International Journal of Renewable Energy Resources 11 (2021) 1-12
https://doi.org/10.22452/ijrer.vol11no1.1

INTEGRATED STRATEGIC AND TACTICAL PLANNING OF NON-EDIBLE BIOMASS-TO-BIOFUEL SUPPLY CHAINS

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Abstract

Iran has a high potential for renewable resources, and biomass is one of the most important of them. While biomass is relatively cheap, the logistic costs are major obstacles in utilizing these sources. In this paper, a mixed-integer linear programming (MILP) model is presented to design the biodiesel supply chain network (BSCN) in Iran. A supply chain model is presented that is in accordance with the real conditions and geographical features of the case study. Since Iran imports most of its edible oils consumption and the cost of producing from these sources are very high, non-edible biomass, including Jatropha Curcas L. (JCL) and waste cooking oil (WCO), are considered as sources of producing biodiesel. In this study, the possibility of capacity expansion of facilities in different periods is considered. The presented approach is used to design a three-echelon, multi-product, multi-period BSCN. This model determines the strategic and tactical decisions, including location, number, capacity of the facilities, production, inventory, and material flow throughout the network. The result of this paper shows the effectiveness of the presented approach for designing the BSCN.

Keywords: Biomass; Biofuels; Sustainability; Supply chain management; Mathematical programming

1. INTRODUCTION

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 fundamental human necessities, in a cleaner and more effective way that can be sustained in the future (Winkler, 2007). Nowadays, energy is undoubtedly crucial for sustainable development and the prosperity of a community. Increment in the energy efficiency of processes applying sustainable resources can very helpful in achieving sustainable development (Hepbasli, 2008). There is a need to develop new energy resources to replace or reduce the use of nonrenewable energy resources (such as coal, petroleum, natural gas, etc.) (Li et al., 2009).

Renewable energies (REs) are considered as one of the potential solutions for climate change, energy security, and sustainable growth (Swain and Karimu, 2020). REs are produced by 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 important in dealing with the energy supply issues and climate change issues (Salamanca et al., 2012).

Biomass is becoming among the most typically applied RE sources in recent years. Biofuels are fuels produced from biomass sources that are commonly used for transportation. Bioethanol and biodiesel that include the most utilized liquid biofuels, are known to be suitable substitutions for petrol and diesel, respectively. Biofuels can be used in existing engines with major modifications (Devarajan et al., 2017). While the biomass is reasonably cheap, the logistic costs play an important role in the price of the biomass delivered to the biorefinery (Atashbar et al., 2016). Since numerous biomass producers are involved in this supply chain, quantitative models can be beneficial to assess and optimize the related costs, the required resources, and the consumption of energy (Ba et al., 2016). Because of the restriction of fossil fuel sources and their negative influences on the environment, in recent years, there have been a lot of researches on designing biofuel supply chains. In designing the BSCN, the strategic decisions, for instance, the location, number, size, and capacity of facilities, and the tactical decisions, like production quantity, mode of transportation, inventory, and transported product among various facilities, are determined (An et al., 2011a). In this study, a MILP model is proposed for designing the BSCN in Iran. The main novelties of this study are summarized as follows:

- Considering only non-edible biomass for biofuel production,
- Integrating tactical and strategic decisions for designing the biofuel supply chains,
- Considering the possibility of capacity expansion of facilities in different periods,
- Considering rail and road transportation modes for effective material flow throughout the network,
- Applying the proposed model in a real case study in Iran.

2. LITERATURE REVIEW

There are different methodologies for designing the biofuels supply chains in the literature, like simulation, mathematical programming models, and GIS (Bai et al., 2011). The mathematical programming models were the most applied method in the literature (Ghaderi et al., 2016). In this section, researches most related to our work are reviewed. Papapostolou et al. (2011) presented a mathematical programming model for designing the biofuel supply chain that considered parameters influencing the efficiency of the entire value chain. The value chain included feedstock production, biofuel production, blending, distribution, and consumption of biofuels. Andersen et al. (2012) presented a MILP model for designing the BSCN in Argentinean, considering Jatropha, sunflower, and soybean as feedstock. Ahn et al. (2015) developed a deterministic mathematical programming method for designing a BSCN that simultaneously considered resource, and demand constraints. This model helped in determining the location and the amount of feedstock, and the location and the size of refineries. Due to complicacy of real world problems, some researchers used nonlinear models in developing biodiesel supply chain networks. Ren et al. (2015) presented a nonlinear programming model for the purpose of assessing the sustainability of BSCN. This model employed the emergy indicator, and multiple locations for building biodiesel plants, multiple feedstocks, and multiple transport modes were considered. Also, in some researches, multi-objective models were developed in designing the BSCN. Ng et al. (2013) synthesized rubber seed supply chain network in Malaysia. A mixed-integer nonlinear model that maximized biomass utilization was presented.

