vector $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bj}, \ldots, a_{Bn})$ is resulted, where a_{Bj} indicates the preference of the criterion B over the criterion j .
4. The preference of all the criteria over the worst criterion is determined by the experts or decision-makers. The result of others-to-worst comparisons is called the vector $A_W = (a_{1W}, a_{2W}, \ldots, a_{jW}, \ldots, a_{nW})$, where a_{jW} denotes the preference of the criterion j over the criterion W.
5. The optimal weights are computed $(w^*_{1,} w^*_2, \ldots, w^*_n)$

The optimal weights are calculated by minimizing the maximum absolute difference of $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$ for all the criteria j translated into the following optimization problem:

$$\min \max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$$

s.t.

$$\sum_{j=1}^{n} w_j = 1$$

$$w_j \geq 0, \text{ for all } j \tag{1}$$

Model (1) is converted into:
min ξ
s.t.

$$|w_B - a_{Bj}w_j| \leq \xi, \text{ for all } j$$

$$|w_j - a_{jW}w_W| \leq \xi, \text{ for all } j$$

$$\sum_{j=1}^{n} w_j = 1$$

$$w_j \geq 0, \text{ for all } j \tag{2}$$

By solving Model 2, both the consistency ratio (ξ^*) and optimal weight of the criteria, $(w^*_{1,} w^*_2, \ldots, w^*_n)$, are computed at different levels of a hierarchical tree called local weights. We then check the acceptability of the provided pairwise comparisons calculating the input-based consistency ratio (CR) of the provided data and see if the CRs are below their associated thresholds listed in Liang et al., [54].

In a hierarchical tree with more than one level, the weight of sub-criteria in the last level, called global weight, is calculated by multiplying the local weights that belong to the same branch in the hierarchical tree.

3.2. *PROMETHEE*

The PROMETHEE family, which includes PROMETHEE I and PROMETHEE II, was developed by Brans [55]. While PROMETHEE I is used for partial ranking, PROMETHEE II can be used to make a complete ranking of alternatives. Ease-of-use [56] and a wide range of applications [17], and its powerful features with regard to ranking (which is the ultimate purpose of our analysis) justify using PROMETHEE in this study. PROMETHEE II is applied as follows.

Step 1. Calculation of deviation between two alternatives

within a specific criterion using:

$$d_j(a,b) = g_j(a) - g_j(b) \text{ for all } j \tag{3}$$

where $d_j(a,b)$ shows the deviation of the alternatives a and b.

Step 2. Application of the preference functions by:

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \textit{ for all } j \tag{4}$$

where $P_j(a,b) \in [0,1]$ represents the preference of the alternative a compared to the alternative b in criterion j and $F_j[.]$ denotes the type of preference functions for criterion j. There are six general preference functions according to Brans and Vincke [57] to calculate$P_j(a,b)$.

Step 3. Computation of a global preference index through:

$$\pi(a,b) = \sum_j P_j(a,b) w_j,\ \forall (a,b) \in A, \tag{5}$$

where A and w_j indicate a set of alternatives and weight of the criterion j, respectively. Here, the weights w_j are provided by BWM.

Step 4. Computation of both positive and negative outranking flows using:

$$\varnothing^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \tag{6}$$

$$\varnothing^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \tag{7}$$

$\varnothing^+(a)$ and $\varnothing^-(a)$ in Equations (6) and (7), respectively, express how much a dominates all $(n-1)$ alternatives and how much a is dominated by all the other alternatives.

Step 5. Computation of the overall performance of each alternative by:

$$\varnothing(a) = \varnothing^+(a) - \varnothing^-(a) \tag{8}$$

Considering $\varnothing(a)$, the alternatives can be ranked.

3.2.1. Theoretical extension of PROMETHEE II

PROMETHEE works on the basis of the distance between the alternatives in terms of the decision-making criteria ($d_j(a,b) = g_j(a) - g_j(b)$ for all j). Different preference functions are used to assign meaning to different distances (Step 2). However, a problem occurs when two exactly identical distances (on different parts of the performance range of the alternatives) for the same criterion have a different meaning. In such cases, the PROMETHEE II assigns the same preference value to the two distances, which may cause confusion. To clarify this issue, suppose we have four alternatives a, b, c and d which are evaluated with respect to criterion j, and suppose that $g_j(a) < g_j(b) < g_j(c) < g_j(d)$ and $d_j(a,b) = d_j(c,d)$. As can be seen, the distance between a and b is equal to the distance between c and d (all with respect to the same criterion j). The same distance (which is calculated in the first step of the method) results in the same preference in the second step (regardless of the preference function being used). Although this presents no problem with the criteria with linearly increasing or decreasing value functions, for the criteria with other types of value functions (see Ref. [12], for instance) this could be misleading. For instance, suppose that we have a value function for criterion j as presented in Fig. 3. It becomes clear that, although $d_j(a,b) = d_j(c,d)$, $P_j(a,b) \neq P_j(c,d)$, PROMETHEE presents the preferences as being equal or $P_j(a,b) = P_j(c,d)$, which is incorrect.

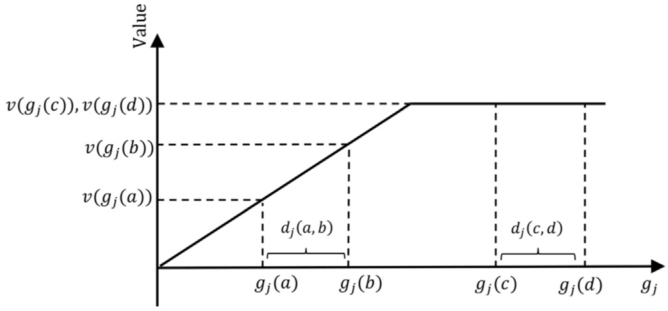


Fig. 3. A value function presenting the performance of four alternatives.

