

Biodiesel Supply Chain Network Design Under Hybrid Uncertainties: A Novel Multi-objective Robust Fuzzy Stochastic Approach

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Research Article

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Biodiesel supply chain network design under hybrid uncertainties: a novel multi-objective robust fuzzy stochastic approach

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Abstract

In the biofuel supply chain, there may be various and hybrid uncertainties that, if ignored, can lead to inefficient network design. In this study, a multi-objective robust fuzzy stochastic programming (MORFSP) model is proposed for designing biodiesel supply chain network (BSCN) under different and hybrid uncertainties. This model simultaneously minimizes total cost of the BSCN and total environmental impacts of activities of the network. Fixed costs and environmental impact of opening facilities are described as fuzzy variables. Demands, supplies, other costs and environmental impacts are considered as fuzzy scenario based variables. The proposed MORFSP model considers different risks, including possibilistic variability and scenario variability related to economic and environmental objective functions, and unsatisfied demand costs. This model is applied in a real case study to design a BSCN in Iran. Waste cooking oil (WCO), and some non-edible plants like *Salvia lerifolia* (SL) and *Jatropha Curcas L.* (JCL) are considered as sources of producing biodiesel. The proposed approach used for designing a four-echelon, multi-period, and multi-product, of BSCN. The results show the effectiveness of the proposed model for designing the BSCN under hybrid uncertainties.

Keywords: Bioenergy; Biodiesel; Sustainable development; Supply chain network design; Hybrid uncertainties; Multi-objective robust fuzzy stochastic programming

1-Introduction

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Sustainable development (SD) comprises a thorough and integrated way to the economic, social and environmentally functions (Karakosta and Askounis 2010). An SD approach seeks to provide services which meet basic human needs, in a cleaner and more efficient way that can be sustained in the future (Winkler 2007; Suganthi 2018). Nowadays, energy is undoubtedly crucial for sustainable development and the prosperity of a community (Chaharsooghi and Rezaei 2016; Tan et al. 2018). Increase of energy consumption causes some problems like depleting energy sources and creating pollution (Shakouri and Kazemi 2017). Increment in the energy efficiency of processes applying sustainable resources can very help in achieving sustainable development (Hepbasli 2010; Ulonska et al. 2018). There is a need to developing new energy resources to replace or reduce the use of nonrenewable energy resources (like natural gas, petroleum, coal, etc.) (Li et al. 2009; Ruiz et al. 2016; Rezaei et al. 2020a).

Renewable energies (REs) are considered as one of the potential solutions for climate change, energy security and sustainable growth (Huang et al. 2011; Swain and Karimu 2020). REs are produced applying harmless techniques that have less harmful impact on the environment in contrast to other kinds of energy (Chaharsooghi et al. 2015). So, renewable energy sources seem to be an effective solution for achieving sustainable development (Rezaei et al. 2013). Nowadays, developing RE is becoming a hot topic since it is crucial in dealing with energy supply issue and climate change issue (Cai et al. 2012; Salamanca et al. 2012).

Biomass is becoming among the most typically applied RE sources in the recent years. Biofuels are fuels produced from biomass sources that are commonly used for transportation (Mousavi Ahranjani et al. 2018). Bioethanol and biodiesel that include the most utilized liquid biofuels, are fine substitution for petrol and diesel, respectively (Babazadeh et al. 2017b). Biofuels can be used in existing engines with major modifications (Devarajan et al. 2017; Xu and Xu 2018).

While the biomass is fairly cheap, the logistic costs play main role in the price of the biomass delivered to the biorefinery (Steiner et al. 2012; Atashbar et al. 2016). Since numerous producers of biomass are involved in this supply chain, quantitative models can be beneficial to assess and optimize the related costs, the required resources, and the consumptions of energy (Ba et al. 2016).

Because of restriction of fossil fuel sources and their negative influences on environment, in recent years, there have been a lot of researches on designing biofuel supply chain. In designing the BSCN, the strategic decisions for instance the size, number, capacity and location of facilities, and the tactical decisions, like production quantity, mode of transportation, inventory, and transported product among various facilities are determined (An et al. 2011; Santibañez-Aguilar et al. 2016a).

In this article, multi-objective robust fuzzy stochastic programming model is presented for designing a BSCN under hybrid uncertainties. The main novelties of this study are summarized as follows:

- In this study, the different and hybrid uncertainties that exist in the real world in the biofuel supply chains are considered. So that some uncertain variables have fuzzy nature and some have fuzzy stochastic nature.

- According to the literature, fuzzy stochastic approach has not been used to model the biofuel supply chain. Due to the specific characteristics of the supply chain of these fuels and excising different and hybrid uncertainties related to this field, in this study, a robust fuzzy stochastic programming model is proposed for designing the supply chain.
- A multi-objective robust fuzzy stochastic programming model is presented for designing a BSCN under different and hybrid uncertainties that simultaneously minimizes the total cost of the BSCN and the total environmental impacts of the activities of the supply chain.
- This model considers the different risks in the network, such as possibilistic variability and scenario variability related to economic and environmental objective functions, and unsatisfied demand costs.
- Possibility of capacity expansion of facilities in different periods is considered.
- The presented model is applied in a real case study in Iran.

The Structure of this article is as follows:

In Section 2, the researches related to this work are described. In Section 3, the mathematical formulation which groups the main constraints and the objective functions is discussed. In Section 4, the proposed robust fuzzy stochastic programming approach is presented. A case study to examine the proposed approach is discussed in Section 5. Lastly, the final conclusions are stated in Section 6.

2- Literature review

There are different methodologies for designing biofuels supply chain in the literature, like mathematical programming models, simulation, and GIS (Bai et al. 2011). The mathematical programming models were the most applied method (Ghaderi et al. 2016).

In this section, researches most related to our work are reviewed.

In the most studies, deterministic mathematical programming models were applied to design the BSCN.

Camero et al (2015) developed a mixed integer linear programming (MILP) model to design a supply chain of forest residues. This model maximized the net present value of the supply chain over the horizon time. Ahn et al. (2015) presented a deterministic mathematical programming method for designing a BSCN which simultaneously considered resource, and demand constraints. This model helped for determining the location and the amount of feedstock, and the location and the size of refineries. Babazadeh et al. (2017c) proposed a method according to DEA approach and mathematical programming model for designing of BSCN. Firstly, locations for cultivating JCL were evaluated through unified DEA method based on some social and climatic criteria. Afterwards, the areas that had attained the desired scores were selected as candidate areas for cultivating JCL and by a MILP model the BSCN model is designed.

One of the challenges in designing the BSCN is existence of different uncertainties, including, biomass demand, supply, price, etc. (Bairamzadeh et al. 2018a). There are various approaches in the literature to dealing with uncertainty:

Some studies have used stochastic planning approach. For example, Giarola et al. (2011) proposed a two-stage stochastic mixed integer programming model to design a biofuel supply chain in the southeastern United States, in which biofuel supply, demand, price and technology are varied in different scenarios. Marufuzzaman et al. (2014) developed a stochastic programming method to design a BSCN under technology development and biomass supply uncertainties. They developed a MOMILP model that optimized costs and emissions of the network.

Fuzzy programming is another widely used approach in dealing with uncertainties. Tong et al. (2014a) presented a linear integer programming model to design a biofuel supply chain. To deal with the uncertainty of the parameters, they have used the fuzzy programming approach. To address the uncertainties, Babazadeh et al. (2017a) proposed a multi-objective possibilistic planning model for the second generation BSCN under uncertainty.

In recent years, the robust optimization approach has paid more attention due to its high capability in the face of risk and uncertainty (Bertsimas et al. 2011; Pishvae and Khalaf 2016). Kim et al. (2011) developed a scenario-based robust MILP model for designing a biofuel supply chain network under demand uncertainty. Zhang and Jiang (2017) designed a BSCN model, which includes both strategic and tactical levels. They presented a multi-objective robust model under biodiesel price uncertainty. They took Suzhou, a city in China, as a case study for verifying the presented method.

Some of the studies that have used mathematical programming approach under uncertainty are summarized in Table 1.

Table 1. A review of some biofuels supply chain network design studies under uncertainty

| References | Modeling approach | | | Objective function | | Uncertainty modeling approach | | |
|------------------------|-------------------|------|-------|--------------------|---------------|-------------------------------|-------------------|---------------------|
| | MOMILP | MILP | MINLP | Economical | Environmental | Stochastic programming | Fuzzy programming | Robust optimization |
| (Kim et al. 2011) | | * | | * | | * | | |
| (Dal-Mas et al. 2011) | | * | | * | | * | | |
| (Awudu and Zhang 2012) | | * | | * | | * | | |
| (Tong et al. 2014a) | | * | | * | | | * | |
| (Tong et al. 2014b) | | | * | * | | | | * |

| | | | | | | | | |
|-----------------------------------|---|---|---|---|---|---|---|---|
| (Santibañez-Aguilar et al. 2016b) | * | | | * | * | * | | |
| (Quddus et al. 2017) | | | * | * | * | * | | |
| (Babazadeh et al. 2017a) | | | * | * | * | | * | |
| (Bairamzadeh et al. 2018b) | | * | | * | | | | * |

According to the literature, in the research related to biofuel supply chain modeling, different and hybrid uncertainties in the real world have not been considered. Therefore, in this study, a novel robust fuzzy stochastic programming model has been presented for this field. In this approach, some variables have fuzzy nature and some have fuzzy scenario nature. This model takes into account the different risks, including possibilistic variability, scenario variability, and unsatisfied demand costs. In addition, a multi-objective robust fuzzy stochastic programming model is presented for designing the BSCN under hybrid uncertainties that simultaneously minimizes the total cost of the network and the total environmental impacts of the activities.

