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A Multi-Criteria Approach for Biomass Crop Selection under Fuzzy Environment

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Abstract

The type of biomass crop has a significant impact on the feasibility of ethanol production. Since biomass crop type can have various environmental and economic impacts, the selection of an optimal crop type is a multi-criteria decision-making (MCDM) problem. In this paper, we determine criteria for decision makers and farmers to select the crop type in biomass production. In this method, literature is reviewed and analyzed in order to build up the evaluation model. We provide the evaluation criteria with respect to economic, environmental, and social aspects and use these criteria to evaluate a set of biomass crop types for Kansas among available alternatives. A fuzzy analytical hierarchy process (FAHP) method is considered to establish an evaluation model and identify weights of the determined criteria.

Keywords

Multi-Criteria Decision Analysis, Fuzzy, AHP, Biomass, Crop Selection

1. Introduction

Exploration of the right energy source for continuous economic development has been a hot topic for decades. Energy demand increases year by year; therefore, there is a future need for a certain, sustainable world energy source since fossil-based energy is known to be limited and not environment friendly. Ethanol, an alternative fuel, has the potential to replace fossil-based fuel and is practically used in many countries. Biomass-based energy is considered to be promising, especially for countries that have a suitable infrastructure and agricultural fields for its production. However, finding the most suitable crop type for biomass production will affect the feasibility of this source. The most suitable biomass type for a country may vary depending on the geographical conditions and technological capabilities. In some countries, like Brazil, ethanol is mostly produced from sugarcane, and the rate of ethanol reached almost 50% of the gasoline market there in 2009 [1], while in the U.S., which is the number one producer and consumer of ethanol in the world [2], the biomass is produced from corn. This variability of biomass sources in different regions and counties raises the question of what biomass type is the most suitable source for ethanol production.

Selecting the type of biomass crop is a very important decision in the future of ethanol production. It affects not only the economic feasibility of ethanol production but also the consequences on society and the environment. It can also be considered to be a strategic decision because the type of biomass affects the technology to be used in the conversion facility. In addition, selecting the type of biomass crop is a critical and operational decision for farmers and farmer cooperatives since the equipment in which they will invest and the allocation of their land will depend on this decision. Some energy crops, such as switchgrass, require at least ten years be devoted to its production since this biomass crop can produce a yield for ten or more years when it is established. This decision also affects the environment since each crop type also impacts soil erosion, carbon dioxide sequestration, and water quality. This property eventually affects the soil quality and future of the land in crop production [3]. Another aspect to be considered in the selection of crop type is the social impact. Choosing a certain type of crop for biomass production can change society in terms of the unemployment rate, working conditions, and welfare [4], [5].

The selection of crop type for a country or a region is certainly a complicated problem because it is important to consider various, possibly conflicting, aspects such as economic, environmental, and sociological outcomes of crop type selection and biomass production, as mentioned above. Since multi-criteria decision making (MCDM) is defined as systematic decision making under various criteria that conflict, crop type selection for producing biomass is also an MCDM problem. Not only biomass crop type selection but many real-life problems are considered MCDM problems since a set of alternatives along with various criteria are involved in the decision making. In many cases, the criteria that play a role in this process conflict with one another.

MCDM generally involves criteria that have different units, such as dollars, time, dimensions etc., which also makes the acquisition of convenient data very expensive and the comparison among the criteria difficult during the decision-making process. For this reason, some solution methods for MCDM that greatly assist in the solution of such complex problems [6] have been developed. Researchers have proposed a number of methods, all of which have different performances and are capable of solving MCDM problems [7]. The analytic hierarchy process (AHP) is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps decision makers find the one that best suits their needs. In this paper, the AHP is used as an MCDM method in biomass crop selection because of its applicability to a wide range of problems.

The remainder of this paper is organized as follows: In section 2, we briefly introduce AHP, review the literature regarding biomass crop type selection, and define the problem statement. In section 3, we explain crop type alternatives in Kansas and provide the criteria to be considered in the selection of these alternatives. In section 4, we present, step by step, the proposed fuzzy analytical hierarchy process (FAHP). Finally, section 5 provides concluding remarks along with some discussion.