To resolve this issue, we propose replacing the alternative scores $g_j(.)$ by their value $v(g_j(.))$ in the first step. There are several value functions that can be used, in this study we use the one suggested by Ref. [18].

Another interesting implication of using the values instead of the alternative scores is that we can now safely use only one type of the preference functions suggested in the second step of the original PROMETHEE, i.e. the V-shape type (see Fig. 4), because the use of value functions in the first step assigns the same meaning to all the differences. In other words, as $v(g_j(.)) \in [0,1]$, we have normalized distances that have the same meaning for all the alternatives and with respect to all the criteria.

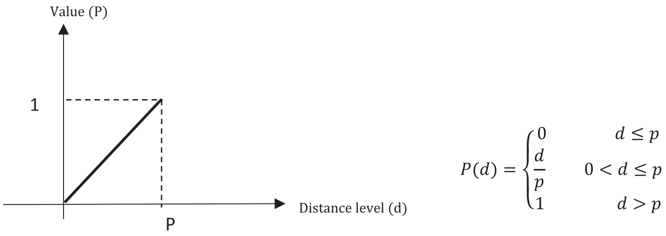
To apply the functions in this research, first, based on the experts' opinions, the type of preference function is determined for the criteria in the last level of Fig. 1, after which the threshold value(s) of each preference functions were determined by interviewing 12 experts. Indeed, we collected the opinions of 12 expert to value the data collected from different database in Iran. At this stage, all experts are corn cultivation specialists in the Agriculture Organization of Khorasan Razavi or Agricultural Research, Education and Extension Organization (AREEO), with over 20 years of work experience. The main results of the interviews and shapes of the criteria preference functions are presented in Table 1.

4. Results and discussion

In this section, we begin by discussing the results of the experts' opinion regarding the weight of criteria calculated by BWM, divided into the three dimensions of sustainability (see Fig. 1), after which extended PROMETHEE II is used to rank of suitability for corn cultivation of the various provinces of Iran.

4.1. Weight of the criteria and sub-criteria

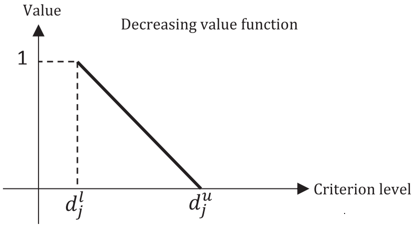
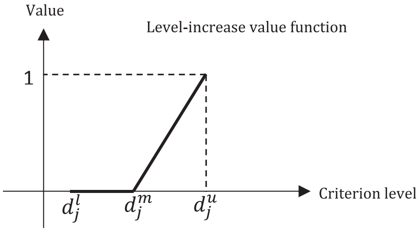
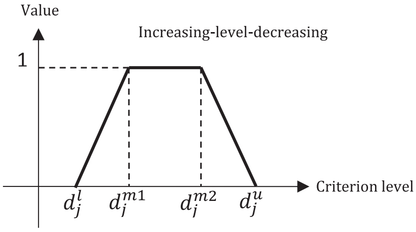
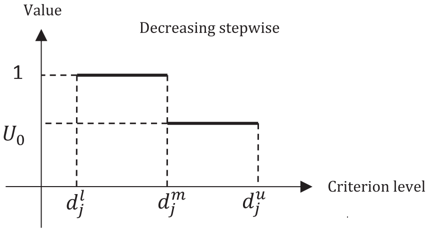
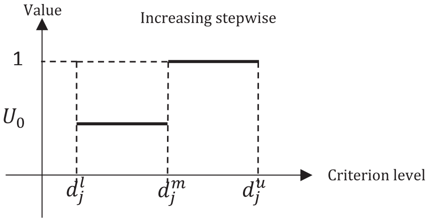
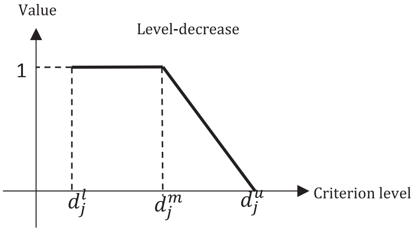
Fig. 5 shows the weights of the economic, environment and social dimensions (the three main criteria). As can be seen, the *economic* dimension has the highest weight, closely followed by the *environmental* dimension, and they are both much more important



$$P(d) = \begin{cases} 0 & d \le p \\ \frac{d}{p} & 0 < d \le p \\ 1 & d > p \end{cases}$$

Fig. 4. V-shape preference function.

Table 1
The piecewise linear preference functions used in this study.