One of the challenges in designing the BSCN is related to the uncertainty of parameters, including biomass demand, supply, price, etc. (Bairamzadeh et al., 2018). Marufuzzaman et al. (2014) presented a stochastic programming method to design a BSCN under technology development and biomass supply uncertainties. They proposed a MOMILP model that optimized costs and emissions of the supply chains. Zhang and Jiang (2017) proposed 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. Depending on the planning horizon, there are different decision levels. Some are strategic decisions that are usually related to long-term goals (one to several years). In the field of biofuels, such decisions include determining the location and capacity of refineries, determining the type of transportation, and so on. Akgul et al. (2010) presented a MILP model for designing a biomass supply chain network. The purpose of the model was to find the size and location of the biorefineries. Wang et al. (2012) proposed a mathematical programming model for determining the optimal size and location of the facilities in a biofuel supply chain. The tactical decisions are related to the medium-term goals (one to several months). In the biofuels supply chains, the amount of products that must be cultivated in each farm in each period and inventory planning are among these decisions. Dunnett et al. (2007) designed a biofuel supply chain for 12 periods of a month. They considered some tactical activities such as cultivation, drying, and storage. Zhu et al. (2011) considered some items, including low bulk density, seasonal cultivation constraints, climatic effects, etc., for designing a bioethanol supply chain. If each of the strategic and tactical decisions is considered alone, there is no guarantee that the obtained solution will be the global optimal solution of the problem, because the result may be a local optimal solution. Motivated by the shortcomings in literature, in this article, a new integrated model is presented that considers both tactical and strategic decisions in designing BSCN. This integrated model considers long-term (strategic) decisions, like location, number, and capacity of the facilities, and considers medium-term (tactical) decisions, including the quantity of production, inventory, and transportation of materials in different periods. Besides, in this study, in order to bring the model closer to the real world, the capacities of refineries are accounted over each period through discrete decision variables.

The presented model is applied in a real case study to design the BSCN in Iran. There is air pollution in most cities of Iran, which causes many people to die every year, and also makes a lot of direct and indirect costs, such as closing schools, universities, and markets in the country. Therefore, the Iranian government must consider serious policies to replace fossil fuels with biofuels. It should be noted that the price of biodiesel in the country is much higher than diesel, which has made its development very difficult. Optimal designing of BSCN can reduce many of these costs. Therefore, in this article, a

MILP model is presented to design the BSCN in Iran. The proposed designed BSCN considers the specific climate and domestic issues of the country to bring it closer to the real world. For example, most researches in the literature used edible oil sources such as corn, palm, etc. in the biofuel supply chains. But, since Iran imports most of its edible oil consumption (about 80%), utilizing these edible sources for producing biodiesel is irrational. Therefore, in this study, non-edible sources, including JCL and WCO, are selected as sources to produce biodiesel. Water scarcity is another severe problem in Iran. In addition to the fact that Jatropha has very high efficiency in converting to biodiesel, it is a plant that needs very little water for cultivation and can be cultivated in the most arid and semi-arid parts of Iran.

3. MODEL FORMULATION

In this paper, according to the stated case study, a three-echelon, multi-product, multi-period BSCN is designed. The structure of the BSCN, considered in this research, is shown in Figure 1. According to Figure 1, the JCL products are shipped from cultivation centers to JCL oil extraction facilities. Besides, the collected WCO from supply locations is transported to biorefinery centers. In biorefineries, the collected WCO is pre-treated, and then biodiesel is produced through pre-treated WCO and JCL oil. Eventually, biodiesel is shipped from biorefineries to customer centers for blending by diesel