2. Literature Review and Problem Statement

The nature of problem solving in MCDM methods involves a number of steps: modeling the problem, defining relevant criteria, weighting the criteria and criteria elements, defining alternatives, and ranking alternatives [8]. AHP, which was developed by Saaty in the 1970s, is an MCDM method that is easy to use for decision makers and capable of solving complex problems with conflicting criteria. The AHP provides a rational and comprehensive framework for structuring a problem, comparing and weighting the elements in the structure, and ranking the alternatives [8]. The AHP is particularly effective for those cases when there are multiple options and when the criteria have different units. Since its invention, some improvements have been introduced by researchers. Furthermore, the AHP has been widely applied in many problems and shown to work efficiently in energy policy to select suppliers [9], [10]. Recently, some studies have been undertaken to make this method more robust, consistent, and efficient. One of these studies involves the conversion of expert opinions to numbers since the scale used in the evaluation of criteria is not always in number form, and some efficient techniques are needed in the conversion. Therefore, a fuzzy approach has been developed based on the fuzzy set theory, which was introduced by Zadeh in 1965 and formalized by Laarhoven and Pedrycz [11]. Various fuzzy AHP approaches and models were developed later by many researchers (see e.g., [12], [13] , [14], [15]).

Biomass crop type selection is a strategic and important decision for farmers and policy makers (government and cooperatives). This procedure includes the evaluation of various criteria in order to determine the best biomass source. Some may think that the higher the profit, the better the outcome, but policy makers also need to evaluate social and environmental impacts of biomass production when they give incentives to producers.

A review of the literature shows various biomass selection studies for different purposes. Some of the studies focus on the biological content of biomass. Kahr et al. [16] evaluate the lignocellulosic ethanol potential of various agricultural residues by conducting real experiments. They test cellulosic biomass, such as wheat straw (*Triticum vulgare*), rye straw (*Secale cereal*), oat straw (*Avena sativa*), and corn stover (*Zea mays*) for second-generation ethanol. Santchurn et al. [17] evaluate four commercial varieties of sugar cane using a randomized complete block design. They identify variable proportions of sucrose and fiber in these biomass genotypes. Ciancolini et al. [18] utilize agglomerative hierarchical cluster analysis to evaluate eight cardoon genotypes for biomass and polyphenol production; nine features are assessed to find significant difference among the genotypes. Vaezi et al. [19] develop a numerical algorithm for the selection of biomass alternatives for gasification purposes.

There are some studies which utilize MCDM methods and the AHP in various decisions related to renewable energy and biomass sources. For example, Dael et al. [20] propose an AHP model for selecting the location in a region for biomass valorization. They identify four main criteria and 22 subcriteria, and apply the model in Belgium in order to determine the potentially interesting locations to establish a biomass project. Balezentiene [21] offer a fuzzy method to prioritize energy crops for a reasonable energy crop-mix. They only consider energy crops that are suitable for the Lithuanian climate. In their study, Kabak and Dagdeviren [22] evaluate the renewable energy sources with a hybrid

MCDM model based on BOCR (Benefits, Opportunities, Costs and Risks) and ANP (Analytic Network Process). They compare five renewable energy sources (hydro, geothermal, solar, wind, and biomass) in Turkey as an application of their model. For a similar purpose, Yazdani-Chamzini et al. [23] propose an integrated COPRAS-AHP methodology to select the best renewable energy project by considering social, economic, technological, and environmental criteria. Saelee et al. [24] develop a TOPSIS multi-criteria model for the biomass type selection for boilers. Their criteria compare wood chips, palm shells, and wood pellets for boilers under the criteria of efficiency, price, ease to operate, global warming potential, and acidification potential. There are also some mathematical modeling approaches that have been developed by researchers. In order to determine the best biomass production location, Cobuloglu and Buyuktahtakin [25] propose a mixed integer linear programming method for the biomass production from switchgrass on cropland, grassland, and marginal land. They also consider the environmental effects of switchgrass cultivation in their model.

2.1 Problem Statement

To the best of our knowledge, biomass crop selection has not been studied using the AHP or any other MCDM tool, which have been widely and repetitively employed in other areas. In addition to AHP methodology, the criteria to be considered for biomass selection have not yet been identified. Some researchers focus directly on maximization of yield and economics, others simply evaluate the environmental outcomes, and some focus on both environmental and economic impacts, but their solution method does not quantify all parameters that can affect the biomass selection.