Criteria	Piecewise linear preference functions	Equations
• Land cost[a] • Cultivation cost[a] • Technology cost[a]		$U_{ij}=\begin{cases}\frac{d_j^u-x_{ij}}{d_j^u-d_j^l} & d_j^l\le x_{ij}\le d_j^u\\ 0 & \mathit{Otherwise}\end{cases}$
• Solar radiation		$U_{ij}=\begin{cases}0 & d_j^l\le x_{ij}\le d_j^m\\ \frac{x_{ij}-d_j^m}{d_j^u-d_j^m} & d_j^m\le x_{ij}\le d_j^u\\ 0 & \mathit{Otherwise}\end{cases}$
• Temperature • Moisture • Unemployment • Human development index		$U_{ij}=\begin{cases}\frac{x_{ij}-d_j^l}{d_j^{m1}-d_j^l} & d_j^l\le x_{ij}\le d_j^{m1}\\ 1 & d_j^{m1}\le x_{ij}\le d_j^{m2}\\ \frac{d_j^u-x_{ij}}{d_j^u-d_j^{m2}} & d_j^{m2}\le x_{ij}\le d_j^u\\ 0 & \mathit{Otherwise}\end{cases}$
• Air pollution (CO_2 emission)		$U_{ij}=\begin{cases}1 & d_j^l\le x_{ij}\le d_j^m\\ U_0 & d_j^m\le x_{ij}\le d_j^u\\ 0 & \mathit{Otherwise}\end{cases}$
• Distance to population center • Potential for a variety of nutrients • Water resource availability • Food security • Soil quality		$U_{ij}=\begin{cases}U_0 & d_j^l\le x_{ij}\le d_j^m\\ 1 & d_j^m\le x_{ij}\le d_j^u\\ 0 & \mathit{Otherwise}\end{cases}$
• Wind blow		$U_{ij}=\begin{cases}1 & d_j^l\le x_{ij}\le d_j^m\\ \frac{d_j^u-x_{ij}}{d_j^u-d_j^m} & d_j^m\le x_{ij}\le d_j^u\\ 0 & \mathit{Otherwise}\end{cases}$

[a] Because detailed information was not obtained for land, cultivation and technology costs for the cultivation of corn in provinces of Iran, the value function being described was applied to those categories.

than the third (*social)* dimension. The unstable economic conditions in Iran, due to high inflation and recession [58], as well as a lack of government support when it comes to purchasing agricultural implements in Iran, are the main reasons why the economic dimension was assigned a relatively high weight.

Based on the expert opinions, *investment costs* are the most important sub-criterion within the economic dimension (see Fig. 6-A). The reason is that, under unstable economic conditions as a result of sanctions, accessibility to land and agricultural machinery, which are categorized as sub-criteria of investment costs, is far

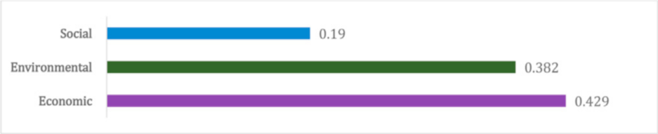


Fig. 5. The weight of the criteria in Level 1.

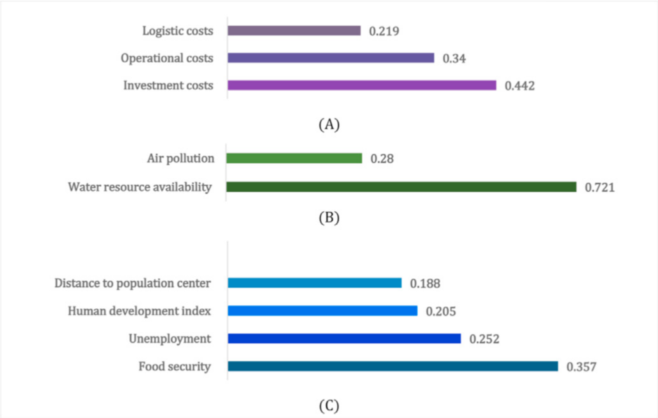


Fig. 6. The weight of the criteria in Level 2.

more difficult than other requirements [49]. *Operational costs* and *logistic costs* are the other two important criteria in this category (see Fig. 6-A).

Similar to the study conducted by Anggraini et al. [41], of the two criteria in the environmental dimension, the weight of *water resource availability* is significantly higher than that of *air pollution* (see Fig. 6-B), due to geographical conditions and poor water management in Iran [59,60]. According to the experts, *food security* was the main criterion of the social category (see Fig. 6-C), due to the fact that Iran's economy relies heavily on agricultural products [61,62]. As a result, cultivating corn for large-scale bioethanol production would have a major impact on the country's food security. *Unemployment rate*, *human development index* and *distance to the population center* are the other criteria in the social category (see Fig. 6-C). High unemployment rate and low population density are the reasons why *unemployment rate* is considered more important that *distance to the population center.*

Of the two sub-criteria in the category of *investment costs, land cost* is much more important than *technology cost* (see Fig. 7-A), considering the need for a large amount of land to cultivate corn as a raw material of bioethanol [63], combined with an unprecedented rise of land prices in Iran [64]. The results of weighting the criteria categorized into *operation costs* indicates that *climate condition* is more important than the other three criteria when it comes to corn cultivation in Iran (see Fig. 7-B). The sheer volume of corn needed to use as raw material and the importance of climate condition in the production of bioethanol are the two main factors that determine the high weight of *climate condition* in this category. *Soil quality*, *cultivation cost* and *potential for a variety of nutrients* are the other criteria in this category (see Fig. 7-B). According to the respondents, the weight of *land availability* to rank corn cultivation areas in Iran is higher than that of *transportation network* (see Fig. 7-C), due to the increasing population rate and the similarity of the provinces of Iran in terms of road infrastructure [65].

