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RESEARCH PAPER

Multi-Objective Rough Best-Worst Method to Evaluate Sustainability of a Biofuel Energy Supply Chain

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ABSTRACT
The role of sustainability dimensions in the value creation process has received much attention. Adopting a proper set of key performance indicators leads to accurate calculation of chain value. This paper focuses on the dimensions of sustainability in the biofuel supply chain and seeks to evaluate the value in the chain. First, the importance of biofuels and its various types are discussed. Then, a new model is presented by designing the proposed energy chain and considering its sustainability dimensions and indicators in uncertain environment. Rough set theory is one of the best mathematical tools for dealing with uncertainty. The proposed biofuel energy supply chain is modeled to obtain the total value of the system considering sustainability indicators and layers of the supply chain. A multi-objective rough mathematical formulation is presented and solved. Best-worst method was integrated to determine the significance score of sustainability indicators. Finally, the model of the rough linear mathematical program is solved with optimization tools and the sustainable value of the chain is obtained.

KEYWORDS: *Biofuel supply chain; Multiple objective decision making; Rough set.*

1. Introduction

Energy supply has always been a challenge for human beings. On the other hand, one of the concerns of human society is to provide a suitable environment for a healthy life in order to enjoy material well-being and peace of mind. In addition to paying attention to the environment, paying attention to economic development and social progress creates a single concept called sustainability. This concept explains the human behavior towards the provision and use of resources on the planet, while not endangering its status and respecting the needs of future resources and provides them with the opportunity to use these resources. Today, human beings seek to replace the resources they have used for years; Resources that are less harmful to the environment, easier to obtain and less expensive to use. For this reason, human beings have resorted to the use of new or renewable energies. It is also important to consider how these resources are converted into energy for a variety of uses. Currently, renewable energy and sustainable supply chain play an important role in the global energy industry. Biofuels include a wide range of fuels which are derived from biomass [1]. We currently have four generations of biofuels. First generation biofuels designate ethanol and biodiesel generated from food crops. Second, third and fourth generation biofuels are defined as liquid fuels from nonfood sustainably grown feedstock and agricultural wastes. Biofuels have been investigated as alternative resources to resolve the demanding consumption of conventional fossil fuels, to minimize the economic and environmental impact, and to secure the sustainability for decades. Usage of biofuel will allow a balance to be sought between social, economic and environmental developments in the future [2].

Research background studies in this paper are conducted from the perspective of biofuel supply chain. In the [3] study, biofuel production technology was studied and the biofuel supply chain is drawn based on the method of biofuel production according to economic and environmental factors and the social dimension is not mentioned and the mathematical model lacks

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uncertainty. In the [4] research, a model for optimizing the 4th generation biofuel supply chain network is presented. In the article, the dimensions of sustainability are mentioned but not included in the model. The mathematical model has uncertainties but the value of the chain is not calculated. In the [5] research, a biofuel supply chain with two economic and environmental criteria is presented and, like many studies, the social criterion is ignored. The research [6] presents a biofuel supply chain model that achieves environmental, economic and social potential and provides the share of this chain in GDP but the value of the chain is not calculated.

According to the studies that are summarized in Table 1 below, no research has been done in the field of biofuel supply chain modeling based on the dimensions of sustainability and their indicators to obtain the value of the chain due to the uncertainty of rough. Therefore, research gaps in this field can be classified as follows: Lack of explanation of indicators for each dimension of sustainability with respect to sustainable goals, no use of sustainable goal rates for calculating chain value, no use of rough tools to deal with problem uncertainty, no use of mathematical model to calculate chain value.

Tab. 1. A summary of related works

	Description						
	Model type		Sustainability				
Research	quantitative	qualitatively	environmental	economic	social	uncertainty	value evaluate
[7]		✓	✓	✓	✓	✓	
[8]		✓				✓	
[9]		✓	✓				
[10]		✓	✓	✓	✓	✓	
[11]	✓					✓	
[12]		✓	✓	✓	✓	✓	
[13]		✓			✓		
[14]	✓		✓	✓		✓	
[15]	✓		✓	✓	✓	✓	
[16]		✓	✓	✓	✓		
[6]	✓		✓	✓	✓	✓	
[5]	✓		✓	✓		✓	✓
[4]	✓					✓	✓
[3]	✓		✓	✓			

This paper introduces a three-layer energy supply chain; it is important to note that each of these layers separately focuses on the dimensions of sustainability with respect to their characteristics. According to the three dimensions of sustainability, we are faced with a multi-objective model that calculates the sustainable value for each indicator in each dimensions of the layer of the supply chain. According to the obtained values and also according to the interactions of the supply chain layers, we introduce the uncertainty with Rough method, which can be used to calculate the sustainable value of the whole chain in uncertain condition.

2. Method

2.1. Problem definition

The biofuel supply chain introduced in this paper consists of three basic layer including raw materials (biomass) and its suppliers, bio-refinery and customer. The proposed supply chain is depicted in Figure 1.

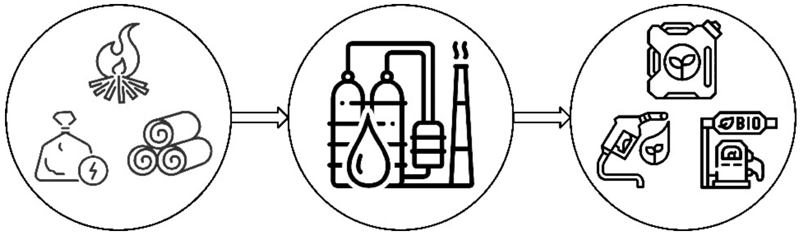

Fig. 1. Proposed supply chain

2.1.1. Raw material: non-food crops (second generation)

Nonfood crops compose the second-generation biofuels including food wastes, wood and agricultural wastes and cooking oil residue [17]. Second-generation biofuel is organized from remainders of food crops and their byproducts [18]. The processes of biofuel production are expensive becoming bottlenecks of the second-generation production in large volume [19]. On the other hand, research and development potential of the second-generation biofuel promising a glorious future source of energy [20].

2.1.2. Bio-refinery: second generation

A bio-refinery can be defined as an industrial facility that converts biomass and other biological raw materials into products that can be used in conversion industries such as chemical resources, biofuels, energy (heat and power). Second-generation bio-refineries mainly include the lignocellulosic biomass as their feedstock.

2.1.3. Customer

The customer in this paper is defined by two perspectives. The first view is based on the business-to-business (B2B) model, which represents customer such as hotels, restaurants, factories, and corporate customer in general. The next view is based on the (B2C) model, in which customers use biofuels directly. One of the most important applications of biofuels is to be used as an alternative to gasoline and as a fuel used in cars. The scope of use of biofuels is very wide and includes various cases that show the importance of this type of fuel in the world.