The literature review shows a lack of studies that define all criteria, their relations, and their relative importance for biomass crop type selection along with the utilization of a MCDM method that provides weighting of criteria and ranking of alternatives. In this paper, we are interested in determining the best type of biomass with the help of the fuzzy AHP. As the initial stage of this problem, we develop the aspects and criteria to be evaluated while deciding on the biomass crop type by using expert opinions and literature. After establishing the structure of decision making in the AHP, we use trapezoidal fuzzy numbers to quantify verbal expressions into crisp numbers. With the help of this structure and the proposed model, decision makers can identify the best biomass type in other regions.

3. Crop Type Alternatives and Development of the Structure

Biomass refers to biological material obtained from plants, organics, and residues. Among different sources of renewable energy, after conversion, biomass can be used directly in transportation fuel or as an additive. This has been one of the major energy sources in many countries. In general, biomass can be divided into three categories: food crops and their agricultural residues, energy crops (lignocellulose), and forest materials. Among these categories, the crop types most common in Kansas and have potential to be biomass sources are listed and explained briefly.

3.1. Food Crops

Food crops are the type of crops that are primarily used for food production. They are also used as a biomass source in ethanol production. Among food crops, corn is used to produce most ethanol. Forest residues have not been considered for this specific example since they are scarcely available in Kansas.

Corn: Corn is the biggest biofuel source in the U.S., although it has high energy consumption rates. In other words, the output-input ratio is low since it requires good irrigation and high fertilization. The risk associated with price fluctuations is low for corn since it has a good market, either as ethanol or as food. However, using corn for energy production has been debated because of world hunger, which can be alleviated by corn production.

Sugarcane: After corn, sugarcane is the second most widely used biomass in biofuel production in the world [26]. It requires a warmer climate to grow. As the result of high biofuel production from sugarcane in Brazil, conversion to biofuel is a developed technology, and sugarcane production has a low risk of price fluctuations. However, sugarcane production is sensitive to fertilizers, harvesting, irrigation, climate, and disease. Unlike corn and wheat, sugarcane is a perennial grass, and most parts of it can be converted to biofuel.

Wheat: Because of its high wheat production, Kansas is known as the “bread basket” of America. Wheat has high protein content so it is a valuable food source for human beings, but it is also used for bioethanol production. It grows from its own seeds, and requires seeding and irrigation every year, which increases the production cost, although the conversion from its biomass is efficient.

3.2. Energy Crops

Energy crops, or lignocelluloses, are commonly used as feedstock. With the development of conversion technology, perennial crops have started to be called energy crops because of their low input and high energy yield.

Switchgrass: Switchgrass, a bunchgrass native to North America, is a perennial that does not need to be seeded every year. It has been promoted by the federal government because of its benefits to the environment, such as a reduction of soil erosion and greenhouse gas emissions. It can also grow on marginal lands that are not used for farming. It requires little irrigation and few fertilizers. Its cellulose breaks down to biofuel easier than corn cellulose. Many studies have been undertaken to increase its conversion efficiency [27].

Miscanthus: Miscanthus, another energy crop commonly used in Europe because of its efficiency, may have some invasive properties in some parts of the U.S. because of its spread with rhizomes. This warm season perennial grass is tolerant to cold weather and, therefore, has the potential to be grown as a biomass source in Kansas. It can grow on less-productive land types, such as marginal lands. It does require irrigation for a higher yield, but compared to all other crop types, it has very high yield [28].

3.3 Structure

Following a review of the literature, some studies mention the criteria to be considered in biomass production. However, this information is not compactly given in any one study. Therefore, a number of sources have been compiled in order to identify aspects and criteria for biomass crop selection. The main factors that can affect the biomass crop type selection are listed as economic, environmental, and social aspects. There are nineteen criteria under these aspect which are presented in Figure 1. Short definitions of these each criteria are also provided below in order to explain what they measure in this study.