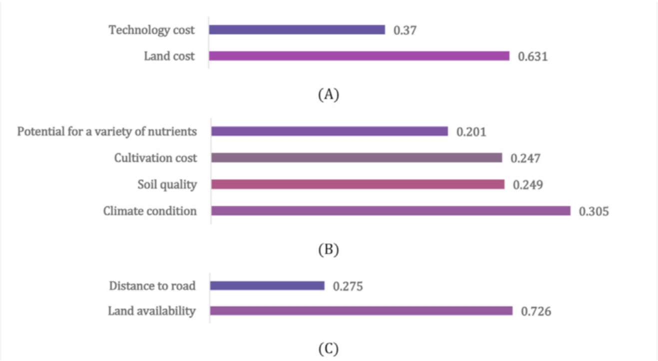


Fig. 7. The weight of the criteria in Level 3.

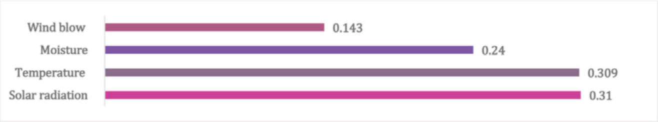


Fig. 8. The weight of the criteria in Level 4.

Experts considered *solar radiation* and *temperature* to be the most important sub-criteria in the climate condition category (see Fig. 8). Temperature was also identified as the most important factor by Kihoro et al. [32] and Maddahi et al. [38], in all cases because of the high impact they have on the production of corn [66]. *Moisture* and *wind blow* were ranked as the second and third sub-criteria in this category.

We also checked the consistency of the pairwise comparisons provided by the experts, considering the thresholds from Ref. [67] where we found all of them acceptable.

4.2. Rank of provinces of Iran

To identify the optimal corn cultivation areas in Iran, the global weight of the criteria presented in Table 2 was calculated. Of the 17 criteria listed in Table 2, the impact of *water resource availability*, *land cost* and, and *air pollution* on the ranking of alternatives is higher than that of the other criteria.

Using the global weight and the results of the extended PROMETHEE II calculated by Visual PROMETHEE software, the suitability of the different provinces of Iran for corn cultivation is determined, with Kordestan, Lorestan and Mazandaran proving to be the most suitable alternatives when it comes to the production

Table 2
The global weight of the criteria.

Criteria	Global weight	Rank
Water resource availability (C_{13})	0.276	1
Land cost(C_1)	0.120	2
Air pollution (C_{12})	0.107	3
Technology cost (C_2)	0.070	4
Land availability(C_{10})	0.069	5
Food security (C_{17})	0.068	6
Unemployment (C_{14})	0.048	7
Human development index (C_{15})	0.039	8
Soil quality (C_3)	0.037	9
Cultivation cost (C_5)	0.036	10
Distance to population center (C_{16})	0.036	11
Potential for a variety of nutrients (C_4)	0.030	12
Transportation network(C_{11})	0.026	13
Solar radiation (C_6)	0.014	14
Temperature (C_7)	0.014	15
Moisture (C_8)	0.011	16
Wind blow (C_9)	0.007	17

Table 3
Rank of provinces of Iran.

Provinces of Iran	$\varnothing^+$	$\varnothing^-$	$\varnothing$	Rank
Kordestan	0.1988	0.0174	0.1814	1
Lorestan	0.1815	0.0367	0.1449	2
Mazandaran	0.1623	0.0480	0.1144	3
Zanjan	0.1478	0.0519	0.0958	4
Gilan	0.1476	0.0588	0.0888	5
North Khorasan	0.1284	0.0558	0.0726	6
Kermanshah	0.1421	0.0855	0.0566	7
Hormozgan	0.1539	0.1089	0.0450	8
South Khorasan	0.1243	0.0848	0.0396	9
Ilam	0.1157	0.0829	0.0328	10
Semnan	0.1179	0.1037	0.0142	11
Alborz	0.1177	0.1044	0.0133	12
Golestan	0.1083	0.1071	0.0012	13
Chaharmahal and Bakhtiari	0.1004	0.1130	−0.0125	14
Razavi Khorasan	0.1012	0.1164	−0.0152	15
West Azarbaijan	0.1014	0.1230	−0.0216	16
Hamadan	0.0933	0.1258	−0.0325	17
Kohgeluyeh and Boyer-Ahmad	0.1342	0.1739	−0.0397	18
Ardabil	0.0839	0.1268	−0.0429	19
Qazvin	0.0792	0.1227	−0.0434	20
Markazi	0.0743	0.1542	−0.0799	21
East Azarbaijan	0.0969	0.1822	−0.0853	22
Isfahan	0.0694	0.1598	−0.0904	23
Qom	0.0485	0.2598	−0.2113	24
Tehran	0.0598	0.2854	−0.2256	25

of corn as a raw material for bioethanol production (see Table 3). Note that the value of alternatives in the 17 criteria and the turning point of the value functions are presented in Tables B and C in Appendix, respectively.

The columns of $\varnothing^+$ and $\varnothing^-$ called the PROMETHEE I partial ranking, indicate the outranking and outranked characters of each provinces of Iran, respectively. In other words, using the $\varnothing^+$ and $\varnothing^-$ which are the main advantages of PROMETHEE, we can identify the strength and weakness of provinces of Iran for the corn cultivation location selection problem. Therefore, according to the information presented, we conclude that Kordestan and Tehran are the strongest and weakest places for corn cultivation as a raw material of bioethanol production in Iran (see Table 3).