3- Problem description and formulation

The structure of the presented BSCN is shown in Figure 1. It is a four-echelon, multi-period, and multi-product supply chain network under hybrid uncertainties. As this figure shows, JCL and SL products are shipped from their corresponding cultivation centers to oil extracting facilities. JCL oil and SL oil are obtained in oil extraction facilities and transported to biorefineries. WCOs are collected from suppliers and transported to refineries for pre-treating. In biorefineries, biodiesel is produced through JCL oils, SL oils, and waste cooking oils. Afterwards, the produced biodiesel is shipped from refineries to distribution facilities. Lastly, the biodiesel is shipped from distribution facilities to consumption centers.

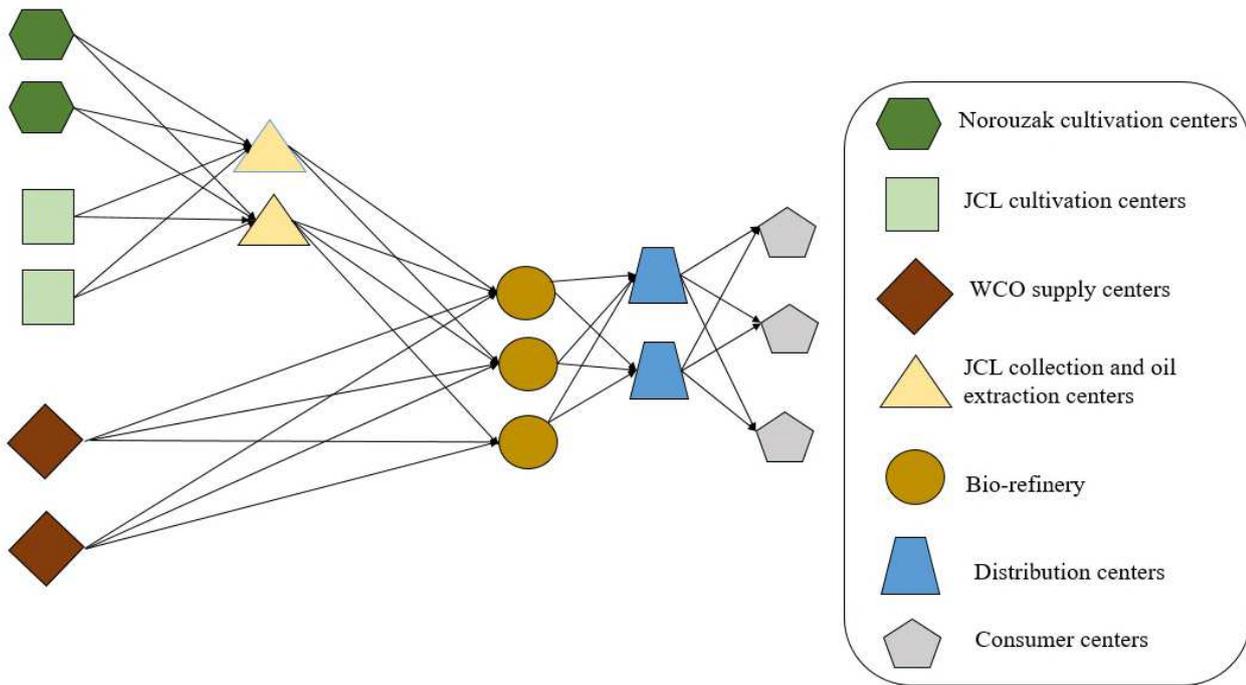


Figure 1. Proposed biodiesel supply chain network

3-1- Assumptions and notations

The general assumptions used for mathematical modeling are summarized as follows:

- The locations of biodiesel consumption centers are known and fixed.
- Potential areas for cultivating of JCL and SL and opening of other facilities are known.
- Transportation is done by 2 modes of road and rail.
- The capacity of JCL and SL farms, established oil extraction facilities, and distribution facilities are not fixed. These capacities are calculated over planning horizon by continuous variables.
- Required capacity for each refinery is calculated through adding capacity alternatives to the initial corresponding capacity.
- The opened facilities will be active until the end of the planning horizon.
- Fixed costs and environmental impact of opening facilities are uncertain and are described as fuzzy variables.
- Demands, supply of waste oils, the other costs, and some environmental impacts are uncertain and are considered as fuzzy scenario based variables.

The notations used to formulate the model are described in the following. It should be noted that uncertain parameters are introduced with a tilde on.

Sets

f Set of candidate locations for planting JCL

| | |
|-----|---|
| n | Set of candidate locations for planting SL |
| g | Set of locations for waste oil supply sites |
| i | Set of candidate locations for oil extraction sites |
| j | Set of candidate locations for biorefinery sites |
| k | Set of candidate locations for biodiesel distribution sites |
| m | Set of biodiesel demand centers |
| l | Set of transportation modes |
| p | Set of capacity selection for refinery sites |
| t | Set of time period |
| s | Set of scenarios |

Technical parameters

| | |
|--------------------|---|
| \tilde{D}_{mts} | Biodiesel demand of consumer center m at year t in scenario s |
| $\tilde{W}O_{gts}$ | Amount of WCO supplied through supplier g at year t in scenario s |
| LA_f | Minimum allowable area for cultivating JCL in area f |
| UA_f | Maximum allowable area for cultivating JCL in area f |
| LN_n | Minimum allowable area for cultivating SL in area n |
| UN_n | Maximum allowable area for cultivating SL in area n |
| LC_i | Minimum allowable capacity of oil extraction facility in area i |
| UC_i | Maximum allowable capacity of oil extraction facility in area i |
| LB_j | Minimum allowable biorefinery capacity in area j |
| UB_j | Maximum allowable biorefinery capacity in area j |
| LS_k | Minimum allowable capacity of distribution facility in area k |
| US_k | Maximum allowable capacity of distribution facility in area k |
| $Min x$ | Minimum number of JCL cultivation centers |
| $Min y$ | Minimum number of SL cultivation centers |
| csl | Percentage of customer service level |
| α | α – cut |
| η_{ft} | Amount of JCL products per hectare in area f at year t |
| τ | Amount of SL products per hectare |
| θ | JCL conversion rate to its oil |
| φ | SL conversion rate to its oil |
| β | WCO conversion rate to its pre-treated form |

| | |
|-------------|---|
| γ | JCL oil conversion rate to biodiesel |
| Δ | SL oil conversion rate to biodiesel |
| ω | Pre-treated WCO conversion rate to biodiesel |
| CW_{jt} | Initial biorefinery j capacity at year t |
| R_{pjt} | Capacity option p for biorefinery j at year t |
| p_s | Probability of occurring scenario s |
| DJT_{fli} | Distance between JCL planting site f and oil extracting facility i via mode l |
| DNT_{nli} | Distance between SL planting site n and oil extracting facility i via mode l |
| DWT_{glj} | Distance between supplier g and biorefinery j via mode l |
| DOT_{ilj} | Distance between oil extracting facility i and biorefinery j via mode l |
| DBT_{jlk} | Distance between biorefinery j and distribution facility k via mode l |
| DMT_{klm} | Distance between distribution facility k and customer m via mode l |

Cost parameters

| | |
|--------------------------|---|
| $\tilde{\pi}_{mts}$ | penalty cost per unit of unsatisfied demand of consumer m at year t in scenario s |
| $\widetilde{FC}J_f$ | Fixed cost for cultivating JCL in area f |
| $\widetilde{FC}N_n$ | Fixed cost for cultivation of SL in area n |
| $\widetilde{FC}C_i$ | Fixed cost for establishing oil extraction facility in area i |
| $\widetilde{FC}B_j$ | Fixed cost for establishing biorefinery in area j |
| $\widetilde{FC}S_k$ | Fixed cost for establishing distribution facility in area k |
| $\widetilde{VC}J_{fs}$ | Unit variable cost for cultivating JCL in area f in scenario s |
| $\widetilde{VC}N_{ns}$ | Unit variable cost for cultivating SL in area n in scenario s |
| $\widetilde{VC}C_{its}$ | Unit variable cost of oil extracting facility i at year t in scenario s |
| $\widetilde{VC}B_{jts}$ | Unit variable cost of biorefinery j at year t in scenario s |
| $\widetilde{VC}S_{kts}$ | Unit variable cost of distribution facility k at year t in scenario s |
| $\widetilde{PC}J_{fts}$ | Unit cost for producing JCL products in area f at year t in scenario s |
| $\widetilde{PC}N_{nts}$ | Unit cost for producing SL products in area n at year t in scenario s |
| $\widetilde{PC}C_{gts}$ | Unit cost for collecting WCO from supply center g at year t in scenario s |
| $\widetilde{PC}O_{its}$ | Unit cost for extracting oil from JCL products at oil extraction facility i at year t in scenario s |
| $\widetilde{PC}ON_{its}$ | Unit cost for extracting oil from SL products at oil extraction facility i at year t in scenario s |

| | |
|----------------------------|--|
| \widetilde{PCW}_{jts} | Unit cost for pre-treating WCO at biorefinery j at year t in scenario s |
| \widetilde{PCB}_{jts} | Unit cost for producing biodiesel at biorefinery j at year t in scenario s |
| \widetilde{ICJ}_{its} | Cost of holding inventory of JCL products at oil extracting facility i at year t in scenario s |
| \widetilde{ICN}_{its} | Cost of holding inventory of SL products at oil extracting facility i at year t in scenario s |
| \widetilde{ICB}_{jts} | Cost of holding inventory of biodiesel at biorefinery j at year t in scenario s |
| \widetilde{ICS}_{kts} | Cost of holding inventory of biodiesel at distribution facility k at year t in scenario s |
| \widetilde{JCT}_{flits} | Cost of transporting JCL products between JCL planting site f and oil extracting facility i via mode l at year t in scenario s |
| \widetilde{NCT}_{nlits} | Cost of transporting SL products between SL planting site n and oil extracting facility i via mode l at year t in scenario s |
| \widetilde{WCT}_{gljts} | Cost of transporting WCO between supplier g and biorefinery j via mode l at year t in scenario s |
| \widetilde{OCT}_{iljts} | Cost of transporting JCL oil between oil extracting facility i and biorefinery j via mode l at year t in scenario s |
| \widetilde{ONCT}_{iljts} | Cost of transporting SL oil between oil extracting facility i and biorefinery j via mode l at year t in scenario s |
| \widetilde{BCT}_{jlkts} | Cost of transporting biodiesel between biorefinery j and distribution facility k via mode l at year t in scenario s |
| \widetilde{MCT}_{klmts} | Cost of transporting biodiesel between distribution facility k and customer m via mode l at year t in scenario s |