2.2. Sustainability

2.2.1. Sustainability indicators

In this section, for each dimension of sustainability, a set of key performance indicators in the value creation process is identified and presented in tables 2 to 4 for each layer of the proposed biofuel supply chain.

Tab. 2. First layer

First Layer: raw material		
environmental	economic	social
Greenhouse, CO_2 emissions	Capacity to create sustainable growth	Food security
Soil quality (erosion, acidification, degradation)	To generate income and employment	Average time spent on volunteering
land use change	Return on investment related to environmental protection	Equal opportunities
Water use and quality (availability and productivity)	Rate of investment in environmental technology	Social initiative at national and local level
Biodiversity	Gross margin ratio growth	Farm workers
Availability of marginal lands	Effective use of resources	Healthy living and working conditions

Tab. 3. Second Layer

Second Layer: bio-refinery		
environmental	economic	social
Renewable resource rates	Increase the flexibility of processes related to the raw materials used	Encourage employees to embrace cultural change
Efficiency material use rates	Reduce energy intensity	Improving the quality of working conditions
Direct or indirect GHG emission rates	Improve overall productivity and process reliability	health and job safety
Waste reduction rate	Income spent	The rate of social innovation
Recycled material used rate	Dedicated energy production costs	Investor satisfaction
-	Total investment	Employee satisfaction rate

Tab. 4. Third layer

Third Layer: Customer		
environmental	economic	social
Air quality and pollution	Annual energy cost of urban and rural households	Biofuel Support (Advanced)
Reduce the concentration of the ozone layer	Fuel price fluctuations	Advanced biofuel policy support status
global warming	Energy efficiency	Customer satisfaction
Living environment	-	human health
-	-	next generations
-	-	social responsibility

A generic sustainability dimensions are depicted in Figure 2.

Fig. 2. Sustainable dimensions

2.2.2. Sustainable goal rate (SGR)

In the following, the rate of sustainability goals of the indicators introduced in the last section has been evaluated according to the opinion of experts and reports of global organizations [2]. The population size of experts was 45 from renewable energy specialists and researchers. The results are shown in table 5 to 7 for the corresponding layer, respectively.

In defining goals and sets of indicators, maintaining strategic coherence between the elements is important. Strategic goals of three dimensions of sustainability interact with each other: for example, achieving employee satisfaction and respect for improving the quality of working conditions leads to improved production processes, and this achieves goals related to the economic dimension such as improving overall productivity and process reliability. At the same time, achieving environmental goals is strategically linked to the economic dimension.

Tab. 5. SGR for the first layer (raw material)

$I_{EN\,11}$	88%	$I_{EC\,11}$	80%	$I_{SO\,11}$	100%
$I_{EN\,12}$	100%	$I_{EC\,12}$	100%	$I_{SO\,12}$	40%
$I_{EN\,13}$	100%	$I_{EC\,13}$	100%	$I_{SO\,13}$	73%
$I_{EN\,14}$	100%	$I_{EC\,14}$	85%	$I_{SO\,14}$	56%
$I_{EN\,15}$	96%	$I_{EC\,15}$	81%	$I_{SO\,15}$	90%
$I_{EN\,16}$	79%	$I_{EC\,16}$	78%	$I_{SO\,16}$	100%

Tab. 6. SGR for the second layer (bio-refinery)

$I_{EN\,21}$	100%	$I_{EC\,21}$	92%	$I_{SO\,21}$	76%
$I_{EN\,22}$	100%	$I_{EC\,22}$	100%	$I_{SO\,22}$	91%
$I_{EN\,23}$	72%	$I_{EC\,23}$	90%	$I_{SO\,23}$	100%
$I_{EN\,24}$	64%	$I_{EC\,24}$	60%	$I_{SO\,24}$	65%
$I_{EN\,25}$	64%	$I_{EC\,25}$	88%	$I_{SO\,25}$	60%
$I_{EN\,26}$	-	$I_{EC\,26}$	100%	$I_{SO\,26}$	44%

Tab. 7. SGR for the third layer (customer)

$I_{EN\,31}$	100%	$I_{EC\,31}$	100%	$I_{SO\,31}$	100%
$I_{EN\,32}$	80%	$I_{EC\,32}$	90%	$I_{SO\,32}$	95%
$I_{EN\,33}$	84%	$I_{EC\,33}$	74%	$I_{SO\,33}$	40%
$I_{EN\,34}$	98%	$I_{EC\,34}$	-	$I_{SO\,34}$	100%
$I_{EN\,35}$	-	$I_{EC\,35}$	-	$I_{SO\,35}$	99%
$I_{EN\,36}$	-	$I_{EC\,36}$	-	$I_{SO\,36}$	100%

Sustainability goals have been introduced with the aim of evaluation in the literature of mathematical models for optimization, measurement and evaluation. Due to the uncertainty and dimensions of sustainability, all three objective functions should be considered simultaneously. To calculate the sustainable value, we need the weight of the indicators, so each sustainability index has a different weight that is evaluated by experts. The best-worst rough method is used to obtain the weight of sustainability indicators due to the uncertainty of the model. By combining sustainability goals in the weight of their own sustainability indicators, the value of sustainability indicators is obtained. By placing the value of the sustainability indices in the multi-objective mathematical model, the final value of the chain is calculated using the rough weighted linear method.

2.3. Assumptions

The following assumptions are used in this model:

- Availability of Sustainable Goal Rate (SGR)
- Biofuel renewable energy supply chain
- Three-Layer Supply chain
- Rough Uncertainty

2.4. Notations

The following notations (Table 8) are employed in modeling the proposed problem:

Tab. 8. Notations

i	Index for Layers; $i = 1, 2, 3$
j	Index for Sustainability Dimension; $j = 1, 2, 3$
k	Index for Sustainable Goals; $k = 1, 2, ..., m$
$\underline{a}$	Lower Approximation of Rough Number in First layer
$\overline{b}$	Upper Approximation of Rough Number in First layer
$\underline{c}$	Lower Approximation of Rough Number in Second layer
$\overline{d}$	Upper Approximation of Rough Number in Second layer
$\underline{e}$	Lower Approximation of Rough Number in Third layer
$\overline{f}$	Upper Approximation of Rough Number in Third layer
c	Cost
B	Budget
x	Decision Variable which is the sustainability dimension based on the sustainable goals

3. Mathematical Model

3.1. Rough number

Rough set theory [21] is a suitable method to handle uncertainty which was first introduced by Pawlak.