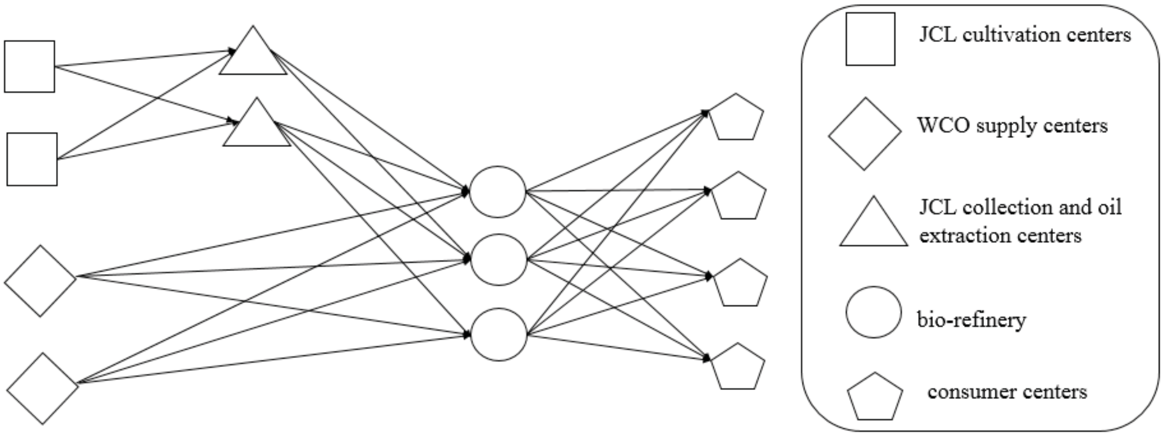

Fig.1 Illustration of the proposed BSCN

3.1. ASSUMPTIONS AND NOTATIONS

It is considered the following assumptions for developing the proposed model:

- Shortage is not allowed, and all biodiesel demands should be satisfied.
- The potential regions for cultivating JCL and the potential locations of other facilities are known.
- Customer centers are fixed and known.
- All of the parameters applied in the BSCN design are assumed to be deterministic.
- Transportations are performed via road and rail transportation modes.
- Capacity of cultivating areas and JCL oil extraction centers are not fixed. These capacities are calculated over the planning horizon by continuous variables.
- Required capacity for each biorefinery is accounted through adding the capacity alternatives to the corresponding initial capacity.

The following is the notation we use in this model. All the parameters are denoted by uppercase symbols, and all the variables are represented by lowercase symbols.

Sets

B	Set of potential areas for cultivating JCL
G	Set of potential areas for supplying WCO
I	Set of potential areas for extracting JCL oil
J	Set of potential areas of biorefineries
M	Set of consumer centers
R	Set of transportation modes
O	Set of capacity option for biorefinery
T	Set of time periods

Parameters

D_{mt}	Biodiesel demand of consumer center m at year t
W_{gt}	Quantity of WCO supplied through supplier g at year t
L_b	Minimum allowable area for cultivating JCL in area b
U_b	Maximum allowable area for cultivating JCL in area b
L_i	Minimum allowable capacity of JCL oil extraction facility in area i
U_i	Maximum allowable capacity of JCL oil extraction facility in area i
L_j	Minimum allowable biorefinery capacity in area j

U_j	Maximum allowable biorefinery capacity in area j
η_{bt}	Quantity of JCL products per hectare in area b at year t
α^1	JCL conversion rate to its oil
α^2	WCO conversion rate to its pre-treated form
β^1	JCL oil conversion rate to biodiesel
β^2	Pre-treated WCO Conversion rate to biodiesel
S_{jt}	Initial biorefinery j capacity at year t
N_{ojt}	Capacity of option o for biorefinery j at year t
$\mathrm{F_b}$	Fixed cost for cultivating JCL in area b
$\mathrm{F_i}$	Fixed cost for establishing JCL oil extraction facility in area i
$\mathrm{F_j}$	Fixed cost for establishing biorefinery in area j
$\mathrm{V_b}$	Unit variable cost for cultivating JCL in area b
$\mathrm{V_{it}}$	Unit variable cost of JCL oil extraction facility i at year t
$\mathrm{V_{jt}}$	Unit variable cost of biorefinery j at year t
$\mathrm{P_{bt}}$	Unit cost for producing JCL products in area b at year t
$\mathrm{P_{gt}}$	Unit cost for collecting WCO in supply center g at year t
$\mathrm{P_{it}}$	Unit cost for extracting oil from JCL products in JCL oil extraction facility i at year t
$\mathrm{PW_{jt}}$	Unit cost for pre-treatmenting WCO in biorefinery j at year t
$\mathrm{P_{jt}}$	Unit cost for producing biodiesel in biorefinery j at year t
$\mathrm{H_{it}}$	Cost of holding inventory per unit of JCL products in JCL oil extraction facility i at year t
$\mathrm{H_{jt}}$	Cost of holding inventory per unit of biodiesel in biorefinery j at year t
A_{brit}	Cost of transporting JCL products between cultivation center b and JCL oil extraction facility i via mode r at year t
A_{grjt}	Cost of transporting WCO between supplier g and biorefinery j via mode r at year t
A_{irjt}	Cost of transporting JCL oil between oil extraction facility i and biorefinery j via mode r at year t
A_{jrmt}	Cost of transporting biodiesel between biorefinery j and consumer m via mode r at year t
E_{ojt}	Fixed cost for adding capacity level o for biorefinery j at year t