Environmental parameters

| | |
|-------------------|---|
| \widetilde{ECJ} | Environmental impact of cultivating each unit of JCL products |
| \widetilde{ECN} | Environmental impact of cultivating each unit of SL products |
| \widetilde{ECB} | Environmental impact of opening each unit capacity of biorefinery |
| \widetilde{ECO} | Environmental impact of opening each unit capacity of oil extraction facility |
| \widetilde{ECK} | Environmental impact of opening each unit capacity of distribution facility |
| \widetilde{EO} | Environmental impact of producing each unit of JCL oil at oil extracting facility |
| \widetilde{EON} | Environmental impact of producing each unit of SL oil in oil extracting facility |
| \widetilde{EB} | Environmental impact of producing each unit of biodiesel in biorefinery |

| | |
|--------------------------|---|
| \widetilde{EJT}_{fui} | Environmental impact of transporting each unit of JCL products between JCL planting site f and oil extracting facility i via mode l |
| \widetilde{ENT}_{nli} | Environmental impact of transporting each unit of SL products between SL planting site n and oil extracting facility i via mode l |
| \widetilde{EWT}_{glj} | Environmental impact of transporting each unit of WCO between supplier g and biorefinery j via mode l |
| \widetilde{EOT}_{ilj} | Environmental impact of transporting each unit of JCL oil between oil extracting facility i and biorefinery j via mode l |
| \widetilde{EONT}_{ilj} | Environmental impact of transporting each unit of SL oil between oil extracting facility i and biorefinery j via mode l |
| \widetilde{EBT}_{jlk} | Environmental impact of transporting each unit of biodiesel between biorefinery j and distribution facility k via mode l |
| \widetilde{EMT}_{jlk} | Environmental impact of transporting each unit of biodiesel between biorefinery j and distribution facility k via mode l |
| \widetilde{EIJ} | Environmental impact of holding inventory each unit of JCL products in oil extracting facility |
| \widetilde{EIN} | Environmental impact of holding inventory each unit of SL products in oil extracting facility |
| \widetilde{EIB} | Environmental impact of holding inventory per unit of biodiesel in biorefinery |
| \widetilde{EIS} | Environmental impact of holding inventory per unit of biodiesel in distribution facility |

Decision variables

| | |
|----------|---|
| x_f | Binary variable assuming value of 1 if area f is chosen for JCL cultivation, and 0 otherwise |
| y_n | Binary variable assuming value of 1 if area n is chosen for SL cultivation, and 0 otherwise |
| u_i | Binary variable assuming value of 1 if area i is chosen for establishing oil extraction facility, and 0 otherwise |
| v_{jt} | Binary variable assuming value of 1 if area j is chosen for establishing biorefinery at year t, and 0 otherwise |
| w_k | Binary variable assuming value of 1 if area k is chosen for establishing distribution facility, and 0 otherwise |

| | |
|---------------|---|
| CO_{pjt} | Binary variable assuming value of 1 if capacity p selected to biorefinery j at year t, and 0 otherwise |
| IJ_{its} | JCL products inventory level at oil extraction facility i at year t in scenario s |
| IN_{its} | SL products inventory level at oil extraction facility i at year t in scenario s |
| IB_{jts} | Biodiesel inventory level at biorefinery j at year t in scenario s |
| IS_{kts} | Biodiesel inventory level at distribution facility k at year t in scenario s |
| PJ_{fts} | Quantity of produced JCL at JCL cultivation area f at year t in scenario s |
| PN_{nts} | Quantity of produced SL at SL cultivation area n at year t in scenario s |
| PO_{its} | Quantity of produced JCL oil at oil extracting facility i at year t in scenario s |
| PON_{its} | Quantity of produced SL oil at oil extracting facility i at year t in scenario s |
| PW_{jts} | Quantity of produced pre-treated WCO at biorefinery j at year t in scenario s |
| PB_{jts} | Quantity of produced biodiesel in biorefinery j at year t in scenario s |
| SH_{mts} | Quantity of unsatisfied demand of consumer m at year t in scenario s |
| JT_{flits} | Quantity of JCL products shipped from JCL planting site f to oil extracting facility i via mode l at year t in scenario s |
| NT_{nlits} | Quantity of SL products shipped from SL planting site n to oil extracting facility i via mode l at year t in scenario s |
| WT_{gljts} | Quantity of WCO shipped from supplier g to biorefinery j via mode l at year t in scenario s |
| OT_{iljts} | Quantity of JCL oil shipped from oil extracting facility i to biorefinery j via mode l at year t in scenario s |
| ONT_{iljts} | Quantity of SL oil shipped from oil extracting facility i to biorefinery j via mode l at year t in scenario s |
| BT_{jlkts} | Quantity of biodiesel shipped from biorefinery j to distribution facility k via mode l at year t in scenario s |
| MT_{klmts} | Quantity of biodiesel shipped from distribution facility k to customer m via mode l at year t in scenario s |
| CJ_f | Total cultivated land of JCL in area f |
| CN_n | Total cultivated land of SL in area n |
| CC_{it} | Total capacity of oil extracting facility i at year t |
| CEC_{it} | Quantity of capacity expansion in oil extracting facility i at year t |
| CB_{jt} | Total capacity of biorefinery j at year t |
| CS_{kt} | Total capacity of distribution facility k at year t |

CES_{kt} Amount of expansion of capacity at distribution facility k at year t

3-2- Constraints

Constraint (1) guarantees that the quantity of biodiesel shipped from the biorefineries to a city is at least equal to its corresponding demand. Equation (2) indicates the maximum amount of possible shortage. Constraints (3) to (5) ensure that all JCL, SL and WCO will be shipped to their corresponding facilities.

$$\sum_k \sum_l MT_{klmts} + SH_{mts} \geq \tilde{D}_{mts} \quad \forall m, t, s \quad (1)$$

$$SH_{mts} \leq (1 - csl)\tilde{D}_{mts} \quad \forall m, t, s \quad (2)$$

$$\sum_l \sum_i JT_{flits} = PJ_{fts} \quad \forall f, t, s \quad (3)$$

$$\sum_l \sum_i NT_{nlits} = PN_{nts} \quad \forall n, t, s \quad (4)$$

$$\sum_l \sum_j WT_{gljts} \leq \tilde{W}O_{gts} \quad \forall g, t, s \quad (5)$$

Constraints (6) and (7) represent the quantity of JCL and SL yields in the cultivated areas in each period. Equations (8) to (11) indicate the quantity of extracted JCL oil, extracted SL oil, pre-treated WCO, and produced biodiesel, respectively.

$$PJ_{fts} = \eta_{ft}CJ_f \quad \forall f, t, s \quad (6)$$

$$PN_{nts} = \tau CN_n \quad \forall n, t \quad (7)$$

$$PO_{its} = \theta \sum_f \sum_l JT_{flits} \quad \forall i, t, s \quad (8)$$

$$PON_{its} = \varphi \sum_n \sum_l NT_{nlits} \quad \forall i, t, s \quad (9)$$

$$PW_{jts} = \beta \sum_g \sum_l WT_{gljts} \quad \forall j, t, s \quad (10)$$

$$PB_{jts} = \gamma \sum_i \sum_l OT_{iljts} + \Delta \sum_i \sum_l ONT_{iljts} + \omega PW_{jts} \quad \forall j, t, s \quad (11)$$

Constraint (12) represents that the level of inventory of JCL products at oil extracting facilities in each period of time is equal to the level of inventory in the previous period, in addition to the quantities of JCL shipped to these centers, minus the quantities of JCL converted to JCL oil that transported to biorefineries. Also, Equation (13) shows the level of inventory in oil extraction centers for SL products. Finally, constraints (14) and (15) indicate the level of inventory balance in refineries and distribution centers, respectively.

$$IJ_{its} = IJ_{i,t-1,s} + \sum_f \sum_l JT_{flits} - \left(\frac{1}{\theta}\right) \sum_l \sum_j OT_{iljts} \quad \forall i, t, s \quad (12)$$

$$IN_{its} = IN_{i,t-1,s} + \sum_n \sum_l NT_{nlits} - \left(\frac{1}{\phi}\right) \sum_l \sum_j ONT_{iljts} \quad \forall i, t, s \quad (13)$$

$$IB_{jts} = IB_{j,t-1,s} + PB_{jts} - \sum_l \sum_k BT_{jlkts} \quad \forall j, t, s \quad (14)$$

$$IS_{kts} = IS_{k,t-1,s} + \sum_j \sum_l BT_{jlkts} - \sum_l \sum_m MT_{klmst} \quad \forall k, t, s \quad (15)$$

Constraint (16) represents a logical expression. Constraint (17) guaranties that when a biorefinery is established, it will be active up to the end of time horizon. Similarly, constraint (18) guaranties that when a capacity option is added to a refinery, it will be active up to the end of time period.