Consider U as a universe including all objects and X is a random object from U . There certainly exist a set with k levels showing decision maker's preferences, $Ro = (J_1, J_2, ..., J_k)$, with condition $J_1 < J_2 < ... < J_k$. Then, $\forall X \in U, J_q \in R, 1 \le q \le k$ lower approximation $\underline{Apro}(J_q)$, upper approximation $\overline{Apro}(J_q)$ and boundary interval $Bndr(J_q)$ are determined, respectively, as follows:

$$\underline{Apro}(J_q)=\cup\{X\in U/Ro(X)\le J_q\} \quad (1) \qquad \overline{Apro}(J_q)=\cup\{X\in U/Ro(X)\ge J_q\} \quad (2)$$

$$Bndr(J_q)=\cup\{X\in U/Ro(X)\ne J_q\}=\{X\in U/Ro(X)<J_q\}\cup\{X\in U/Ro(X)>J_q\} \quad (3)$$

The object can be presented with rough number (RoN) defined with lower limit $\underline{Lim}(J_q)$ and upper limit $\overline{Lim}(J_q)$, respectively:

$$\underline{Lim}(J_q)=\frac{1}{M_L}\sum Ro(X)\,|\,X\in\underline{Apro}(J_q) \quad (4)$$

$$\overline{Lim}(J_q)=\frac{1}{M_U}\sum Ro(X)\,|\,X\in\overline{Apro}(J_q) \quad (5)$$

where M_L and M_U show the sum of objects in the lower and upper object approximation of J_q, respectively. For object J_q, rough boundary interval $IRBnd(J_q)$ presents an interval between the lower and the upper limits as:

$$IRBnd(J_q)=\overline{Lim}(J_q)-\underline{Lim}(J_q) \quad (6)$$

The rough boundary interval presents measure of uncertainty. The bigger $IRBnd(J_q)$ value represents the differentiation of experts' preferences, while smaller values represent the harmonized opinions of experts without major deviations. In $IRBnd(J_q)$ are comprised all the objects between lower limit $\underline{Lim}(J_q)$ and upper limit $\overline{Lim}(J_q)$ of rough number $RN(J_q)$. That means that $RN(J_q)$ can be presented using $\underline{Lim}(J_q)$ and $\overline{Lim}(J_q)$.

$$RoN(J_q)=[\underline{Lim}(J_q),\overline{Lim}(J_q)] \quad (7)$$

3.1.1. Operation with rough number

Operation of two rough numbers $RoN(\alpha)=[\underline{Lim}(\alpha),\overline{Lim}(\alpha)]$ and $RoN(\beta)=[\underline{Lim}(\beta),\overline{Lim}(\beta)]$ according to (Zhai et al., 2009) are:

Addition $(+)$ of two rough numbers (α) and (β)

$$RoN(\alpha)+RoN(\beta)=\left[\underline{Lim}(\alpha)+\underline{Lim}(\beta),\overline{Lim}(\alpha)+\overline{Lim}(\beta)\right] \quad (8)$$

Subtraction $(-)$ of two rough numbers (α) and (β)

$$RoN(\alpha)-RoN(\beta)=\left[\underline{Lim}(\alpha)-\underline{Lim}(\beta),\overline{Lim}(\alpha)-\overline{Lim}(\beta)\right] \quad (9)$$

Multiplication $(\times)$ of two rough numbers (α) and (β)

$$RoN(\alpha)\times RoN(\beta)=\left[\underline{Lim}(\alpha)\times\underline{Lim}(\beta),\overline{Lim}(\alpha)\times\overline{Lim}(\beta)\right] \quad (10)$$

Division $(\div)$ of two rough numbers (α) and (β)

$$RoN(\alpha)\div RoN(\beta)=\left[\underline{Lim}(\alpha)\div\underline{Lim}(\beta),\overline{Lim}(\alpha)\div\overline{Lim}(\beta)\right] \quad (11)$$

Scalar multiplication of rough number $RN(\alpha)$, where μ is a nonzero constant

$$\mu\times RoN(\alpha)=\left[\mu\times\underline{Lim}(\alpha),\mu\times\overline{Lim}(\alpha)\right] \quad (12)$$

3.2. Multi attribute rough decision making (MARDM): rough best-worst method

According to the [22] BWM is an easy-to-understand and easy-to-apply MCDM method. Straightly, the steps of BWM follow here:

Step 1. Determine the criteria including m decision makers and a set of evaluation criteria $C=\{c_1,c_2,...,c_n\}$, where n is the number of criteria.

Step 2. Determine the most and least significance criteria.

Step 3. Determine the preference analysis on the most significance criteria (determine the degree of significance for the best criteria). The preference of criteria against each other is shown by $a_{Bj}^e\ (j=1,2,...,n;1\le e\le m)$ being in interval $a_{Bj}^e\in[1,9]$ determining the Best-to-Others (BO) vector as follows:

$$A_B^e=(a_{B1}^e,a_{B2}^e,\ldots,a_{Bn}^e);1\le e\le m \quad (13)$$

where a_{Bj}^{e} shows the influence (preference) of the best criterion B over criterion j, whereby

$a_{BB}^{e}=1$. This is how we obtain BO matrices $A_B^1, A_B^2, ..., A_B^m$ for each expert.

Step 4. Repeat Step 3 for the worst criterion and call the preference value as a_{jW}^{e}, $(j=1,2,...,n;1\le e\le m)$ being in interval $a_{jW}^{e}\in[1,9]$. As a result, an Others-to-Worst (OW) vector is obtained:

$$A_W^e=(a_{1W}^e, a_{2W}^e, ..., a_{nW}^e);1\le e\le m \quad (14)$$

where a_{jW}^{e} represents the influence (preference) of criterion j in relation to criterion W, whereby $a_{WW}^{e}=1$. This is how we obtain OW matrices $A_W^1, A_W^2, ..., A_W^m$ for each expert.

Step 5. Determine the rough BO matrix by computing the average value of all experts' answers leading to form the aggregated sequence matrix:

$$A_B^{*e}=[a_{B1}^m, a_{B2}^m, ..., a_{B1}^k; a_{B2}^1, a_{B2}^2, ..., a_{B2}^m; ...; a_{Bn}^1, a_{Bn}^2, ..., a_{Bn}^m]_{1\times n} \quad (15)$$

where $a_{Bj}^{e}=\{a_{Bj}^1, a_{Bj}^2, ..., a_{Bn}^n\}$ shows sequences of preferences for B criterion. By (1)-(6), the a_{Bj}^{e} is changed into a rough form $RoN(a_{Bj}^e)=[\overline{Lim}(a_{Bj}^e), \underline{Lim}(a_{Bj}^e)]$, where $\underline{Lim}(a_{Bj}^e)$ represents the lower limit and $\overline{Lim}(a_{Bj}^e)$ represents upper limit of the rough sequence $RoN(a_{Bj}^e)$.