Decision Variables

y_b	Binary variable assuming value of 1 if area b is chosen for JCL cultivation, and 0 otherwise
y_i	Binary variable assuming value of 1 if area i is chosen for establishing JCL oil extraction facility, and 0 otherwise
y_{jt}	Binary variable assuming value of 1 if area j is chosen for establishing biorefinery at year t, and 0 otherwise
z_{ojt}	Binary variable assuming value of 1 if capacity level o is added to biorefinery j at year t, and 0 otherwise
k_{it}	JCL products inventory level in JCL oil extraction facility i at year t
k_{jt}	Biodiesel inventory level in biorefinery j at year t
$\mathrm{q_{bt}}$	Quantity of JCL produced in cultivation area b at year t
$\mathrm{q_{it}}$	Quantity of JCL oil produced in JCL oil extraction facility i at year t
$\mathrm{qw_{jt}}$	Quantity of pre-treated WCO produced at biorefinery j at year t
$\mathrm{q_{jt}}$	Quantity of biodiesel produced in biorefinery j at year t
$\mathrm{x_{brit}}$	Quantity of JCL products shipped from cultivation area b to JCL oil extraction facility i via mode r at year t
$\mathrm{x_{grjt}}$	Quantity of WCO shipped from supplier g to biorefinery j via mode r at year t
$\mathrm{x_{irjt}}$	Quantity of JCL oil shipped from JCL oil extraction facility i to biorefinery j via mode r at year t
$\mathrm{x_{jrmt}}$	Quantity of biodiesel shipped from biorefinery j to consumer m via mode r at year t
$\mathrm{c_b}$	Total cultivated land of JCL in area b
$\mathrm{c_{it}}$	Total capacity of JCL oil extraction facility i at year t
$\mathrm{ce_{it}}$	Amount of expansion of the capacity in JCL oil extraction facility i at year t
$\mathrm{c_{jt}}$	Total capacity of biorefinery j at year t

3.2. OBJECTIVE FUNCTION

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

$$\mathrm{FC} = \sum_{b} \mathrm{F_b}\, y_b + \sum_{i} \mathrm{F_i}\, y_i + \sum_{j}\sum_{t} \mathrm{F_j} \left(y_{jt} - y_{j,t-1}\right) + \sum_{o}\sum_{j}\sum_{t} E_{ojt}\left(z_{ojt} - z_{oj,t-1}\right) \tag{1}$$

$$\mathrm{VC} = \sum_{b} \mathrm{V_b}\, \mathrm{c_b} + \sum_{i}\sum_{t} \mathrm{V_{it}}\, \mathrm{c_{it}} + \sum_{j}\sum_{t} \mathrm{V_{jt}}\, \mathrm{c_{jt}} \tag{2}$$

$$\mathrm{PC} = \sum_{b}\sum_{t} \mathrm{P_{bt}}\, \mathrm{q_{bt}} + \sum_{g}\sum_{t} \mathrm{P_{gt}}\, W_{gt} + \sum_{i}\sum_{t} \mathrm{P_{it}}\, \mathrm{q_{it}} + \sum_{j}\sum_{t} \mathrm{PW_{jt}}\, \mathrm{qw_{jt}} + \sum_{j}\sum_{t} \mathrm{P_{jt}}\, \mathrm{q_{jt}} \tag{3}$$