Equations (19) and (20) state the maximum and minimum permissible locations for cultivating of JCL and SL. Constraints (21) to (23) represent the maximum and minimum capacities of oil extracting facilities, biorefineries and distribution centers, respectively.

Equations (24) and (25) state the minimum number of JCL and SL cultivation centers, respectively. Constraints (26) and (27) show the amount of capacity added to each of the oil extraction facilities and distribution facilities, respectively. Equation (28) calculates total capacity of refineries over the planning horizon.

$$CO_{pjt} \leq v_{jt} \quad \forall p, j, t \quad (16)$$

$$v_{jt} \leq v_{j(t+1)} \quad \forall j, t \quad (17)$$

$$CO_{pjt} \leq CO_{pj(t+1)} \quad \forall p, j, t \quad (18)$$

$$x_f LA_f \leq CJ_f \leq x_f UA_f \quad \forall f \quad (19)$$

$$y_n LN_n \leq CN_n \leq y_n UN_n \quad \forall n \quad (20)$$

$$u_i LC_i \leq CC_{it} \leq u_i UC_i \quad \forall i, t \quad (21)$$

$$v_{jt} LB_j \leq CB_{jt} \leq v_{jt} UB_j \quad \forall j, t \quad (22)$$

$$w_k LS_k \leq CS_{kt} \leq w_k US_k \quad \forall k, t \quad (23)$$

$$\sum_f x_f \geq \text{Min } x \quad (24)$$

$$\sum_n y_n \geq \text{Min } y \quad (25)$$

$$CC_{it} = CC_{i,t-1} + CEC_{it} \quad \forall i, t \quad (26)$$

$$CS_{kt} = CS_{k,t-1} + CES_{kt} \quad \forall k, t \quad (27)$$

$$CB_{jt} = CB_{j,t-1} + CW_{jt} (v_{jt} - v_{j,t-1}) + \sum_p R_{pjt} CO_{pjt} \quad \forall j, t \quad (28)$$

Constraints (29) to (31) guaranty that the amount of products shipped to each facility does not exceed the capacity of that facility. Constraints (32) to (34) state that the inventory in each facility should not be more than its corresponding capacity.

$$\sum_f \sum_l JT_{flits} + \sum_n \sum_l NT_{nlits} \leq CC_{it} \quad \forall i, t, s \quad (29)$$

$$\sum_i \sum_l OT_{iljts} + \sum_i \sum_l ONT_{iljts} + \sum_g \sum_l WT_{gljts} \leq CB_{jt} \quad \forall j, t, s \quad (30)$$

$$\sum_j \sum_l BT_{jlkts} \leq CS_{kt} \quad \forall k, t, s \quad (31)$$

$$IJ_{its} + IN_{its} \leq CC_{it} \quad \forall i, t, s \quad (32)$$

$$IB_{jts} \leq CB_{jt} \quad \forall j, t, s \quad (33)$$

$$IS_{kts} \leq CS_{kt} \quad \forall k, t \quad (34)$$

Finally, constraints (35) and (36) state the binary and non-negativity natures of the decision variables, respectively.

$$x_f, y_n, u_i, v_{jt}, CO_{pjt}, w_k \in \{0,1\} \quad (35)$$

$$\text{Continuous decision variables} \geq 0 \quad (36)$$

3-3- Objective functions

The first presented objective function minimizes the total costs, like the fixed costs of establishing the facilities (FC), the variable costs of establishing the facilities (VC), the production costs (PC), the inventory holding costs (IC) and the transportation costs among facilities (TC).

$$\begin{aligned} \widetilde{FC} = & \sum_f \widetilde{FC} J_f x_f + \sum_n \widetilde{FC} N_n y_n + \sum_i \widetilde{FC} C_i u_i + \sum_j \sum_t \widetilde{FC} B_j (v_{jt} - v_{j,t-1}) \\ & + \sum_k \widetilde{FC} S_k w_k \end{aligned} \quad (37)$$

$$\begin{aligned}
\widetilde{VC}_s = & \sum_f \widetilde{VC}J_{fs}CJ_f + \sum_n \widetilde{VCN}_{ns}CN_n + \sum_i \sum_t \widetilde{VCC}_{its}CC_{it} \\
& + \sum_j \sum_t \widetilde{VCB}_{jts}CB_{jt} + \sum_k \sum_t \widetilde{VCS}_{kts}CS_{kt} \quad \forall s
\end{aligned} \tag{38}$$

$$\begin{aligned}
\widetilde{PC}_s = & \sum_f \sum_t \widetilde{PC}J_{fts}PJ_{fts} + \sum_n \sum_t \widetilde{PCN}_{nts}PN_{nts} + \sum_g \sum_t \widetilde{PCC}_{gts}WO_{gts} \\
& + \sum_i \sum_t \widetilde{PCO}_{its}PO_{its} + \sum_i \sum_t \widetilde{PCON}_{its}PON_{its} \\
& + \sum_j \sum_t \widetilde{PCW}_{jts}PW_{jts} + \sum_j \sum_t \widetilde{PCB}_{jts}PB_{jts} \quad \forall s
\end{aligned} \tag{39}$$

$$\begin{aligned}
\widetilde{IC}_s = & \sum_i \sum_t \widetilde{IC}J_{its}IJ_{its} + \sum_i \sum_t \widetilde{ICN}_{its}IN_{its} + \sum_j \sum_t \widetilde{ICB}_{jts}IB_{jts} \\
& + \sum_k \sum_t \widetilde{ICS}_{kts}IS_{kts} \quad \forall s
\end{aligned} \tag{40}$$

$$\begin{aligned}
\widetilde{TC}_s = & \sum_f \sum_l \sum_i \sum_t \widetilde{JCT}_{flits}JT_{flits} + \sum_n \sum_l \sum_i \sum_t \widetilde{NCT}_{nlits}NT_{nlits} \\
& + \sum_g \sum_l \sum_j \sum_t \widetilde{WCT}_{gljts}WT_{gljts} \\
& + \sum_i \sum_l \sum_j \sum_t \widetilde{OCT}_{iljts}OT_{iljts} \\
& + \sum_i \sum_l \sum_j \sum_t \widetilde{ONCT}_{iljts}ONT_{iljts} \\
& + \sum_j \sum_l \sum_k \sum_t \widetilde{BCT}_{jlkts}BT_{jlkts} \\
& + \sum_k \sum_l \sum_m \sum_t \widetilde{MCT}_{klmts}MT_{klmts} \quad \forall s
\end{aligned} \tag{41}$$

So, according to the above terms, the cost objective function can be formulated as by equation (42):

$$\text{Min } Z_1 = \widetilde{FC} + \sum_s p_s (\widetilde{VC}_s + \widetilde{PC}_s + \widetilde{IC}_s + \widetilde{TC}_s) \quad (42)$$

The second presented objective function minimizes the total environmental impact of opening the facilities (EF), production (EP), inventory holding (EI) and transportation (ET).

$$\begin{aligned} \widetilde{EF} = & \sum_f \widetilde{EC} J C J_f + \sum_n \widetilde{ECN} C N_n + \sum_i \sum_t \widetilde{ECO} C C_{it} + \sum_j \sum_t \widetilde{ECB} C B_{jt} \\ & + \sum_k \sum_t \widetilde{ECK} C S_{kt} \end{aligned} \quad (43)$$

$$\widetilde{EP}_s = \sum_i \sum_t \widetilde{EO} P O_{its} + \sum_i \sum_t \widetilde{EON} P O N_{its} + \sum_j \sum_t \widetilde{EB} P B_{jts} \quad \forall s \quad (44)$$

$$\begin{aligned} \widetilde{EI}_s = & \sum_i \sum_t \widetilde{EIJ} I J_{its} + \sum_i \sum_t \widetilde{EIN} I N_{its} + \sum_j \sum_t \widetilde{EIB} I B_{jts} \\ & + \sum_k \sum_t \widetilde{EIS} I S_{kts} \quad \forall s \end{aligned} \quad (45)$$

$$\begin{aligned} \widetilde{ET}_s = & \sum_f \sum_l \sum_i \sum_t \widetilde{EJT}_{fli} D J T_{fli} J T_{flits} + \sum_n \sum_l \sum_i \sum_t \widetilde{ENT}_{nli} D N T_{nli} N T_{nlits} \\ & + \sum_g \sum_l \sum_j \sum_t \widetilde{EWT}_{glj} D W T_{glj} W T_{gljts} \\ & + \sum_i \sum_l \sum_j \sum_t \widetilde{EOT}_{ilj} D O T_{ilj} O T_{iljts} \\ & + \sum_i \sum_l \sum_j \sum_t \widetilde{EONT}_{ilj} D O N T_{ilj} O N T_{iljts} \\ & + \sum_j \sum_l \sum_k \sum_t \widetilde{EBT}_{jlk} D B T_{jlk} B T_{jlkts} \\ & + \sum_k \sum_l \sum_m \sum_t \widetilde{EMT}_{jlk} D M T_{klm} M T_{klmts} \quad \forall s \end{aligned} \quad (46)$$

Similarly, according to the above terms, the Environmental objective function can be formulated by Equation (47):

$$\text{Min } Z_2 = \widetilde{EF} + \sum_s p_s (\widetilde{EP}_s + \widetilde{EI}_s + \widetilde{ET}_s) \quad (47)$$

3-4- Multi-objective approach

Many methods have been presented in the literature for solving multi-objective optimization problems. One of these methods is bounded objective function (BOF) method. In this approach, a problem with several objective functions converts to a single-objective problem. In the BOF method, the minimum and maximum values of objective function F_i are determined by the decision maker and are represented by L^i and U^i , respectively.