As shown in Fig. 9, Kordestan, a province in the west of Iran, performs well on 12 criteria, including *soil quality*, *potential for a variety of nutrients* and *land availability,* (see Fig. 9). Lorestan, which is also located in the west of the country, also performed well on 12 criteria, including *potential for a variety of nutrients*, *human development index* and *land availability* (see Fig. 9). Of 17 criteria, Mazandaran, a province in northern Iran, performed well on in 11 criteria, including *potential for a variety of nutrients*, *wind blow* and *water resource availability* (see Fig. 9). Finally, Tehran, which was ranked as the least suitably option, only performed well on 6 criteria, including *solar radiation*, *temperature*, *food security, unemployment, transportation network* and *moisture* (see Fig. 9). The location of the four places is depicted in Fig. 10.

5. Validation of the results

To evaluate the result of the hybrid methodology, we collected the opinion of seventeen experts who were involved in the weighting the criteria. Of seventeen experts whose opinion were collected by interview, nine of them were working as university researchers and others were members of AREEO. The average work experience of experts is 13.5. The validation was done based on two different questions. In this regard, we first asked the respondents if they disagree with the result of the BWM in levels 1 to 4 in Fig. 1, explain their reasons. As indicated in Table 4, the result of the BWM in the categories of environment and social with 100% and 41.1% of votes have the most and the least agreement. Although the number of answers for *food security* in the social dimension is less than 50%, as indicated in the negative column of Table 4, the experts appeared to be unable to reach a consensus on any given criterion.

5.1. Sensitivity analysis

According to the predictions, we will have a significant increase in the importance of criteria categorized into both environmental and social dimensions for several sustainability problems in the near future [68]. The growth of global warming [69] and environmental problems [70] along with social issues such as unemployment rate [71] due to the population growth, are among the factors that justify the prediction in increasing the importance of social and environmental dimensions. Bearing the aforementioned points in mind, we analyze the score of provinces of Iran according to the various weighting conditions. To this end, we use the lowest value of the economic dimension derived from the views of experts (i.e., 0.156) and add the difference between this number and the current weight of economic dimension (i.e., 0.273) to the other two sustainability pillars according to the following scenarios.

Scenario I: Increasing the weight of environment pillar by 0.273.
Scenario II: Increasing the weight of social pillar by 0.273.
Scenario III: Increasing the weight of both social and environment pillars by 0.136.

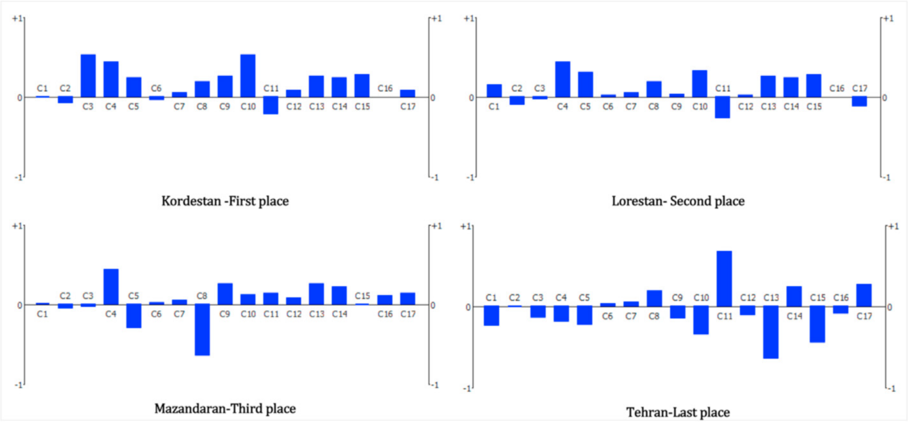


Fig. 9. Performance of the first three provinces and also the last province in different criteria to cultivate corn in Iran.