Thus, for sequence $RoN(a_{Bj}^e)$, a BO matrix $A_B^{*1}, A_B^{*2}, ..., A_B^{*m}$ is obtained. Also, the average rough sequence for BO matrix is computed using (16) as follows:

$$RN(\bar{a}_{Bj})=RN(a_{Bj}^1, a_{Bj}^2, ..., a_{Bj}^e)=\begin{cases}\bar{a}_{Bj}^{L}=\frac{1}{m}\sum_{e=1}^{m}a_{Bj}^{eL}\\ \bar{a}_{Bj}^{U}=\frac{1}{m}\sum_{e=1}^{m}a_{Bj}^{eU}\end{cases} \quad (16)$$

where, e is the $e-th$ expert $(e=1,2,...,m)$, $RoN(a_{Bj}^e)$ is the rough sequences. Then, the average rough BO is obtained as follows:

$$\bar{A}_B=[\bar{a}_{B1}, \bar{a}_{B2}, ..., \bar{a}_{Bn}]_{1\times n} \quad (17)$$

Step 6. Determine the rough WO matrix being the average answers of all experts:

$$A_W^{e*}=[a_{1W}^1, a_{1W}^2, ..., a_{1W}^m; a_{2W}^1, a_{2W}^2, ..., a_{2W}^m; ...; a_{nW}^1, a_{nW}^2, ..., a_{nW}^m]_{1\times n} \quad (18)$$

where $a_{jW}^{e}=\{a_{jW}^1, a_{jW}^2, ..., a_{nW}^m\}$ represents the sequence with which the relative significance of criterion j is described in relation to criterion W. As in Step 5, using Equations (1)-(6), the rough sequences $RoN(a_{jW}^e)=[\overline{Lim}(a_{jW}^e), \underline{Lim}(a_{jW}^e)]$ is in hand and then the averaged OW matrix is formed using experts e, $(1\le e\le m)$ opinions:

$$RoN(\bar{a}_{jW})=RoN(a_{jW}^1, a_{jW}^2, ..., a_{jW}^e)=\begin{cases}\bar{a}_{jW}^{L}=\frac{1}{m}\sum_{e=1}^{m}a_{jW}^{eL}\\ \bar{a}_{jW}^{U}=\frac{1}{m}\sum_{e=1}^{m}a_{jW}^{eU}\end{cases} \quad (19)$$

$RoN(a_{jW})$ is the rough sequences and the averaged OW matrix is:

$$\bar{A}_W=[\bar{a}_{1W}, \bar{a}_{2W}, ..., \bar{a}_{nW}]_{1\times n} \quad (20)$$

Step 7. Calculation of the optimal rough values of the weight coefficients of the criteria $[RoN(W_1), RoN(w_2), ..., RoN(w_n)]$ from set C being the difference in the maximum absolute values (21):

$$\left|\frac{RoN(w_B)}{RoN(w_j)}-RoN(a_{Bj})\right| and \left|\frac{RoN(w_j)}{RoN(w_W)}-RoN(a_{jW})\right| \quad (21)$$

for each value of j is minimized. This occurs when $\sum_{j=1}^{n}w_j^L\le 1$ and $\sum_{j=1}^{n}w_j^U\ge 1$. In this way, the condition is met that the weight coefficients are found at interval $w_j \in [0,1]$, $(j = 1,2,...,n)$ that $\sum_{j=1}^{n} w_j = 1$.

The previously defined limits will be presented in the following min-max model:

$$\min_j \max \left\{ \left| \frac{RoN(w_B)}{RoN(w_j)} - RoN(a_{Bj}) \right|, \left| \frac{RoN(w_j)}{RoN(w_W)} - RoN(a_{jW}) \right| \right\}$$

$$s.t. \begin{cases} \sum_{j=1}^{n} w_j^L \le 1 \\ \sum_{j=1}^{n} w_j^U \ge 1 \\ w_j^L \le w_j^U, \forall j = 1,2,...,n \\ w_j^L, w_j^U \ge 0, \forall j = 1,2,...,n \end{cases} \quad (22)$$

where $RoN(w_j) = [\underline{Lim}(w_j), \overline{Lim}(w_j)] = [w_j^L, w_j^U]$ is the rough weight coefficient of a criterion. The counterpart of Model (22) is the following model:

$$\min \xi$$

$$s.t. \begin{cases} \left| \frac{w_B^L}{w_j^U} - \overline{a}_{Bj}^U \right| \le \zeta ; \left| \frac{w_B^U}{w_j^L} - \overline{a}_{Bj}^L \right| \le \zeta \\ \left| \frac{w_j^L}{w_W^U} - \overline{a}_{jW}^U \right| \le \zeta ; \left| \frac{w_j^U}{w_W^L} - \overline{a}_{jW}^L \right| \le \zeta \\ \sum_{j=1}^{n} w_j^L \le 1 \\ \sum_{j=1}^{n} w_j^U \ge 1 \\ w_j^L \le w_j^U, \forall j = 1,2,...,n \\ w_j^L, w_j^U \ge 0, \forall j = 1,2,...,n \end{cases} \quad (23)$$

where $RoN(w_j) = [w_j^L, w_j^U]$ represents the optimum values of the weight coefficients, $RoN(w_B) = [w_B^L, w_B^U]$ and $RoN(w_W) = [w_W^L, w_W^U]$ represents the weight coefficients of the best and worst criterion respectively, while $RoN(\overline{a}_{jW}) = [\overline{a}_{jW}^L, \overline{a}_{jW}^U]$ and $RoN(\overline{a}_{Bj}) = [\overline{a}_{Bj}^L, \overline{a}_{Bj}^U]$, respectively, represent the values from the average rough OW and rough BO matrices (see Equations (17) and (20)).

By solving model (23) we obtain the optimal values of the weight coefficients for the evaluation criteria $[RoN(w_1), RoN(w_2), ..., RoN(w_n)]$ and ξ^*.

3.3. Multi objective rough decision making (MORDM): linear weighted sum rough method (LWSRM)

In this paper, due to the uncertainty in the values obtained from the sustainability indicators, the objective function of the problem is of the rough type and a crisp feasible set is considered. Therefore, in the following model (8), problems with a crisp feasible set and rough objective function are introduced:

$$\begin{aligned} &\max(f_i) \\ &\sum_{j=1}^{n} \sum_{k=1}^{n} \left[\underline{a}_{jk}, \overline{b}_{jk} \right] x_{jk} \\ &\max(f_i) \\ &\sum_{j=1}^{n} \sum_{k=1}^{n} \left[\underline{c}_{jk}, \overline{d}_{jk} \right] x_{jk} \\ &\max(f_i) \\ &\sum_{j=1}^{n} \sum_{k=1}^{n} \left[\underline{e}_{jk}, \overline{f}_{jk} \right] x_{jk} \end{aligned} \quad (24)$$

Due to the nature of the problem for the proposed objective functions, the utility functions are defined as follows (Model 9):

$$\begin{aligned} &\max(U_{fi}) \\ &\sum_{j=1}^{n} \sum_{k=1}^{n} \left[\underline{a}_{jk}, \overline{b}_{jk} \right] x_{jk} \\ &\max(U_{fi}) \\ &\sum_{j=1}^{n} \sum_{k=1}^{n} \left[\underline{c}_{jk}, \overline{d}_{jk} \right] x_{jk} \\ &\max(U_{fi}) \\ &\sum_{j=1}^{n} \sum_{k=1}^{n} \left[\underline{e}_{jk}, \overline{f}_{jk} \right] x_{jk} \end{aligned} \quad (25)$$