As shown in Equations (48)-(50), in this method, the most important objective function, i.e. $F_r(X)$, is minimized and other objective functions are placed in constraints and a high and low limit is considered for them. By changing the values of L^i and U^i , the Pareto frontiers of the problem can be obtained.

$$\text{Min } F_r(X) \quad (48)$$

S. t.

$$g_i \leq 0 \quad \forall j \quad (49)$$

$$L^i \leq F_i(X) \leq U^i \quad \forall i, \quad i \neq r \quad (50)$$

4- The proposed robust fuzzy stochastic programming approach

In this section the presented robust fuzzy stochastic programming (RFSP) model is defined. The presented model is based on the robust scenario-based programming model and fuzzy possibilistic programming model. The proposed RFSP model can consider hybrid uncertainties.

Consider the following mathematical model.

$$\text{Min } \tilde{f}x + \tilde{c}_s y_s \quad (51)$$

$$Ay_s \geq \tilde{d}_s \quad (52)$$

$$Bx = 0 \quad (53)$$

$$Dy_s \leq \tilde{e}_s \quad (54)$$

$$x \in \{0, 1\}, \quad y_s \geq 0 \quad (55)$$

Where \tilde{f} has fuzzy nature, \tilde{c}_s , \tilde{d}_s , and \tilde{e}_s have fuzzy scenario nature. The general model of fuzzy stochastic programming is as follows:

$$\text{Min } F + \lambda v(\tilde{F}) + \gamma \sum_s p_s \theta_s + \omega \sum_s p_s SH_{mts} \pi_{mts} \quad (56)$$

$$Ay_s \geq (2 - 2\alpha)d_s^2 + (2\alpha - 1)(d_s^2 + d_s^4) \quad (57)$$

$$Bx = 0 \quad (58)$$

$$Dy_s \leq (2\alpha - 1)(e_s^1 - e_s^3) + (2 - 2\alpha)e_s^1 \quad (59)$$

$$\left(\frac{\left(F^1 - \frac{1}{3}F^3 - F_s^2 \right) + \left(F^2 + \frac{1}{3}F^4 - F_s^1 \right)}{2} + \frac{F_s^4 - F_s^3}{6} \right) + \theta_s \geq 0 \quad \forall s \quad (60)$$

$$\left(\frac{\left(F_s^1 - F^2 - \frac{1}{3}F^4 \right) + \left(F_s^2 - F^1 + \frac{1}{3}F^3 \right)}{2} + \frac{F_s^3 - F_s^4}{6} \right) + \theta_s \geq 0 \quad \forall s \quad (61)$$

$$x \in \{0, 1\}, \quad y_s \geq 0 \quad (62)$$

As Equation (56) shows, the objective function is composed of several components, which are as follows:

- The weighted possibilistic mean value of the objective function is obtained by Equation (63).
- Possibilistic variability of the objective function is calculated by Equation (64).
- The third term of Equation (56) shows the scenario variability of the objective function.
- Finally, the fourth term of Equation (56) represents the unsatisfied demand costs.

In Equation (56), λ and γ represents the weight of possibilistic variability and scenario variability, respectively. ω is a coefficient that adjust the weighted penalty for possible violation of each constraint.

It should be noted that, if we use trapezoidal fuzzy numbers for expression $\tilde{f}x + \tilde{c}_s y_s$; i.e. $\tilde{f}_i = (f_i^1, f_i^2, f_i^3, f_i^4)$ and $\tilde{c}_{js} = (c_{js}^1, c_{js}^2, c_{js}^3, c_{js}^4)$, F and $v(\tilde{F})$ are obtained by Equations (63) and (64), respectively.

$$F = \sum_i \left(\frac{f_i^1 + f_i^2}{2} + \frac{f_i^4 - f_i^3}{6} \right) x_i + \sum_j \sum_s p_s \left(\frac{c_{js}^1 + c_{js}^2}{2} + \frac{c_{js}^4 - c_{js}^3}{6} \right) y_{js} \quad (63)$$

$$v(\tilde{F}) = \sum_i \left(f_i^2 - f_i^1 + \frac{f_i^3 + f_i^4}{3} \right) x_i + \sum_j \sum_s p_s \left(c_{js}^2 - c_{js}^1 + \frac{c_{js}^3 + c_{js}^4}{3} \right) y_{js} \quad (64)$$

Equations (65) and (66) are also used for constraints (60) and (61):

$$\begin{aligned} \tilde{F}_s = & \left(\sum_i f_i^1 x_i + \sum_j c_{js}^1 y_{js}, \sum_i f_i^2 x_i + \sum_j c_{js}^2 y_{js}, \sum_i f_i^3 x_i + \sum_j c_{js}^3 y_{js}, \sum_i f_i^4 x_i \right. \\ & \left. + \sum_j c_{js}^4 y_{js} \right) = (F_s^1, F_s^2, F_s^3, F_s^4) \end{aligned} \quad (65)$$

$$\begin{aligned} \tilde{F} = & \left(\sum_i f_i^1 x_i + \sum_j \sum_s p_s c_{js}^1 y_{js}, \sum_i f_i^2 x_i + \sum_j \sum_s p_s c_{js}^2 y_{js}, \sum_i f_i^3 x_i \right. \\ & \left. + \sum_j \sum_s p_s c_{js}^3 y_{js}, \sum_i f_i^4 x_i + \sum_j \sum_s p_s c_{js}^4 y_{js} \right) = (F^1, F^2, F^3, F^4) \end{aligned} \quad (66)$$

5- Computational experiments and evaluation

The presented MORFSP model is applied in a real case to design the BSCN in Iran. The results of solving the presented model are described in this section. The model is coded in GAMS software and solved using CPLEX solving method .

In this study, a 7 years planning horizon for implementing the proposed model is considered. SimaPro 8 software is applied to obtain the environmental impacts of the processes. Considering the fact that at least 80% of Iran's edible oils are provided by imports,

it's not logical using edible oil sources for producing biodiesel. Therefore, in this study, JCL and SL that are non-edible plants and compatible with Iran's climate and require little water are selected as biodiesel resources. WCO is also considered as another source of producing biodiesel. The most appropriate locations for cultivation of these plants are considered as the candidate areas, in which 11 and 7 areas are selected for JCL and SL, respectively. In addition, considering the demand of diesel and air pollution problem of the cities (big and industrial cities), 7 cities are selected as biodiesel consumers.

Therefore, in this model 11 candidate areas for cultivation of JCL, 7 potential areas for cultivating SL, 30 potential WCO suppliers, 30 candidate areas for oil extraction facilities, 30 potential areas for biorefineries, 30 candidate areas for distribution facilities, 7 areas for biodiesel consumers, and 2 transportation modes are considered.

In this research, the scenarios and their probability values are obtained based on Pishvaei et al. (2008) and Rezaei et al. (2020b), in which 3 scenarios are designed. The values of the fuzzy and fuzzy stochastic parameters are obtained based on the experts' opinions and according to the structure of the scenarios.

Bounded objective function method is used to solve the presented multi-objective model. In this research, the cost objective function is minimized as the most important objective function, and the environmental objective function is placed in the constraints for different limits. Figure 2 shows the Pareto frontiers for the objectives.

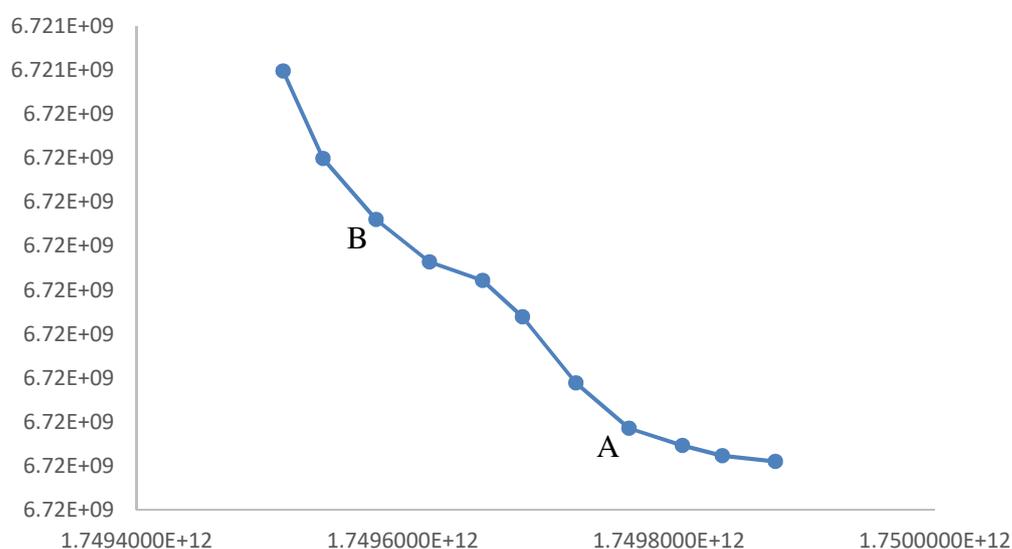


Figure 2. Pareto frontiers for the objectives

As shown in Figure 2, the cost objective function and the environmental objective function are not compatible. Therefore, according to the preferences of the decision maker a point from the Pareto optimal set is selected. The values of the objective functions for the two points of the Pareto optimal set (points A and B) are compared in Table 2.