$$\mathrm{IC} = \sum_{i}\sum_{t} \mathrm{H_{it}}\, k_{it} + \sum_{j}\sum_{t} \mathrm{H_{jt}}\, k_{jt} \tag{4}$$

$$\mathrm{TC} = \sum_{b}\sum_{r}\sum_{i}\sum_{t} \mathrm{A}_{brit}\, \mathrm{x_{brit}} + \sum_{g}\sum_{r}\sum_{j}\sum_{t} \mathrm{A}_{grjt}\, \mathrm{x_{grjt}} + \sum_{i}\sum_{r}\sum_{j}\sum_{t} \mathrm{A}_{irjt}\, \mathrm{x_{irjt}} + \sum_{j}\sum_{r}\sum_{m}\sum_{t} \mathrm{A}_{jrmt}\, \mathrm{x_{jrmt}} \tag{5}$$

3.3. CONSTRAINTS

Equation (6) guarantees that the quantity of biodiesel moved from biorefineries to customer centers is equal to their demands. Constraints (7) and (8) state that in each period, all JCL and WCO are moved to oil extraction centers and biorefineries, respectively.

$$\sum_{j}\sum_{r} \mathrm{x_{jrmt}} = D_{mt} \qquad \forall\, m,\, t \tag{6}$$

$$\sum_{r}\sum_{i} \mathrm{x_{brit}} = \mathrm{q_{bt}} \qquad \forall\, b,\, t \tag{7}$$

$$\sum_{r}\sum_{j} \mathrm{x_{grjt}} = W_{gt} \qquad \forall\, g,\, t \tag{8}$$

Constraint (9) represents the quantity of JCL yields in the cultivation areas. Constraints (10) and (11) state the quantity of JCL oil and pre-treated WCO at oil extraction facilities and biorefineries, respectively. Constraint (12) calculates the quantity of produced biodiesel at biorefineries.

$$\mathrm{q_{bt}} = \eta_{bt}\mathrm{c_b} \qquad \forall\, b,\, t \tag{9}$$

$$\mathrm{q_{it}} = \alpha^1 \sum_{b}\sum_{r} \mathrm{x_{brit}} \qquad \forall\, i,\, t \tag{10}$$

$$\mathrm{qw_{jt}} = \alpha^2 \sum_{g}\sum_{r} \mathrm{x_{grjt}} \qquad \forall\, j,\, t \tag{11}$$

$$\mathrm{q_{jt}} = \beta^1 \sum_{i}\sum_{r} \mathrm{x_{irjt}} + \beta^2 \mathrm{qw_{jt}} \qquad \forall\, j,\, t \tag{12}$$

Constraints (13) and (14) enforce the inventory balance for JCL seeds and biodiesel at oil extraction centers and biorefineries, respectively

$$k_{it} = k_{i,t-1} + \sum_{b}\sum_{r} \mathrm{x_{brit}} - \left(\frac{1}{\alpha^1}\right)\sum_{r}\sum_{j} \mathrm{x_{irjt}} \quad \forall\, i,\, t \tag{13}$$

$$k_{jt} = k_{j,t-1} + \mathrm{q_{jt}} - \sum_{r}\sum_{m} \mathrm{x_{jrmt}} \qquad \forall\, j,\, t \tag{14}$$

Constraint (15) represents a logical expression. Constraint (16) states that when a biorefinery is opened in any time period, it will be operative up to the end of the time horizon. Also, constraint (17) guarantees when a capacity option is added to a biorefinery, it will be operative up to the end of the time horizon. Equations (18)- (20) show the minimum and maximum required capacities of the facilities. Equation (21) considers capacity expansion for established JCL oil extraction facilities. Equation (22) calculates the total capacity of biorefineries over the planning horizon