Due to the existence of different indicators and their preferences over each other, the utility function has been used. Now the cost limit is added to the introduced model:

$$\begin{aligned}
&\max(U_{fi})\\
&\sum_{j=1}^{n}\sum_{k=1}^{n}\left[\underline{a}_{jk},\overline{b}_{jk}\right]c_{jk}x_{jk}\\
&s.t.\\
&\sum_{j=1}^{n}c_{jk}\le B_1 \quad \forall k=\{1,2,\dots,m\}\\
&x_{jk}\ge 0\\
&\max(U_{fi})\\
&\sum_{j=1}^{n}\sum_{k=1}^{n}\left[\underline{c}_{jk},\overline{d}_{jk}\right]c_{jk}x_{jk}\\
&s.t.\\
&\sum_{j=1}^{n}c_{jk}\le B_2 \quad \forall k=\{1,2,\dots,m\} \qquad (26)\\
&x_{jk}\ge 0\\
&\max(U_{fi})\\
&\sum_{j=1}^{n}\sum_{k=1}^{n}\left[\underline{e}_{jk},\overline{f}_{jk}\right]c_{jk}x_{jk}\\
&s.t.\\
&\sum_{j=1}^{n}c_{jk}\le B_3 \quad \forall k=\{1,2,\dots,m\}\\
&x_{jk}\ge 0
\end{aligned}$$

Model (10) is the final model introduced in this paper. In the next section, a numerical example is solved according to the model. Table 9 is compiled to better understand the formulated model:

Tab. 9. The position of the layers in the model

		u_{11}	Environmental dimension at the first layer		
First layer: raw material	f_1	u_{12}	Economic dimension at the first layer	U_{f1}	
		u_{13}	Social dimension at the first layer		
		u_{21}	Environmental dimension at the second layer		
Second layer: bio-refinery	f_2	u_{22}	Economic dimension at the second layer	U_{f2}	$U(F)$
		u_{23}	Social dimension at the second layer		
		u_{31}	Environmental dimension at the third layer		
Third layer: customer	f_3	u_{32}	Economic dimension at the third layer	U_{f3}	
		u_{33}	Social dimension at the third layer		

4. Numerical Example

To run the best-worst rough algorithm, experts first select the best and worst criteria in each dimension and then determine the vector (BO). In this section, for example, the weight of social dimension elements is determined from the third layer. It should be noted that the number of experts in the first layer is 5, in the second layer is 6 and in the third layer is 7 people.

The experts and specialists mentioned can be energy experts or managers of various companies or people who have worked in the field of key performance or sustainability indicators. They can be environmental activists, social science professors, or economists.

The vector (BO) becomes a matrix (BO) according to the nature of the problem. This matrix shows that preferences are the best criterion over other criteria by experts.

$$A_B^* = \begin{bmatrix} 3 & 3 & 3 & 4 & 4 & 4 & 3 \\ 7 & 7 & 6 & 7 & 6 & 7 & 7 \\ 8 & 9 & 9 & 9 & 9 & 9 & 9 \\ 2 & 3 & 2 & 2 & 2 & 3 & 2 \\ 5 & 5 & 5 & 6 & 6 & 6 & 6 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

After determining the matrix (BO), the experts also determine the matrix (OW). In this dimension, the best (most important) criterion is 6 and the worst (least important) criterion is 3. That is, in the third level of the chain, which is the customer layer, and in the third dimension, sustainability, which is the social dimension, the best and most important criterion is social responsibility and the worst and least important criterion is customer satisfaction.

$$A_W^* = \begin{bmatrix} 6 & 5 & 5 & 5 & 5 & 5 & 6 \\ 4 & 3 & 3 & 3 & 4 & 4 & 4 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 6 & 6 & 7 & 7 & 7 & 7 & 7 \\ 3 & 3 & 3 & 2 & 3 & 2 & 3 \\ 9 & 8 & 8 & 9 & 8 & 9 & 9 \end{bmatrix}$$

Then, using equations (1) to (6), the definitive evaluation of the experts in the (BO) and (WO) matrices is converted to rough numbers. For example, this operation is performed for criterion (1) in the vector (BO) below:

$$c_1 = \{3,3,3,4,4,4,3\}$$

$$\underline{Lim}(3) = 3, \overline{Lim}(3) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43$$

$$\underline{Lim}(3) = 3, \overline{Lim}(3) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43$$

$$\underline{Lim}(3) = 3, \overline{Lim}(3) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43$$

$$\underline{Lim}(4) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43, \overline{Lim}(4) = 4$$

$$\underline{Lim}(4) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43, \overline{Lim}(4) = 4$$

$$\underline{Lim}(4) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43, \overline{Lim}(4) = 4$$

$$\underline{Lim}(3) = 3, \overline{Lim}(3) = \frac{1}{7}(3+3+3+4+4+4+3) = 3.43$$

Then the upper limit and the lower limit of the whole vector are calculated:

$$\underline{c_1} = \frac{3+3+3+3.43+3.43+3.43+3}{7} = 3.18$$

$$\overline{c_1} = \frac{3.43+3.43+3.43+3+3+3+3.43}{7} = 3.67$$

Thus, the rough number of this vector is obtained as $[3.18, 3.67]$. This operation is performed for all criteria of this vector and vector (OW):

$$BO = \begin{Bmatrix} [3.18, 3, 67] \\ [6.51, 6.92] \\ [8.73, 8.98] \\ [2.08, 2.48] \\ [5.32, 5.81] \\ [1.00, 1.00] \end{Bmatrix}, OW = \begin{Bmatrix} [5.08, 5.48] \\ [3.32, 3.81] \\ [1.00, 1.00] \\ [6.51, 6.92] \\ [2.51, 2.92] \\ [8.32, 8.81] \end{Bmatrix}$$

After obtaining the weight coefficients of the criteria, the best-worst optimization model is solved, which is obtained by solving the optimal values of the weight coefficients of the criteria:

$$SO_3=\begin{Bmatrix} RoN(w_1)=[0.1542,0.2698] \\ RoN(w_2)=[0.0750,0.0925] \\ RoN(w_3)=[0.0430,0.0450] \\ RoN(w_4)=[0.2186,0.2260] \\ RoN(w_5)=[0.0602,0.1225] \\ RoN(w_6)=[0.4491,0.4491] \end{Bmatrix}$$