Table 2. The values of objective function (million Rials)

| Points | Cost objective function | | | | Environmental objective function | | |
|----------|-------------------------|---------------------------|----------------------|----------------|----------------------------------|---------------------------|----------------------|
| | Mean | Possibilistic variability | Scenario variability | Un-fulfillment | Mean | Possibilistic variability | Scenario variability |
| A | 1.770873E+09 | 1.39389E+09 | 1.87536E+09 | 911647454 | 7.6927E+11 | 6.1052E+11 | 4.31489E+10 |
| B | 1.770859E+09 | 1.39387E+09 | 1.87535E+09 | 914917764 | 7.6919E+11 | 6.1045E+11 | 4.31433E+10 |

Also the different components of the objective functions for these points are summarized in Table 3.

Table 3. The components of the objective function (million Rials)

| Points | Cost objective function | | | | | Environmental objective function | | | |
|----------|-------------------------|-------------|-------------|-------------------|----------------|----------------------------------|------------|-------------------|----------------|
| | Fixed | Variable | Production | Inventory holding | Transportation | Construction and capacity | Production | Inventory holding | Transportation |
| A | 56537 | 1.25091E+09 | 4.40988E+08 | 4228309 | 74686682 | 7.6409E+11 | 5.1440E+09 | 26429629 | 7138994 |
| B | 56537 | 1.25088E+09 | 4.41113E+08 | 4209219 | 74597988 | 7.6401E+11 | 5.1430E+09 | 26300372 | 7195114 |

In the following, the optimal location of each facility and their capacities, which have been obtained by solving the model, are described. It should be noted that these items are related to point A.

The optimal locations for Jatropha cultivation and the capacity of each of these areas are shown in Figure 3.



Figure 3. Jatropha cultivation areas and their capacities

Similarly, suitable locations for cultivating Noruzak and their capacities are shown in Figure 4.

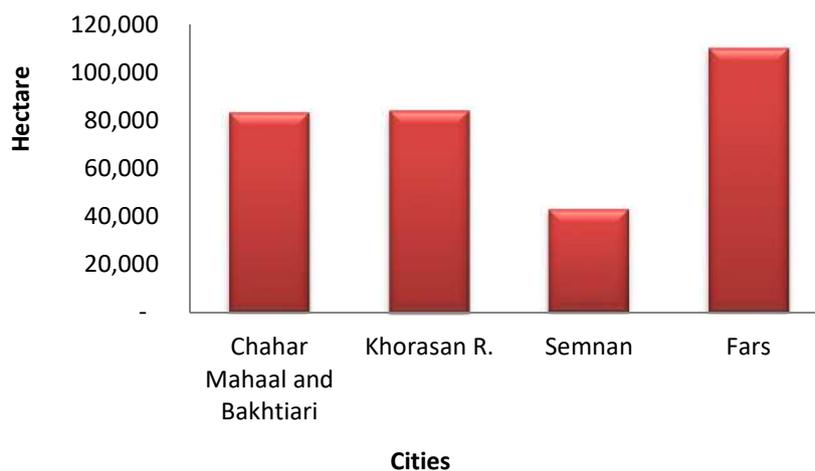


Figure 4. SL cultivation areas and their capacities

The optimal areas for opening oil extraction facilities and biorefinery centers and their corresponding capacities are shown in Tables 4 and 5, respectively.

Table 4. Established oil extraction centers and their capacities

| Cities | Year | | | | | | |
|-----------------------------|---------|---------|---------|---------|---------|---------|---------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Tehran | 20000 | 60000 | 120000 | 160000 | 200000 | 200000 | 200000 |
| Chahar Mahaal and Bakhtiari | 640861 | 640861 | 640861 | 640861 | 640861 | 640861 | 640861 |
| Khorasan R. | 667027 | 707027 | 767027 | 807027 | 847027 | 847027 | 847027 |
| Semnan | 349182 | 389182 | 449182 | 449182 | 529182 | 529182 | 781747 |
| Fars | 849459 | 849459 | 849459 | 849459 | 849459 | 849459 | 849459 |
| Gom | 20000 | 60000 | 120000 | 160000 | 200000 | 200000 | 200000 |
| Kermanshah | 20000 | 60000 | 120000 | 160000 | 200000 | 200000 | 338528 |
| Sum | 2566529 | 2766529 | 3066529 | 3226529 | 3466529 | 3466529 | 3857622 |

Table 5. Established biorefinery centers and their capacities

| Cities | Year | | | | | | |
|-------------|--------|--------|--------|--------|--------|--------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Tabriz | 106000 | 206000 | 306000 | 406000 | 506000 | 606000 | 706000 |
| Isfahan | 120000 | 220000 | 320000 | 420000 | 520000 | 620000 | 720000 |
| Tehran | 105000 | 205000 | 305000 | 405000 | 505000 | 605000 | 705000 |
| Khorasan R. | 110000 | 215000 | 320000 | 425000 | 530000 | 635000 | 740000 |

| | | | | | | | |
|--------|--------|---------|---------|---------|---------|---------|---------|
| Fars | 110000 | 215000 | 320000 | 425000 | 530000 | 635000 | 740000 |
| Gom | 60000 | 115000 | 170000 | 225000 | 280000 | 335000 | 390000 |
| Kerman | 60000 | 115000 | 170000 | 225000 | 280000 | 335000 | 390000 |
| Yazd | 55000 | 105000 | 155000 | 205000 | 255000 | 305000 | 355000 |
| Sum | 726000 | 1396000 | 2066000 | 2736000 | 3406000 | 4076000 | 4746000 |

Finally, the Table 6 shows the established distribution facilities and their corresponding capacities. As shown in this Table, the number of distribution centers is higher than other facilities. The reason for this can be explained by the fact that the model prefers to establish more distribution centers to reduce the transportation costs.

Table 6. Established distribution centers and their capacities

| Cities | Year | | | | | | |
|----------------------------|--------|--------|--------|--------|--------|--------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Tabriz | 53205 | 53205 | 53205 | 53205 | 62718 | 62718 | 62718 |
| Isfahan | 109554 | 126520 | 135638 | 135638 | 135638 | 135638 | 135638 |
| Tehran | 121704 | 126183 | 139391 | 162631 | 170601 | 170601 | 170601 |
| Khorasan R. | 91300 | 92436 | 92436 | 92436 | 92436 | 145007 | 145007 |
| Khuzestan | 32946 | 32946 | 32946 | 63104 | 83693 | 83693 | 83693 |
| Sistan and Baluchestan | 57974 | 64065 | 81483 | 93167 | 104852 | 104852 | 104852 |
| Fars | 90309 | 94681 | 97521 | 100447 | 123553 | 131445 | 131445 |
| Gazvin | 3000 | 11333 | 11333 | 11333 | 11333 | 11333 | 11333 |
| Kohgiluyeh and Boyer-Ahmad | 27809 | 86527 | 86527 | 86527 | 86527 | 86527 | 86527 |
| Lorestan | 3000 | 9118 | 9118 | 9118 | 9118 | 9118 | 9118 |
| Markazi | 15205 | 15205 | 15205 | 15205 | 37511 | 37511 | 37511 |
| Sum | 606006 | 712219 | 754803 | 822811 | 917980 | 978443 | 978443 |

In this section, sensitivity analysis is performed on some important parameters of the model. First, the impact of risk coefficients on the cost objective function is investigated. Figures 5 and 6 show the importance of the coefficient λ_c on the amount of possibilistic variability related to the cost objective function and the total cost objective function, respectively. As shown in these figures, when this risk factor increases, the amount of possibilistic variability decreases and the amount of the cost objective function increases.

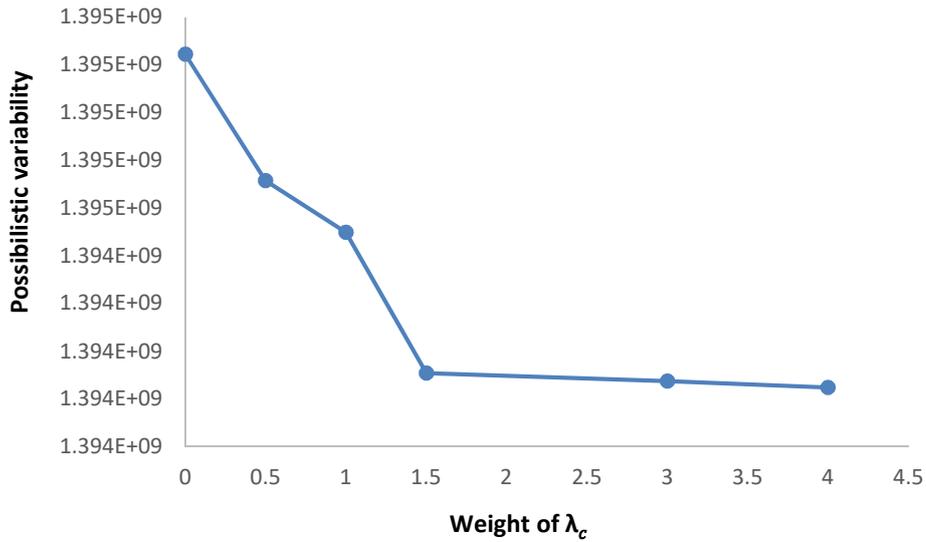


Figure 5- The impact of changes in λ_c on the possibilistic variability of the cost objective function