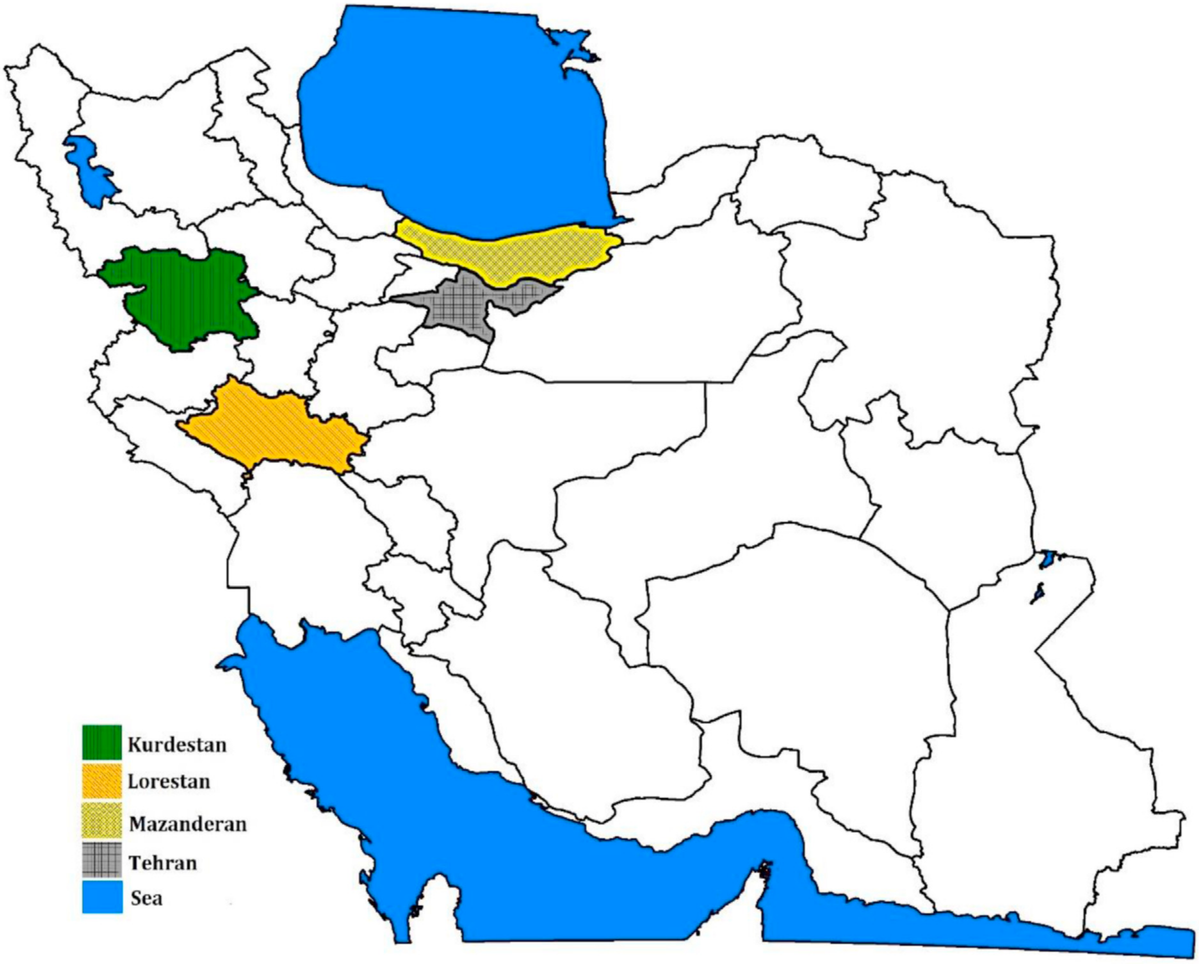


Fig. 10. Location of four alternatives (top three alternatives and the worst one).

Table 4
Results of interviews.

Results of BWM	Level in hierarchical structure	No. of votes		Reasons	
		In favor	Against	Experts who agree	Experts who disagree
Economic	First	13 (76.4%)	4 (23.6%)	• Economic justification is the cornerstone of professional growth	• According to Iran's condition environmental issues are among main concerns
Investment costs	Second (Economic)	10 (58.8%)	7 (41.2%)	• Investing in planting activities lead to less cost growth	• In some places of Iran production costs are far more than investment costs
Food security	Second (Social)	7 (41.2%)	10 (58.8%)	• Corn consumers have no suitable alternative in Iran	• Due to the climatic conditions of Iran, food security can be compensated by other crops • Other social factors (such as unemployment rate) are more important than the food security
Water resource availability	Second (Environment)	17 (100%)	0	• The water crisis in Iran is a serious problem	
Land cost	Third (Investment costs)	14 (82.4%)	3 (17.6%)	• To cultivate corn as raw material of bioethanol production, a large area of land is needed	• Due to sanctions, Iran faces some problems to import technologies used for agricultural purposes
Climate condition	Third (Operation costs)	12 (71%)	6 (29%)	• Iran has different type of climate conditions • Climatic characteristics have great impact on the corn yield	• Accessibility to the nutrients and the quality of soil are not the same in all the parts of Iran.
Land availability	Third (Logistic costs)	14 (82.4%)	3 (17.6%)	• Most Iranians make a living from agriculture • Traditionally, farmers cultivate certain crops in Iran	• Transportation costs are different among the provinces of Iran
Solar radiation and temperature	Forth (Climate condition)	16 (94%)	1 (6%)	• Both of them have a great impact on the performance of corn	• Moisture is also an important criterion

Table 5
Results of sensitivity analysis.

Scenario I		Scenario II		Scenario III	
Provinces of Iran	Phi	Provinces of Iran	Phi	Provinces of Iran	Phi
Razavi Khorasan	0.300	Kordestan	0.207	Razavi Khorasan	0.236
East Azarbaijan	0.276	Razavi Khorasan	0.172	Kordestan	0.234
Kordestan	0.261	Hamadan	0.155	East Azarbaijan	0.204
West Azarbaijan	0.244	Kermanshah	0.148	West Azarbaijan	0.195
Hamadan	0.235	West Azarbaijan	0.147	Hamadan	0.195
Kermanshah	0.212	East Azarbaijan	0.133	Kermanshah	0.179
Golestan	0.201	Lorestan	0.126	Lorestan	0.138
Lorestan	0.150	Zanjan	0.091	Golestan	0.134
Zanjan	0.074	Golestan	0.068	Zanjan	0.082
Ardabil	0.073	Isfahan	0.047	Isfahan	0.036
Mazandaran	0.061	Markazi	0.041	Mazandaran	0.019
Isfahan	0.025	Qazvin	−0.001	Markazi	0.018
Markazi	−0.005	North Khorasan	−0.007	Ardabil	−0.004
Tehran	−0.054	Mazandaran	−0.024	Qazvin	−0.040
Qazvin	−0.078	Tehran	−0.028	Tehran	−0.040
North Khorasan	−0.083	Ilam	−0.053	North Khorasan	−0.045
Gilan	−0.120	Semnan	−0.062	Ilam	−0.096
Ilam	−0.139	Kohgeluyeh and Boyer-Ahmad	−0.069	Semnan	−0.120
Semnan	−0.178	Ardabil	−0.080	Kohgeluyeh and Boyer-Ahmad	−0.125
Kohgeluyeh and Boyer-Ahmad	−0.182	Chaharmahal and Bakhtiari	−0.119	Gilan	−0.137
Chaharmahal and Bakhtiari	−0.212	Qom	−0.127	Chaharmahal and Bakhtiari	−0.165
Hormozgan	−0.251	Alborz	−0.144	Qom	−0.192
South Khorasan	−0.256	Gilan	−0.153	Alborz	−0.219
Qom	−0.258	South Khorasan	−0.190	South Khorasan	−0.223
Alborz	−0.295	Hormozgan	−0.279	Hormozgan	−0.265