This is done for other sustainable dimensions at all layers of the chain, and the weight of the sustainable elements is obtained according to the best-worst rough method as follows:

$$EN_1=\begin{Bmatrix} RoN(w_1)=[0.3416,0.4024] \\ RoN(w_2)=[0.1779,0.2040] \\ RoN(w_3)=[0.0977,0.1440] \\ RoN(w_4)=[0.2560,0.2730] \\ RoN(w_5)=[0.0741,0.1013] \\ RoN(w_6)=[0.0530,0.0530] \end{Bmatrix}, EC_1=\begin{Bmatrix} RoN(w_1)=[0.2010,0.2132] \\ RoN(w_2)=[0.3922,0.4107] \\ RoN(w_3)=[0.1362,0.1546] \\ RoN(w_4)=[0.1623,0.1747] \\ RoN(w_5)=[0.0385,0.0385] \\ RoN(w_6)=[0.0699,0.0879] \end{Bmatrix}$$

$$SO_1=\begin{Bmatrix} RoN(w_1)=[0.4106,0.4242] \\ RoN(w_2)=[0.0394,0.0399] \\ RoN(w_3)=[0.1084,0.1196] \\ RoN(w_4)=[0.0443,0.0784] \\ RoN(w_5)=[0.1690,0.2863] \\ RoN(w_6)=[0.2281,0.2378] \end{Bmatrix}, EN_2=\begin{Bmatrix} RoN(w_1)=[0.3892,0.3892] \\ RoN(w_2)=[0.2244,0.2961] \\ RoN(w_3)=[0.1317,0.1455] \\ RoN(w_4)=[0.0677,0.1101] \\ RoN(w_5)=[0.0532,0.0590] \end{Bmatrix}$$

$$EC_2=\begin{Bmatrix} RoN(w_1)=[0.1440,0.1626] \\ RoN(w_2)=[0.2471,0.3006] \\ RoN(w_3)=[0.0678,0.1294] \\ RoN(w_4)=[0.0415,0.0421] \\ RoN(w_5)=[0.0751,0.0804] \\ RoN(w_6)=[0.4244,0.4390] \end{Bmatrix}, SO_2=\begin{Bmatrix} RoN(w_1)=[0.0433,0.0433] \\ RoN(w_2)=[0.2474,0.3801] \\ RoN(w_3)=[0.3948,0.4312] \\ RoN(w_4)=[0.0523,0.0533] \\ RoN(w_5)=[0.1733,0.1936] \\ RoN(w_6)=[0.0883,0.1090] \end{Bmatrix}$$

$$EN_3=\begin{Bmatrix} RoN(w_1)=[0.4567,0.4883] \\ RoN(w_2)=[0.2313,0.2670] \\ RoN(w_3)=[0.1359,0.1646] \\ RoN(w_4)=[0.0806,0.0823] \end{Bmatrix}, EC_3=\begin{Bmatrix} RoN(w_1)=[0.4512,0.4919] \\ RoN(w_2)=[0.3171,0.4251] \\ RoN(w_3)=[0.0830,0.0830] \end{Bmatrix}$$

After obtaining the rough weight coefficients, it is time to combine these coefficients with the relevant sustainable goals to determine the value of each element of the sustainable dimensions at each layer of the chain, for example the social dimension from the third layer according to Equations (8) to (12):

$$I_{EN2}=\begin{Bmatrix}1\\1\\0.72\\0.64\\0.64\end{Bmatrix}\times EN_2=\begin{Bmatrix}RoN(w_1)=[0.3892,0.3892]\\RoN(w_2)=[0.2244,0.2961]\\RoN(w_3)=[0.1317,0.1455]\\RoN(w_4)=[0.0677,0.1101]\\RoN(w_5)=[0.0532,0.0590]\end{Bmatrix}=IEN_2^*\begin{Bmatrix}[0.3892,0.3892]\\[0.2244,0.2961]\\[0.0949,0.1048]\\[0.0433,0.0705]\\[0.0340,0.0378]\end{Bmatrix}$$

We perform this operation for all elements in different layers:

$$IEN_1^*=\begin{Bmatrix}[0.3006,0.3541]\\[0.1779,0.2040]\\[0.0977,0.1440]\\[0.2560,0.2730]\\[0.0711,0.0972]\\[0.0419,0.0419]\end{Bmatrix},IEC_1^*=\begin{Bmatrix}[0.1608,0.1706]\\[0.3922,0.4107]\\[0.1362,0.1546]\\[0.1379,0.1485]\\[0.0312,0.0312]\\[0.0545,0.0.686]\end{Bmatrix}$$

$$ISO_1^*=\begin{Bmatrix}[0.4106,0.4242]\\[0.0157,0.0160]\\[0.0791,0.0873]\\[0.0242,0.0439]\\[0.1521,0.2577]\\[0.2281,0.2378]\end{Bmatrix},IEC_2^*=\begin{Bmatrix}[0.1325,0.1496]\\[0.2471,0.3006]\\[0.0610,0.1168]\\[0.0249,0.0253]\\[0.0660,0.0707]\\[0.4244,0.4390]\end{Bmatrix}$$

$$ISO_2^*=\begin{Bmatrix}[0.0330,0.0330]\\[0.2251,0.3459]\\[0.3948,0.4312]\\[0.0399,0.0346]\\[0.1039,0.1161]\\[0.0389,0.0479]\end{Bmatrix},IEN_3^*=\begin{Bmatrix}[0.4567,0.4883]\\[0.1850,0.2136]\\[0.1141,0.1382]\\[0.0789,0.0806]\end{Bmatrix}$$

$$IEC_3^*=\begin{Bmatrix}[0.4512,0.4919]\\[0.2854,0.3826]\\[0.0614,0.0614]\end{Bmatrix},ISO_3^*=\begin{Bmatrix}[0.1542,0.2698]\\[0.0712,0.0878]\\[0.0172,0.0180]\\[0.2186,0.2260]\\[0.0595,0.1213]\\[0.4491,0.4491]\end{Bmatrix}$$

4.1. Objective function

In this section, after obtaining the value of sustainable indicators in each dimension of the chain, the optimization model for each layer is formed as follows:

$$F_1=\begin{cases} f_1=[0.3006,0.3541]x_{11}+[0.1779,0.2040]x_{12}+[0.0977,0.1440]x_{13} \\ +[0.2560,0.2730]x_{14}+[0.0711,0.0972]x_{15}+[0.0419,0.0419]x_{16} \\ f_2=[0.1608,0.1706]x_{21}+[0.3922,0.4107]x_{22}+[0.1362,0.1546]x_{23} \\ +[0.1379,0.1485]x_{24}+[0.0312,0.0312]x_{25}+[0.0545,0.0.686]x_{26} \\ f_3=[0.4106,0.4242]x_{31}+[0.0157,0.0160]x_{32}+[0.0791,0.0873]x_{33} \\ +[0.0242,0.0439]x_{34}+[0.1521,0.2577]x_{35}+[0.2281,0.2378]x_{36} \end{cases}$$