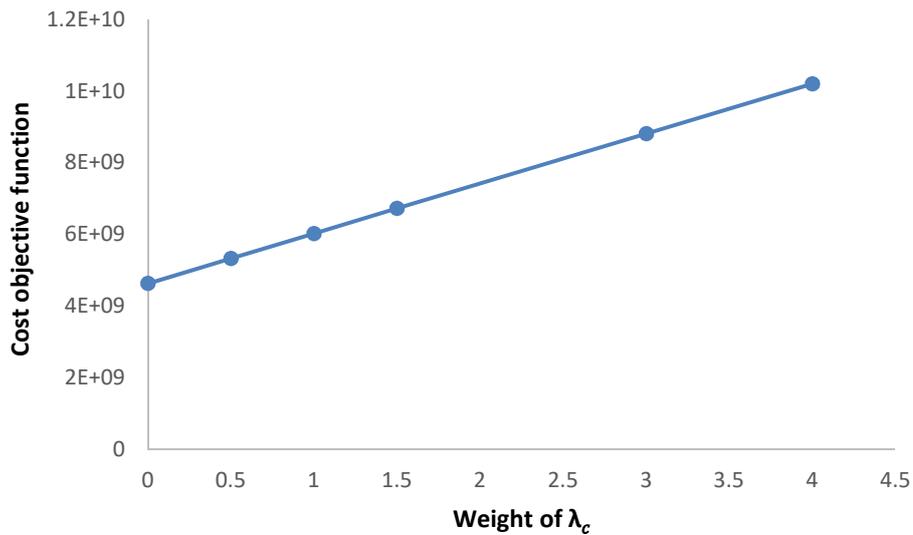


Figure 6- The impact of changes in λ_c on the cost objective function

Similarly, Figure 7 and 8 show the importance of the coefficient γ_c on the amount of scenario variability of the cost objective function and the total value of cost objective function. As this coefficient increases, the amount of scenario variability decreases and the value of the cost objective function increases.

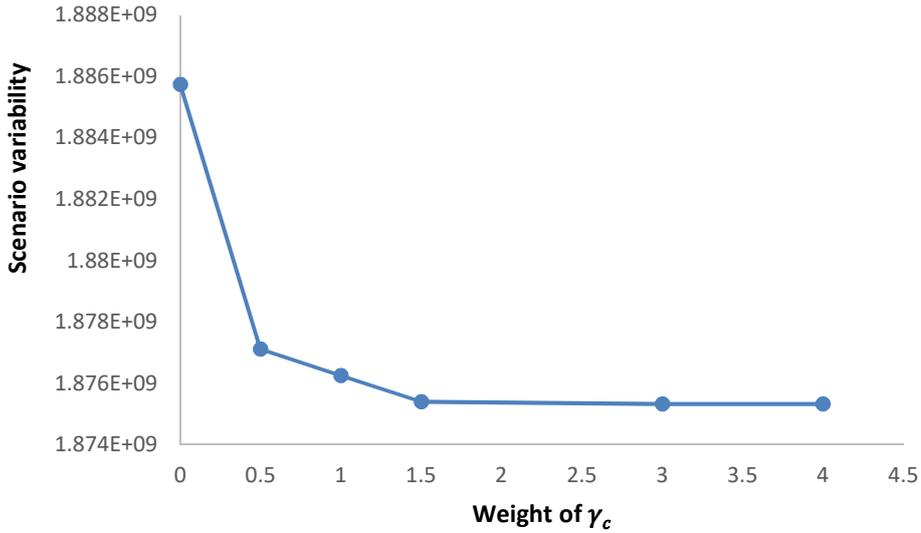


Figure 7- The impact of changes in γ_c on the scenario variability of the cost objective function

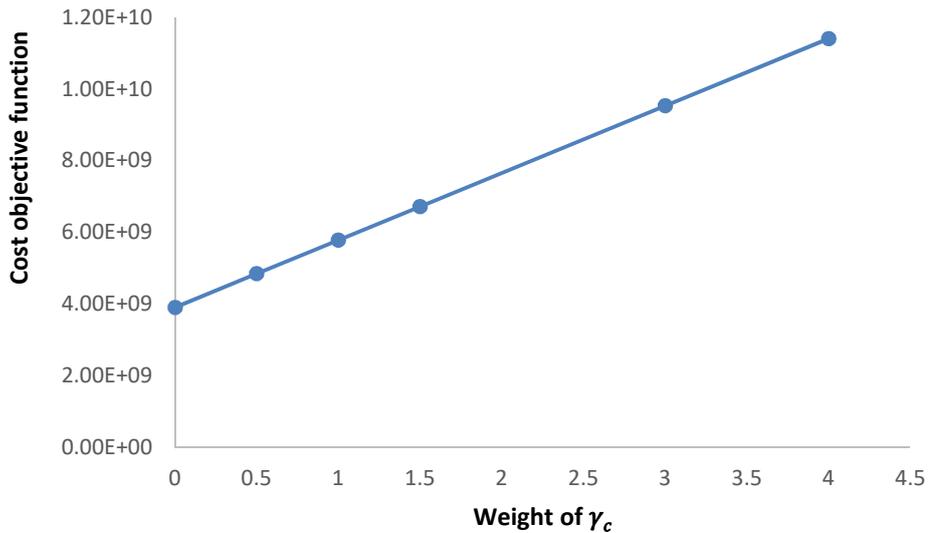


Figure 8- The impact of changes in γ_c on the cost objective function

According to Figure 5 and 7, when the values of these coefficients are zero, there is the greatest risk of decision making. Because at these points, possibilistic variability and scenario variability have their maximum values. In fact, by determining these coefficients, the robustness of the optimal solutions can be controlled according to the preferences of decision makers.

Figure 9 shows the importance of the coefficient ω on the amount of unsatisfied demand cost. According to this figure, by increasing this coefficient, the amount of unsatisfied demand cost decreases. Indeed, by increasing this coefficient, the feasibility

robustness will be high. Besides, according to Figure 10, by increasing ω , the total cost will increase.

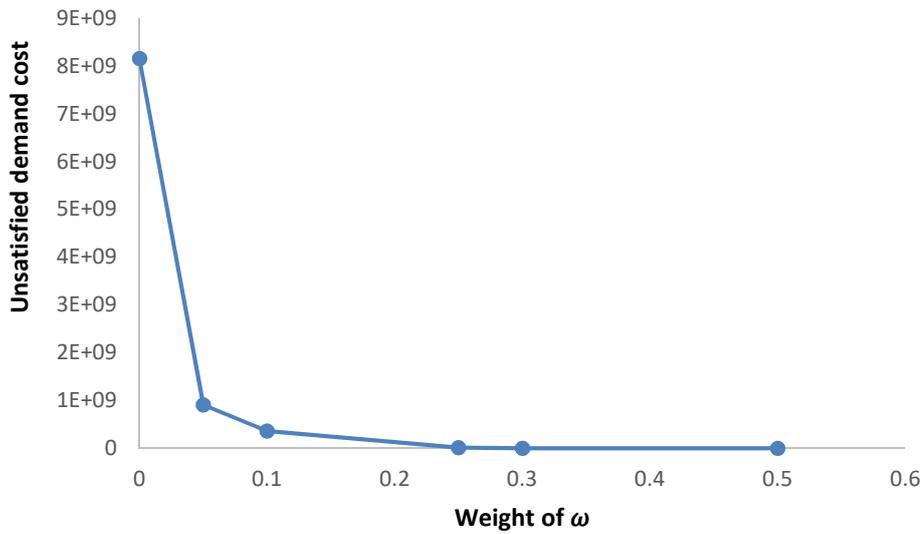


Figure 9- The impact of changes in ω on the unsatisfied demand cost

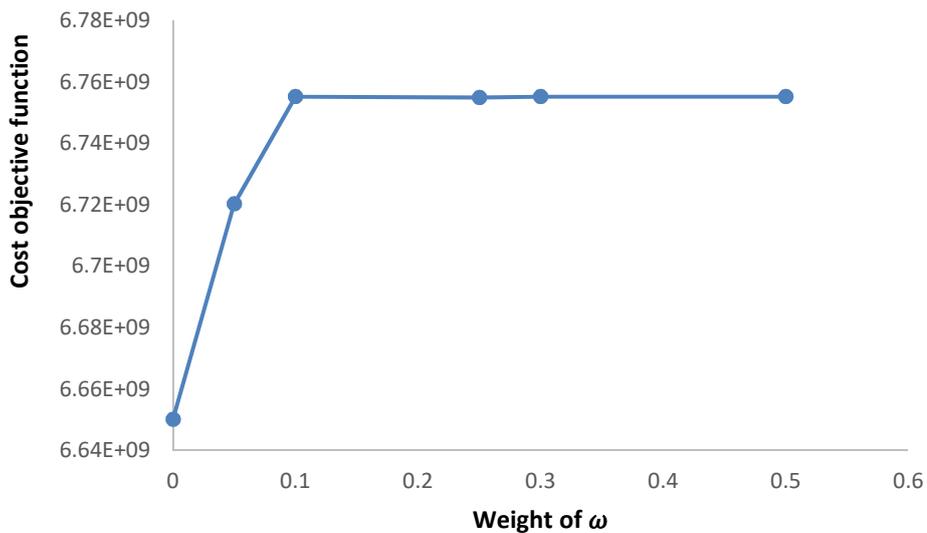


Figure 10- The impact of changes in ω on the cost objective function

In the following, the impact of risk coefficients on the environmental objective function is investigated. Figures 11 and 12 show the impact of λ_e on possibilistic variability values of the environmental objective function and the values of the total environmental objective function. According to Figure 11, for different values of λ_e , these values remain almost constant and do not show much sensitivity to this coefficient. But as shown in Figure 12, by increasing this coefficient, the value of the environmental objective function will increase.