3.3.1 Economic

The following is a list of criteria under the economic aspect of the biomass crop type [29], [30]:

- Input: Measures the cost of each biomass crop type during the establishment stage, and involves the cost associated with land preparation, machinery, fertilizers, pesticide, and labor.
- Output: Measures the yield amount and productivity of biomass crop on the proposed land type. The harvested amount of biomass yield is the measurement unit.
- Production cost: Measures the cost associated with the biomass crop during its production, particularly for the time between seeding and harvesting. The application of fertilizers, herbicides, irrigation and labor cost can be considered as the production cost.
- Storage and transportation cost: Measures the need for biomass storage and associated cost of storage and transportation requirements.
- Conversion rate: Measures technologic conversion efficiency while converting the biomass into biofuel. The rate of gallons of ethanol per tonne can be taken as the efficiency rate in this criterion.
- Sales risk: Considers the risk of farmers in terms of the sale of the biomass. Price fluctuations and uncertainty in the market can be a unit of measurement.
- Equipment and knowledge: Measures the availability of equipment during all cycles and the practical knowledge of farmers about the cultivation of that particular crop type.
- Robustness: Measures the insurance cost, strength of the crop type, and its adaption to hard conditions. Resistance to drought, cold and hot weather, and durability can be considered a measurement unit.

3.3.2 Environmental

Six criteria are related to the environmental aspects of biomass production [29], [31], [32], [33]:

- Soil quality: Evaluates the benefits on the soil as a result of cultivation. The capability of increasing soil organic carbon and decreasing soil erosion are factors that can be considered in soil quality.
- Carbon emission: Measures the total reduction of CO_2 emissions during the overall lifecycle as a result of biomass production and usage of ethanol produced from that product.
- Usage of chemicals: Evaluates the negative effects of biomass production on the soil quality. The requirement of high fertilizers and herbicides is the measurement unit.
- Water quality/requirement: Involves the capability of filtering the underground and soil water. The higher need for water will decrease the capability.

- Biodiversity and wildlife: Measures the effect of biomass production from a crop type on the biodiversity and wildlife by considering bird and insect populations.
- Land type: Evaluates the impact of biomass production on a certain land type; cropland, grassland, and marginal land, on the environment.
- Invasiveness: Measures risks associated with the invasion of a crop type over the region. The dispersal rate and its harms can be considered the measurement unit.

3.3.3 Social

Social aspects are summarized under five criteria as given below:

- Technological development: Measures the gap between current stage and the future in terms of potential technological developments such as ethanol conversion rate and productivity on farms.
- Workforce requirement: Evaluates the employment and gain of the workforce as a result of biomass production.
- Contribution to welfare: Considers the capability of the increment in the welfare of society and economic development as a result of biomass production. Rise of the gross domestic product can be used as the measurement unit.
- Sustainable energy: Measures the capability of replacing the fossil fuel.
- Compete for food: Evaluates the change of the food security. The measurement unit is the potential allocation of cropland for biomass production.