We summarize the results of the three scenarios in Table 5. As seen, after decreasing the weight of the economic dimension, Kordestan, which was initially ranked as a first alternative (see Table 3), is also ranked as a suitable option in the three scenarios (see Table 5). On the other hand, Khorasan Razav and East Azarbaijan, which were initially at the 15th and 28th places (see Table 3), are ranked as alternatives with good performance in the three scenarios (see Table 5). In general, considering the three scenarios, we can conclude that Kordestan, Lorestan, Zanjan and Kermanshah are appropriate areas to grow corn as a raw material of bioethanol production in Iran.

6. Conclusion and future research

Bioethanol as a biofuel that has the potential to reduce the carbon footprint of fossil fuels considerably. Selecting a suitable location to cultivate biomass (such as corn) to be used as a raw material for the production of biofuel, is a main challenge in the bioethanol production process. To solve that problem, this study used a hybrid methodology, consisting of BWM and an extended version of PROMETHEE II, to assess the potential of different locations, using MCDA-based approach.

The method was used to determine the suitability of the various provinces of Iran for the cultivation of corn, to be used as a biomass resource in the production of bioethanol production, in the form of a case study. To that end, a sustainable framework was proposed that included economic, social and environmental criteria. The framework provides a road map for policymakers to design a strategic plan for biomass production in the future. It can also be useful to evaluate other agricultural cultivation areas. To calculate the weight of the criteria in the framework, the opinions of a sample of experts in Iran were collected via a BWM questionnaire in the second step. The results indicated that *water resource availability*, *land cost* and *air pollution,* respectively, are the most important factors in selecting suitable corn cultivation areas in Iran. Finally, the suitability of the provinces of Iran was evaluated using a hybrid of piecewise linear value functions and the extended PROMETHEE II method. The results indicate that, of the 31 provinces of Iran, Kordestan is the most suitable location for corn cultivation in Iran (followed closely by Lorestan and Mazandaran).

The framework and result of this study have several implications for researchers and practitioners. Researchers can use the sustainable framework to evaluate and cluster farmlands, while agricultural practitioners in Iran can use the results of this study to inform future decision-making regarding corn cultivation, and Iranian policy-makers can design more efficient programs to develop the country's agriculture. As such, the framework and methodology can also be used in other developing countries.

Among the limitations of this study were the limited access to experts with knowledge and experience regarding the cultivation of corn and data about the performance of alternatives in different criteria. However, the framework proposed in this study does provide valuable opportunities for future study. For instance, although the assumption that there are hierarchical relations among the different criteria simplifies the process of identifying a suitable, taking a closer look at the actual relations among the criteria in the framework can improve the reliability of results. To that end, applying decision-making trial and evaluation laboratory (DEMATEL) is suggested for future research.

Credit author statement

Conceptualization: Siamak Kheybari. Investigation: Siamak Kheybari and Jafar Rezaei. Methodology: Siamak Kheybari. Resources: Mahsa Javdanmehr and Fariba Mahdi Rezaie. Supervision: Jafar Rezaei. Validation: Siamak Kheybari. Writing – review & editing: Siamak Kheybari, Jafar Rezaei, Mahsa Javdanmehr and Fariba Mahdi Rezaie.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A
Definition of criteria presented in Fig. 1.

Criteria	Definition
Investment cost	The fixed cost related to cultivation in each place
Land cost	Land prices in each region
Technology cost	The cost of technology for the cultivation of corn in the candidate locations
Operational cost	The costs that have a direct relation to the corn cultivation process
Soil quality	The strength and potential of the soil for sustainable crop production
Potential for a variety of nutrient	Existence of suitable environment for corn growth
Cultivation cost	The cultivation cost of corn in the candidate locations
Climate condition	A suitable climate with high annual solar irradiation and an optimum temperature range which allows growth at high productivity levels
Solar radiation	Amount of solar radiation in candidate locations
Temperature	The air temperature of the candidate places
Moisture	Moisture content of each place
Wind blow	Amount of wind blow in each region
Logistic costs	The costs related to transportation and accessibility
Land availability	The land which is available to cultivate corn
Transportation network (Distance to main road)	Distance of each place from different transportation networks
Air pollution (CO2 emission)	Existence of carbon dioxide in each area
Water resource availability	The amount of water resources that provide water in necessary conditions
Unemployment	The number of people who are unemployed as a percentage of the labor force in each region (Unemployment rate)
Human development index	Human development index is a factor to measure the average achievement of key dimensions of human development
Distance to population center	The distance of the cultivation area from the population centers
Food security	Exploring the variability and conditions of each environment to ensure food security in corn production