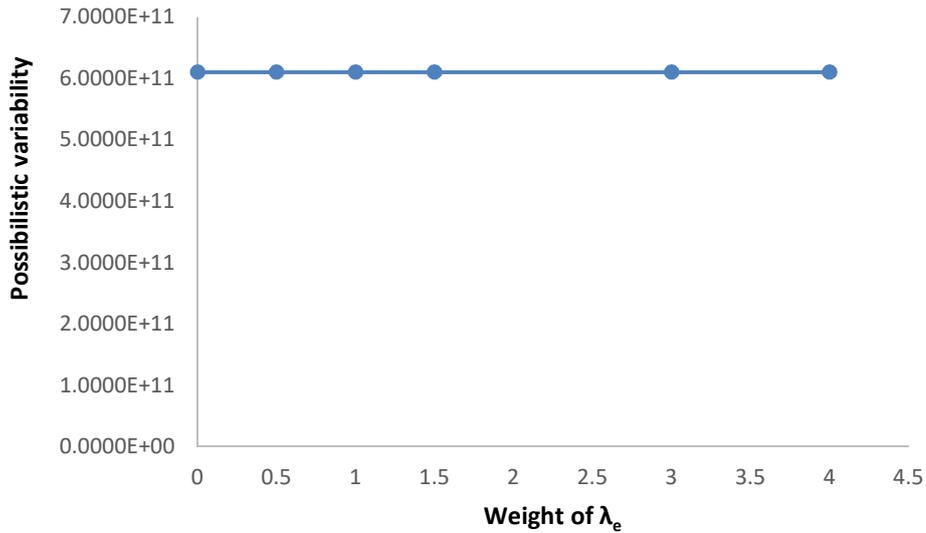


Figure 11- The impact of changes in λ_e on the possibilistic variability of the environmental objective function

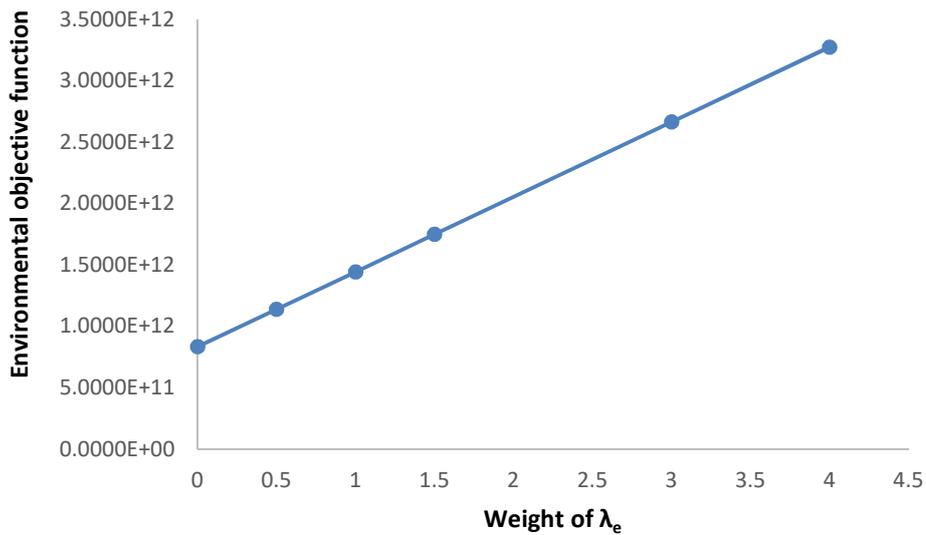


Figure 12- The impact of changes in λ_e on the environmental objective function

Similarly, the scenario variability of the environmental objective function and the total value of the environmental objective function for different values of γ_e are shown in Figures 13 and 14. As this coefficient increases, the amount of scenario variability first decreases and then remains constant. However, the total value of the environmental objective function increases with increasing this coefficient.

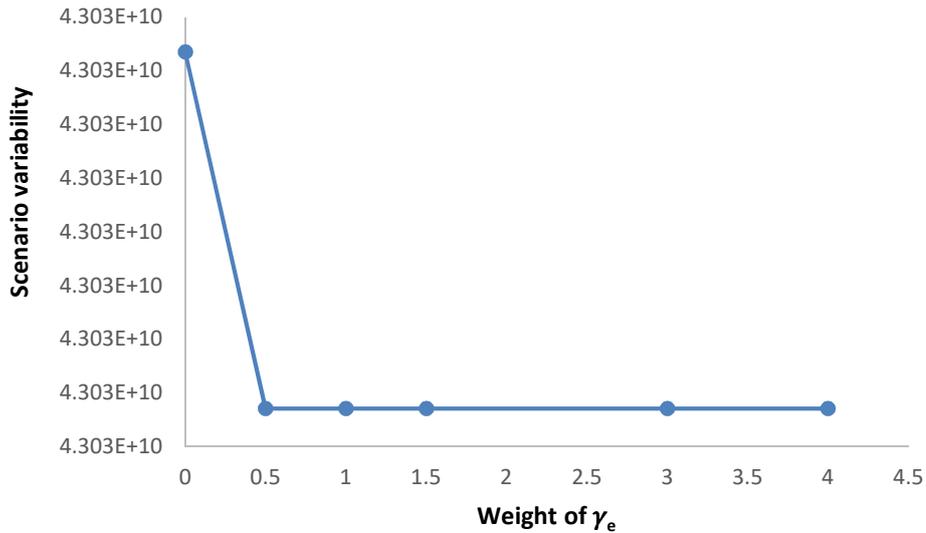


Figure 13- The impact of changes in γ_e on the scenario variability of the environmental objective function

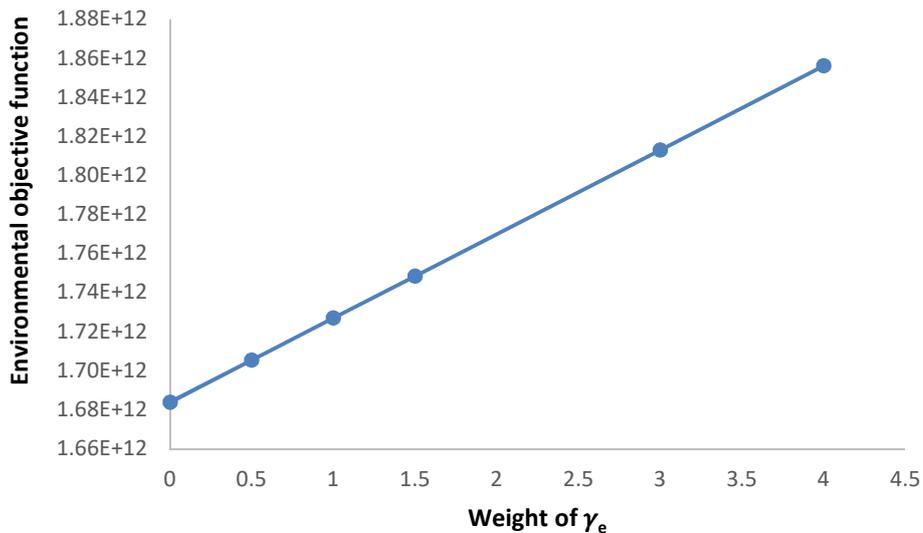


Figure 14- The impact of changes in γ_e on the environmental objective function

The results of sensitivity analysis show that the sensitivity of the environmental objective function to risk coefficients is less than the cost objective function. This can be explained by the fact that the fluctuations and uncertainties of the parameters of the environmental objective function are less than the cost objective function ones.

6- Conclusion

Despite the fact that biodiesel has good properties that could be an appropriate alternative to petrodiesel, has not a large share of the energy market due to its high production cost. Effective and efficient design of BSCN can decrease a lot of of these costs. Iran has great

potential of RE resources especially biomass. While the biomass is fairly cheap, the logistic costs are major obstacles in utilizing these sources.

Biodiesel supply chain can be subject of several uncertain parameters that may greatly affect the optimal configuration . Therefore, in this paper, a fuzzy stochastic optimization model is presented to design a BSCN under hybrid uncertainty. The amount of fixed cost for establishing the facilities, and environmental impact of opening of capacities are described as fuzzy variables. The quantity of demands, supplies and some costs (producing, inventory holding, and shipment) and some environmental impacts (producing, inventory holding, and shipment) are consider as fuzzy scenario based variables.

In this paper, a multi-objective robust fuzzy stochastic programming model is proposed for designing the BSCN under hybrid uncertainty. The presented model aims to simultaneously minimize the total cost and the total environmental impacts of activities of the supply chain network. The results show the effectiveness of the presented approach for designing the BSCN.

The proposed model is implemented in a real case study to design Iran's BSCN. Due to, importing most of edible oils and high cost of producing from these sources, utilizing edible oil sources for producing biodiesel in Iran is irrational. So, in this paper, WCO, JCL and SL are regarded as sources of producing biodiesel. The proposed model determines the optimum location, number, and capacity of the centers of JCL and SL cultivating, oil extraction, distribution and biorefineries.

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