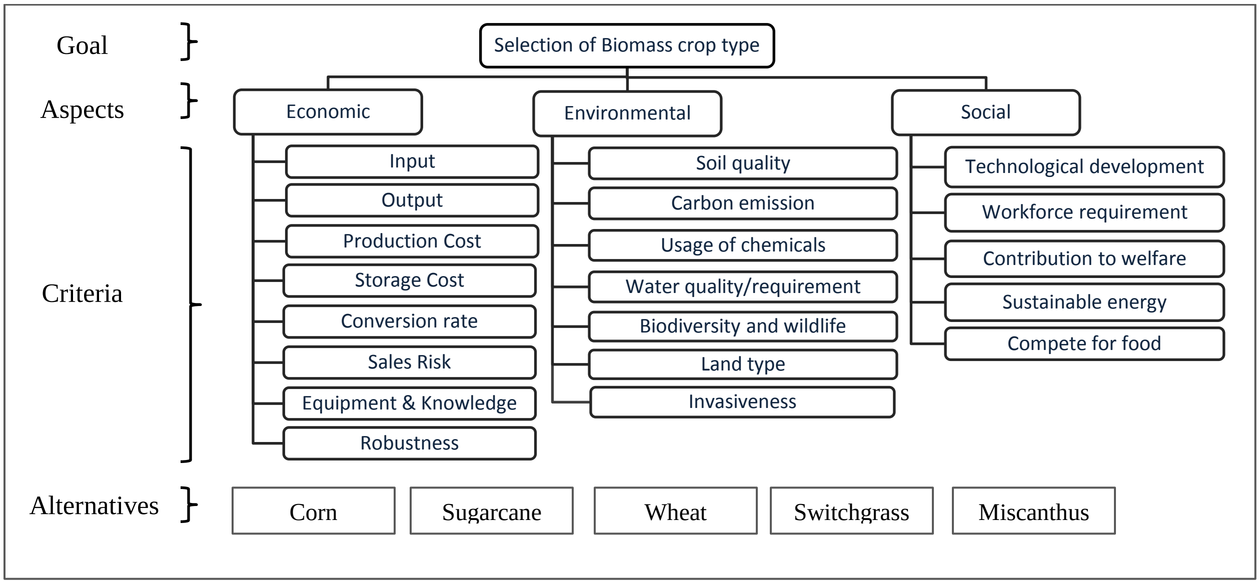

Figure 1. AHP decision model for biomass crop type selection

4. FAHP Methodology

In this study, a fuzzy multi-criteria decision-making procedure, which was proposed for the first time by Zeng et al. [34] and also used by Kahraman and Kaya [9], is modified to evaluate and select the most appropriate alternative. First, we decompose the decision problem into a hierarchy of more easily comprehended subproblems. Once the hierarchy is built, the experts systematically evaluate its various elements by comparing them to one another, two at a time (pair-wise comparison). In making the comparisons, the experts must assign a definite number, within a scale of 1 to 9, in order to compute priority vectors. The fundamental scale for pair-wise comparison is summarized in Table 1. Moreover, the corresponding reciprocals 1, 1/2, 1/3, …, 1/9 are used for a reverse comparison.

Although the AHP method has some advantages during the decision-making process, on the other hand, factor comparisons often involve some amount of uncertainty and subjectivity, which cannot be handled by typical AHP methodology. To illustrate, the expert might provide a range rather than a single number to compare two factors or may not give a definite scale to the comparison because of lack of adequate information and expertise. For the indicated reasons, flows of the classical AHP method may be compensated by employing the fuzzy AHP approach.

Table 1. Saaty's pair-wise comparison scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another
9	Extreme importance	Evidence favoring one element over another is of highest possible order of affirmation
Even scales of 2, 4, 6, and 8 are used to compromise slight differences between two classifications.		

The FAHP method was first introduced by Laarhoven and Pedrycz [35]. In following years, many FAHP methods have been constructed by researchers (see, e.g., [12], [13], [35], [14], [15], [36]). Despite FAHP's widespread application, it may lead to inconsistencies and misinterpretations during implementation in practice. To overcome these difficulties, a newly proposed method by Zeng et al. [34] is slightly modified by adding an additional step of ranking trapezoidal fuzzy numbers [37]. Fuzzy aggregation is used to create group decisions, and then defuzzification is employed to transform the fuzzy scales into crisp scales to calculate weights of priorities in this method. By applying fuzzy aggregation operators, the group preference of each factor is computed. Afterwards, trapezoidal fuzzy scores of each alternative are ranked by their magnitudes. Steps of the methodology presented by Zeng et al. [34] are given as follows:

Step 1: Measure factors in the hierarchy. Experts are required to provide their judgments on the basis of their knowledge and expertise for each factor at the bottom level in the hierarchy. They can provide a precise numerical value, a range of numerical values, a linguistic term, or a fuzzy number.

Step 2: Compare factors using pair-wise comparisons. Experts are required to compare every factor pair-wise in their corresponding section structured in the hierarchy and calibrate them on either a crisp or a fuzzy scale.

Step 3: Convert preferences into a standardized trapezoidal fuzzy number (STFN). As described in steps 1 and 2, because the values of factors provided by experts are crisp, e.g., a numerical value, a range of numerical values, a linguistic term, or a fuzzy number, the STFN is employed to convert these experts' judgments into a universal format for the composition of group preferences. Let U be the universe of discourse, U = [0,u]. A STFN can be defined as $\tilde{A}=(a^l, a^m, a^n, a^u)$, where $0 \le a^l \le a^m \le a^n \le a^u$, as shown in Figure 1, and its membership function is

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{(x-a^l)}{(a^m-a^l)} & \text{for } a^l \le x \le a^m \\ 1 & \text{for } a^m \le x \le a^n \\ \dfrac{(a^n-x)}{(a^u-a^n)} & \text{for } a^n \le x \le a^u \\ 0 & \text{for otherwise} \end{cases} \tag{1}$$