For the second layer:

$$F_2=\begin{cases} f_1=[0.3892,0.3892]x_{11}+[0.2244,0.2961]x_{12}+[0.0949,0.1048]x_{13} \\ +[0.0433,0.0705]x_{14}+[0.0340,0.0378]x_{15} \\ f_2=[0.1325,0.1496]x_{21}+[0.2471,0.3006]x_{22}+[0.0610,0.1168]x_{23} \\ +[0.0249,0.0253]x_{24}+[0.0660,0.0707]x_{25}+[0.4244,0.4390]x_{26} \\ f_3=[0.0330,0.0330]x_{31}+[0.2251,0.3459]x_{32}+[0.3948,0.4312]x_{33} \\ +[0.0399,0.0346]x_{34}+[0.1039,0.1161]x_{35}+[0.0389,0.0479]x_{36} \end{cases}$$

For the third layer:

$$F_3\begin{cases} f_1=[0.4567,0.4883]x_{11}+[0.1850,0.2136]x_{12}+[0.1141,0.1382]x_{13} \\ +[0.0789,0.0806]x_{14} \\ f_2=[0.4512,0.4919]x_{21}+[0.2854,0.3826]x_{22}+[0.0614,0.0614]x_{23} \\ f_3=[0.1542,0.2698]x_{31}+[0.0712,0.0878]x_{32}+[0.0172,0.0180]x_{33} \\ +[0.2186,0.2260]x_{34}+[0.0595,0.1213]x_{35}+[0.4491,0.4491]x_{36} \end{cases}$$

According to the three layers of the supply chain, three objective functions are formed; each of these layers has its own sub-layers based on the dimensions of sustainability. Due to the nature of the problem and the purpose of the problem, which is to obtain the value of the chain, the above functions are transformed in to the form of the utility function and the model constraint, which is of cost type, is added to the model:

$$U_{f1}=\begin{cases} u_{11}=[0.3006,0.3541]x_{11}c_{11}+[0.1779,0.2040]x_{12}c_{12}+[0.0977,0.1440]x_{13}c_{13} \\ +[0.2560,0.2730]x_{14}c_{14}+[0.0711,0.0972]x_{15}c_{15}+[0.0419,0.0419]x_{16}c_{16} \\ u_{12}=[0.1608,0.1706]x_{21}c_{21}+[0.3922,0.4107]x_{22}c_{22}+[0.1362,0.1546]x_{23}c_{23} \\ +[0.1379,0.1485]x_{24}c_{24}+[0.0312,0.0312]x_{25}c_{25}+[0.0545,0.0.686]x_{26}c_{26} \\ u_{13}=[0.4106,0.4242]x_{31}c_{31}+[0.0157,0.0160]x_{32}c_{32}+[0.0791,0.0873]x_{33}c_{33} \\ +[0.0242,0.0439]x_{34}c_{34}+[0.1521,0.2577]x_{35}c_{35}+[0.2281,0.2378]x_{36}c_{36} \\ \sum_{j=1}^{n} c_{jk}\le B_1 \quad \forall k=\{1,2,...,m\} \end{cases}$$

For the second layer:

$$U_{f2}=\begin{cases}u_{21}=[0.3892,0.3892]x_{11}c_{11}+[0.2244,0.2961]x_{12}c_{12}+[0.0949,0.1048]x_{13}c_{13}\\+[0.0433,0.0705]x_{14}c_{14}+[0.0340,0.0378]x_{15}c_{15}\\u_{22}=[0.1325,0.1496]x_{21}c_{21}+[0.2471,0.3006]x_{22}c_{22}+[0.0610,0.1168]x_{23}c_{23}\\+[0.0249,0.0253]x_{24}c_{24}+[0.0660,0.0707]x_{25}c_{25}+[0.4244,0.4390]x_{26}c_{26}\\u_{23}=[0.0330,0.0330]x_{31}c_{31}+[0.2251,0.3459]x_{32}c_{32}+[0.3948,0.4312]x_{33}c_{33}\\+[0.0399,0.0346]x_{34}c_{34}+[0.1039,0.1161]x_{35}c_{35}+[0.0389,0.0479]x_{36}c_{36}\\\sum_{j=1}^{n}c_{jk}\le B_2\quad\forall k=\{1,2,...,m\}\end{cases}$$

For the third layer:

$$U_{f3}\begin{cases}u_{31}=[0.4567,0.4883]x_{11}c_{11}+[0.1850,0.2136]x_{12}c_{12}+[0.1141,0.1382]x_{13}c_{13}\\+[0.0789,0.0806]x_{14}c_{14}\\u_{32}=[0.4512,0.4919]x_{21}c_{21}+[0.2854,0.3826]x_{22}c_{22}+[0.0614,0.0614]x_{23}c_{23}\\u_{33}=[0.1542,0.2698]x_{31}c_{31}+[0.0712,0.0878]x_{32}c_{32}+[0.0172,0.0180]x_{33}c_{33}\\+[0.2186,0.2260]x_{34}c_{34}+[0.0595,0.1213]x_{35}c_{35}+[0.4491,0.4491]x_{36}c_{36}\\\sum_{j=1}^{n}c_{jk}\le B_3\quad\forall k=\{1,2,...,m\}\end{cases}$$

The following data (tables 10 to 12) specify the cost of selecting each indicator, which is expressed as a constraint in the problem model, based on each layer.

Tab. 10. Cost of Indicators in First Layer

First Layer: raw material					
environmental		economic		social	
3.5	c_{31}	2	c_{21}	3.5	c_{11}
1	c_{32}	3.5	c_{22}	2	c_{12}
1	c_{33}	1.5	c_{23}	1.5	c_{13}
1	c_{34}	2	c_{24}	2.5	c_{14}
3	c_{35}	1	c_{25}	1	c_{15}
2.5	c_{36}	1	c_{26}	1	c_{16}

Tab. 11. Cost of Indicators in Second Layer

Second Layer: bio-refinery					
environmental		economic		social	
1	c_{31}	1.5	c_{21}	4	c_{11}
3.5	c_{32}	3	c_{22}	3	c_{12}
4	c_{33}	1.5	c_{23}	1.5	c_{13}
1	c_{34}	1	c_{24}	1	c_{14}
2	c_{35}	1	c_{25}	1	c_{15}
1	c_{36}	4	c_{26}	-	-

Tab. 12. Cost of Indicators in Third Layer

Third Layer: customer					
environmental		economic		social	
2	c_{31}	4.5	c_{21}	4.5	c_{11}
1	c_{32}	4	c_{22}	2.5	c_{12}
1	c_{33}	1	c_{23}	1.5	c_{13}
2	c_{34}	-	-	1	c_{14}
1	c_{35}	-	-	-	-
4.5	c_{36}	-	-	-	-

5. Result and Discussion

The proposed model is solved by optimization software Lingo and the results are given in Table 13 below:

Tab. 13. Results

Preferences	Sustainability value
If the first layer is a priority	$[1.1985, 1.3308]$
If the second layer is a priority	$[1.6378, 1.6960]$
If the third layer is a priority	$[2.0320, 2.1011]$

There are three objectives and thus three preferences. It is shown that, according to the priority of the policy maker the sustainability value of the supply chain is differentiated. If it is on the biomass suppliers, then the sustainability value of the biofuel supply chain is approximately between 1.2 to 1.33 units. Further, the policy maker focuses on bio-refinery layer which requires much more investment then the sustainable value is approximately between 1.64 and 1.7 units. Therefore, it is depending on the policies that are set based on the budget and operational costs to decide which priority is optimal in various conditions.