Table B
Value of provinces of Iran in criteria

Provinces of Iran	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
East Azarbaijan	0.16	0.122	0.808	0.753	0.258	0.874	0.971	1
West Azarbaijan	0.246	0.067	0.808	1	0.31	1	0.893	0.923
Ardabil	0.236	0.083	0.808	0.398	0.313	0.877	0.459	0.421
Isfahan	0.115	0.178	0.157	0.398	0.226	0.879	1	0.968
Alborz	0.16	0.122	0.808	0.398	0.453	0.879	1	1
Ilam	0.241	0.087	0.458	0.398	0.483	0.877	1	0.962
Tehran	0.019	0.154	0.35	0.398	0.267	0.882	1	1
Chaharmahal and Bakhtiari	0.179	0.071	0.458	0.398	0.318	0.82	0.773	1
South Khorasan	0.298	0.084	0.157	0.398	0.602	0.82	1	0.83
Razavi Khorasan	0.269	0.086	0.35	0.398	0.567	0.82	1	1
North Khorasan	0.287	0.099	0.458	0.398	0.486	0.82	1	0.941
Zanjan	0.197	0.092	0.808	0.753	0.512	0.82	0.993	1
Semnan	0.171	0.116	0.157	0.398	0.307	0.82	1	1
Qazvin	0.146	0.123	0.808	0.753	0.418	0.82	1	1
Qom	0.135	0.087	0.157	0.398	0.545	0.82	1	1
Kordestan	0.241	0.085	1	1	0.718	0.82	1	1
Kermanshah	0.301	0.117	0.458	0.398	0.482	0.822	1	1
Kohgeluyeh and Boyer-Ahmad	1	0.106	0.458	0.398	0.323	0.884	1	1
Golestan	0.349	0.072	0.35	0.398	0.377	0.879	1	0.494
Gilan	0.263	0.066	1	1	0.278	0.879	1	0
Lorestan	0.395	0.066	0.458	1	0.778	0.88	1	1
Mazandaran	0.261	0.109	0.458	1	0.195	0.88	1	0.194
Markazi	0.144	0.18	0.808	0.398	0.748	0.88	1	1
Hormozgan	0.275	0.689	0.157	0.398	0.562	0.876	0.952	0
Hamadan	0.251	0.077	0.808	0.753	0.396	0.877	0.904	1

Provinces of Iran	Criteria								
	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
East Azarbaijan	0.05	1	0.596	0.824	0.272	0.884	0.914	0.895	0.05
West Azarbaijan	0.73	1	0.312	0.942	0.533	0.191	1	0.895	0.73
Ardabil	0.39	0.848	0.136	0.942	0.533	1	1	0.895	0.39
Isfahan	1	0.343	0.813	0.942	0.533	0.559	0.585	0.895	1
Alborz	0.83	0	0	0.824	1	0.945	0.306	0.808	0.83
Ilam	0.83	0.289	0.041	0.942	1	1	0.591	0.895	0.83
Tehran	0.6	0.163	1	0.824	0.131	1	0.306	0.808	0.6

(continued on next page)

Table B (*continued*)

Provinces of Iran	Criteria								
	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
Chaharmahal and Bakhtiari	0.75	0.163	0.055	0.942	1	0.097	1	0.895	0.75
South Khorasan	0	0.055	0.163	0.942	1	1	1	0.895	0
Razavi Khorasan	0.32	0.848	1	0.824	0.533	1	0.905	0.808	0.32
North Khorasan	1	0.361	0.068	0.942	1	0.717	1	0.895	1
Zanjan	1	0.632	0.176	1	1	0.359	0.971	0.895	1
Semnan	1	0.073	0.379	1	1	0.335	0.604	0.895	1
Qazvin	1	0.379	0.082	1	0.533	1	0.637	0.895	1
Qom	0.72	0.019	0.136	0.942	0.131	1	0.835	0.808	0.72
Kordestan	1	1	0.136	1	1	1	1	0.895	1
Kermanshah	0.73	1	0.082	0.824	1	0	0.983	0.895	0.73
Kohgeluyeh and Boyer-Ahmad	1	0.217	0.041	0.942	0.533	1	0	0.895	1
Golestan	0.56	0.992	0.217	1	0.533	1	0.981	1	0.56
Gilan	1	0.415	0.109	0.942	1	0.764	0.863	0.895	1
Lorestan	0.78	0.812	0.095	0.942	1	1	1	0.895	0.78
Mazandaran	1	0.614	0.488	1	1	0.979	0.729	1	1
Markazi	1	0.469	0.244	1	0.533	0	0.657	0.895	1
Hormozgan	0.32	0.073	0.407	0.853	1	0.812	0.904	0.895	0.32
Hamadan	0.79	0.974	0.298	0.824	0.533	0.311	1	0.895	0.79

Table C
The turning point of the value functions

Criteria	d_j^u	d_j^{m1}	d_j^{m2}	d_j^m	d_j^l
Land cost	–	–	–	–	–
Cultivation cost	–	–	–	–	–
Technology cost	–	–	–	–	–
Solar radiation	10.8	–	–	–	–
Temperature	44.17	32.5	21.67	–	12.5
Moisture	80	58	41.25	–	16.67
Unemployment	0.15	–	–	–	0.11
Human development index	0.67	–	–	–	0.59
Air pollution (CO_2 emission)	3.4	–	–	3.2	3.05
Distance to population center	5.18	–	–	4.64	4.18
Potential for a variety of nutrients	8.45	–	–	6.36	3.36
Water resource availability	9.73	–	–	3.91	1.27
Food security	4.77	–	–	3.68	2.43
Soil quality	8.23	–	–	4.77	1.91
Wind blow	8	–	–	5	2.5

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