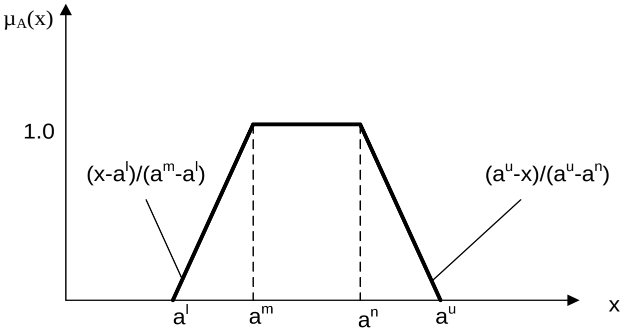

Figure 1. Membership function of STFN A˜

Step 4: Aggregate individual STFNs into group STFNs. The aim of this step is to apply an appropriate operator to aggregate individual preferences made by individual experts into a group preference of each factor. The aggregation of STFN scores is performed by applying the fuzzy weighted trapezoidal averaging operator, which is defined by

$$\tilde{S}_i = \tilde{S}_{i1} \otimes c_1 \oplus \tilde{S}_{i2} \otimes c_2 \oplus ... \oplus \tilde{S}_{im} \otimes c_m \tag{2}$$

where $\tilde{S}_i$ is the fuzzy aggregated score of the factor F_i , $\tilde{S}_{i1}, \tilde{S}_{i2}, ..., \tilde{S}_{im}$ are the STFN scores of the factor F_i measured by m experts $E_1, E_2, ..., E_m$, respectively, $\otimes$ and $\oplus$ denote the fuzzy multiplication operator and fuzzy addition operator, respectively, and $c_1, c_2, ..., c_m$ are contribution factors (CFs) assigned to experts, $E_1, E_2, ..., E_m$ and $\sum_{i=1}^{m} c_i = 1$. Similarly, the aggregation of STFN scales is defined as

$$\tilde{a}_{ij} = \tilde{a}_{ij1} \otimes c_1 \oplus \tilde{a}_{ij2} \otimes c_2 \oplus ... \oplus \tilde{a}_{ijm} \otimes c_m \tag{3}$$

where $\tilde{a}_{ij}$ is the aggregated fuzzy scale of F_i compared to $F_j; \forall i,j \in \{0,1,...,n\}$; $\tilde{a}_{ij1}, \tilde{a}_{ij2}, ..., \tilde{a}_{ijm}$ are the corresponding STFN scales of F_i compared to F_j measured by experts $E_1, E_2, ..., E_m$, respectively.

Step 5: Defuzzify the STFN scales. In order to convert the aggregated STFN scales into matching crisp values that can adequately represent the group preferences, a proper defuzzification is needed. Assuming an aggregated STFN scale $\tilde{a}_{ij} = (\tilde{a}_{ij}^l, \tilde{a}_{ij}^m, \tilde{a}_{ij}^n, \tilde{a}_{ij}^u)$, the matching crisp value a_{ij} can be obtained by

$$a_{ij} = \frac{\tilde{a}_{ij}^l + 2(\tilde{a}_{ij}^m + \tilde{a}_{ij}^n) + \tilde{a}_{ij}^u}{6} \tag{4}$$

where $a_{ii} = 1$, $a_{ji} = 1/a_{ij}$. Consequently, all the aggregated fuzzy scales $\tilde{a}_{ij}$ ($\forall i,j \in \{0,1,...,n\}$) are transferred into crisp scales a_{ij} within the range of [0,9].

Step 6: Calculate the priority weights of factors. Let $F_1, F_2, ..., F_n$ be a set of factors in one section, and a_{ij} is the defuzzified scale representing the quantified judgment on F_i compared to F_j. Pair-wise comparison between F_i and F_j in the same section thus yields an n-by-n matrix defined as

$$A = \begin{array}{c} \begin{array}{cccc} F_1 & F_2 & ... & F_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & ... & a_{1n} \\ \frac{1}{a_{12}} & 1 & ... & a_{2n} \\ ... & ... & ... & ... \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & ... & 1 \end{bmatrix} \end{array}, \quad \forall i,j \in \{1,2,...,n\} \tag{5}$$

where $a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}$. The priority weights of factors in the matrix A can be calculated by using the arithmetic averaging method

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad \forall i,j \in \{1,2,...,n\} \tag{6}$$

where w_i is the section weight of F_i. Assume F_i has t upper sections at different levels in the hierarchy, and $w_{\text{sec}tion}^{(i)}$ is the section weight of the i^{th} upper section that contains F_i in the hierarchy. The final weight w_i' of F_i can be derived by

$$W_i' = w_i \times \prod_{i=1}^{t} w_{\text{section}}^{(i)} \tag{7}$$

All individual upper-section weights of $w_{section}^{(i)}$ can also be derived by equation (6) to prioritize sections within the corresponding cluster in the hierarchy.