On the other hand, the utility of the decision maker if effective on the outputs of the proposed model and accordingly influence the sustainable value of the proposed biofuel supply chain. If the utility function changes, then the formulations and transformation are changed that is common in multi-period decision making. In this case, the model is transformed to a dynamic one in rough environment.

6. Conclusions

This paper dealt with the design of a biofuel energy supply chain and development of a quantitative method for sustainability evaluation. The uncertainty of data is handled with a rough set theory being integrated with best-worst method to provide the significance of indicators of biofuel energy supply chain. The model was then extended to a multi-objective mathematical formulation and optimized using a utility-based optimization. The three layers of the proposed biofuel supply chain was considered as three different objectives that can be separately of simultaneously handled in decision making. The results showed an interval for each preference raised by the decision and policy makers. The effectiveness of the methodology for managerial policy making is completely based on the preferences and utilities of the decision makers. The policy maker can focus on biomass material supply requiring collection centers and services. While, considering bio-refinery centers needs substantial investment of equipment and devises. Also, customer-centric policy making is influenced by customer acceptance rate for development programs on the basis of biofuel energy supply chain. It has indicated that the approach is a useful decision support for strategists to analyze different dimensions of the biofuel energy supply chain sustainability evaluation.

References

[1] J. R. Ziolkowska, "Biofuels technologies: An overview of feedstocks, processes, and technologies," *Biofuels for a More Sustainable Future: Life Cycle Sustainability Assessment and Multi-Criteria Decision Making,* (2019), p. 1.

[2] A. Demırbas, "The social, economic, and environmental importance of biofuels in the future," *Energy Sources, Part B: Economics, Planning, and Policy,* Vol. 12, No. 1, (2017), pp. 47-55.

[3] Y. Li *et al.*, "Economic viability and environmental impact investigation for the biofuel supply chain using co-fermentation technology," *Applied Energy,* Vol. 259, (2020), p. 114235.

[4] M. Arabi, S. Yaghoubi, and J. Tajik, "Algal biofuel supply chain network design with variable demand under alternative fuel price uncertainty: A case study," *Computers & Chemical Engineering,* Vol. 130, (2019), p. 106528.

[5] R. Kesharwani, Z. Sun, C. Dagli, and H. Xiong, "Moving second generation biofuel manufacturing forward: Investigating economic viability and environmental sustainability considering two strategies for supply chain restructuring," *Applied energy,* Vol. 242, (2019), pp. 1467-1496.

[6] Y. K. Nugroho and L. Zhu, "Platforms planning and process optimization for biofuels supply chain," *Renewable energy,* Vol. 140, (2019), pp. 563-579.

[7] I. Awudu and J. Zhang, "Uncertainties and sustainability concepts in biofuel supply chain management: A review," *Renewable and Sustainable Energy Reviews,* Vol. 16, No. 2, (2012), pp. 1359-1368.

[8] B. Sharma, R. G. Ingalls, C. L. Jones, and A. Khanchi, "Biomass supply chain design and analysis: Basis, overview, modeling, challenges, and future," *Renewable and Sustainable Energy Reviews,* Vol. 24, (2013), pp. 608-627.

[9] T. M. Mata, N. S. Caetano, C. A. Costa, S. K. Sikdar, and A. A. Martins, "Sustainability analysis of biofuels through the supply chain using indicators," *Sustainable Energy Technologies and Assessments,* Vol. 3, (2013), pp. 53-60.

[10] D. Yue, F. You, and S. W. Snyder, "Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges," *Computers & Chemical Engineering,* Vol. 66, (2014), pp. 36-56.

[11] Y. Huang, Y. Fan, and C.-W. Chen, "An integrated biofuel supply chain to cope with feedstock seasonality and uncertainty," *Transportation Science,* Vol. 48, No. 4, (2014), pp. 540-554.

[12] G. G. Zaimes, N. Vora, S. S. Chopra, A. E. Landis, and V. Khanna, "Design of sustainable biofuel processes and supply chains: challenges and opportunities," *Processes,* Vol. 3, No. 3, (2015), pp. 634-663.

[13] M. Eskandarpour, P. Dejax, J. Miemczyk, and O. Péton, "Sustainable supply chain network design: An optimization-oriented review," *Omega,* Vol. 54, (2015), pp. 11-32.

[14] Ş. Y. Balaman and H. Selim, "Sustainable design of renewable energy supply chains integrated with district heating systems: A fuzzy optimization approach," *Journal of cleaner production,* Vol. 133, (2016), pp. 863-885.

[15] M. Fattahi and K. Govindan, "A multi-stage stochastic program for the sustainable design of biofuel supply chain networks under biomass supply uncertainty and disruption risk: A real-life case study," *Transportation Research Part E: Logistics and Transportation Review,* Vol. 118, (2018), pp. 534-567.

[16] C. H. d. O. Fontes and F. G. M. Freires, "Sustainable and renewable energy supply chain: A system dynamics overview," *Renewable and Sustainable Energy Reviews,* Vol. 82, (2018), pp. 247-259.

[17] E. A. Heaton *et al.*, "Managing a second generation crop portfolio through sustainable intensification: Examples from the USA and the EU," *Biofuels, Bioproducts and Biorefining,* Vol. 7, No. 6, (2013), pp. 702-714.

[18] S. Begum and Y. Dahman, "Enhanced biobutanol production using novel clostridial fusants in simultaneous saccharification and fermentation of green renewable agriculture residues," *Biofuels, Bioproducts and Biorefining,* Vol. 9, No. 5, (2015), pp. 529-544.

[19] R. E. Sims, W. Mabee, J. N. Saddler, and M. Taylor, "An overview of second generation biofuel technologies," *Bioresource technology,* Vol. 101, No. 6, (2010), pp. 1570-1580.

[20] V. Balan, "Current challenges in commercially producing biofuels from lignocellulosic biomass," *International Scholarly Research Notices,* Vol. 2014, (2014).

[21] Z. Pawlak, "Rough sets," *International journal of computer & information sciences,* Vol. 11, No. 5, (1982), pp. 341-356.

[22] J. Rezaei, "Best-worst multi-criteria decision-making method," *Omega,* Vol. 53, (2015), pp. 49-57.