Step 7: Calculate final fuzzy scores. When the scores and the priority weights of factors are obtained, the final fuzzy scores are

$$(\tilde{F}S) = \sum_{i=1}^{n} \tilde{S}_i W_i^{'}, \quad i = 1, 2, ..., n \tag{8}$$

Step 8: Change format of trapezoidal final fuzzy scores from $\tilde{F}S = (a^l, a^m, a^n, a^u)$ to converted fuzzy score as $\tilde{F}S^c = (x_0, y_0, \sigma, \beta)$ with two defuzzifiers x_0, y_0, left fuzziness $\sigma > 0$, and right fuzziness $\beta > 0$. The membership function is

$$u(x) = \begin{cases} \frac{1}{\sigma}(x - x_0 + \sigma), & x_0 - \sigma \le x \le x_0 \\ 1, & x \in [x_0, y_0] \\ \frac{1}{\beta}(y_0 - x + \beta), & y_0 \le x \le y_0 + \beta \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

where $x_0 = a^m, y_0 = a^n, \sigma = a^m - a^l$ and $\beta = a^u - a^n$.

Step 9: Compare the ($\tilde{F}S^c$) values using an outranking method. In this paper a method proposed by Abbasbandy and Hajjari [37] is used to rank the converted final fuzzy scores. This method works as follows: For an arbitrary trapezoidal fuzzy number $u = (x_0, y_0, \sigma, \beta)$, with parametric form $u = (\underline{u}(r), \overline{u}(r))$, the *magnitude* of the trapezoidal fuzzy number u is

$$Mag(u) = \frac{1}{2}\left(\int_0^1 (\underline{u}(r) + \overline{u}(r) + x_0 + y_0) f(r) dr \right) \tag{10}$$

where $\underline{u}(r) = x_0 - \sigma + \sigma r, \ \overline{u}(r) = y_0 + \beta - \beta r$, and the function $f(r)$ is non-negative and increasing function on [0, 1] with $f(0) = 1$ and $\int_0^1 f(r)dr = \frac{1}{2}.$ In actual applications, function $f(r)$ can be chosen according to the actual situation. In this paper, it is chosen as $f(r) = r$. $Mag(u)$ is used to rank fuzzy numbers. As $Mag(u)$ increases, the fuzzy number increase as well. Therefore, for any two trapezoidal fuzzy numbers u and $v \in \mathrm{E}$ (where E stands for set of fuzzy numbers) is defined to rank *u* and *v* by the *Mag(.)* as follows:

$$Mag(u) > Mag(v) \text{ if and only if } u \succ v,$$
$$Mag(u) < Mag(v) \text{ if and only if } u \prec v,$$
$$Mag(u) = Mag(v) \text{ if and only if } u \sim v.$$

5. Conclusions and Discussions

Crop type selection is an important and strategic decision since it has some various conflicting criteria, which are labeled under three categories (aspects): economic, environmental, and social impacts. In this paper, we have collected a wide range of criteria for selection of biomass crop type and developed a decision-making tool under a fuzzy environment for policy makers. This tool can be used for biomass crop-type selection, which is a MCDM problem, in any region or a country. This unique study determines economic, environmental, and social aspects along with the criteria needed in decision making for crop-type selection, and it is also designed to provide the relative importance of each criteria.

In the future, we will apply the proposed decision making model in this paper as a case study in the state of Kansas. Application will be conducted by interviewing experts to make pair-wise comparisons in order to define weights of each criteria and rank the alternatives. Further studies regarding the analysis of the criteria are needed to utilize the most significant criteria. The most relevant criteria can be obtained by utilizing a structure detection method, such as

Factor Analysis. The solution of the AHP method can also be compared with another MCDM method to obtain more insights regarding the biomass crop type selection.

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