$$z_{ojt} \le y_{jt} \qquad \forall\, o, j, t \tag{15}$$

$$y_{jt} \le y_{j,t+1} \qquad \forall\, j, t \tag{16}$$

$$z_{ojt} \le z_{oj,t+1} \quad \forall\, o, j, t \tag{17}$$

$$y_b L_b \le \mathrm{c_b} \le y_b U_b \quad \forall\, b \tag{18}$$

$$y_i L_i \le \mathrm{c_{it}} \le y_i U_i \quad \forall\, i, t \tag{19}$$

$$y_{jt} L_j \le \mathrm{c_{jt}} \le y_{jt} U_j \quad \forall\, j, t \tag{20}$$

$$\mathrm{c_{it}} = \mathrm{c_{i,t-1}} + \mathrm{ce_{it}} \quad \forall\, i, t \tag{21}$$

$$\mathrm{c}_{\mathrm{jt}} = \mathrm{c}_{\mathrm{j,t-1}} + S_{jt}(y_{jt} - y_{j,t-1}) + \sum_{o} N_{ojt}\, z_{ojt} \qquad \forall\, j,t \tag{22}$$

Constraint (23) ensures that the quantity of transported JCL products from cultivation centers to JCL oil extraction centers does not exceed their capacities. Constraint (24) also guarantees that the total quantity of JCL oil and WCO shipped from their corresponding centers to biorefineries does not exceed their capacities. Constraints (25) and (26) enforce that the level of inventory in the facilities does not exceed their capacities.

$$\sum_{b}\sum_{r} \mathrm{x}_{\mathrm{brit}} \le \mathrm{c}_{\mathrm{it}} \qquad \forall\, i,\, t \tag{23}$$

$$\sum_{i}\sum_{r} \mathrm{x}_{\mathrm{irjt}} + \sum_{g}\sum_{r} \mathrm{x}_{\mathrm{grjt}} \le \mathrm{c}_{\mathrm{jt}} \qquad \forall\, j,\, t \tag{24}$$

$$k_{it} \le \mathrm{c}_{\mathrm{it}} \qquad \forall\, i,\, t \tag{25}$$

$$k_{jt} \le \mathrm{c}_{\mathrm{jt}} \qquad \forall\, j,\, t \tag{26}$$

Finally, constraints (27) and (28) state the binary and non-negativity natures of the decision variables, respectively.

$$y_b\,, y_i,\; y_{jt}\,, z_{ojt} \;\in \{0{,}1\} \tag{27}$$

$$Continuous\ decision\ variables \ge 0 \tag{28}$$

(28) Continuous decision variables≥0

4. CASE STUDY

Because of the young population, increasing energy demand, rapidly rising urbanization, and the development of the economy in Iran, it has been among the most consumer of energy in the world (Mostafaeipour and Mostafaeipour, 2009). Besides fossil fuels, Iran has a great potential for renewable resources because of its geographical situation. The development of renewable resources, besides the environmental conservation, brings an exceptional opportunity to export fossil fuels that can improve the geopolitical position of Iran in the world (Chaharsooghi and Rezaei, 2016). Biofuel is undoubtedly among the most important RE resources in Iran. The government has paid great attention to the usage of these energies (Yahyaee et al., 2013). In the last years, biodiesel has become an excellent alternative to petro-based diesel (Oh et al., 2012). Due to the air pollution problem in Iran's big cities, the replacement of biodiesel with diesel can reduce the air pollution. Since almost 80 % of Iran's edible oil is provided through imports, using edible oil sources for producing biodiesel is unreasonable. So, the cultivation of JCL, which is a non-edible vegetable oil source and is suitable for cultivation in the climatic conditions of Iran, can be an excellent opportunity for Iran. Another challenge in using edible oil sources for producing biodiesel is their significant production cost (Mohammadshirazi et al., 2014). Consequently, WCO, which is much cheaper compared to edible oil sources, can be a good alternative to them (Canakci and Van Gerpen, 1998). Therefore, in this paper, WCO and JCL are selected as the sources of biodiesel production. The presented method is implemented for a 10 years planning horizon. The regions that are most compatible with Iran's climate are considered as potential areas for JCL cultivation, of which 11 locations are selected. There are 30 considered cities in Iran, in which, according to their demand for diesel and air pollution, 18 cities are designated as biodiesel consumers.

5. RESULTS AND DISCUSSION

In this research, a BSCN design model is presented to determine the location, number, and capacity of the facilities in different periods. To solve this MILP model, CPLEX solver of GAMS software is applied. The parameters used in the presented model are obtained from historical data and the scientific studies in the literature. For example, Table 1 shows the different values of the conversion rates.

Table 1 The values of the conversion rates (percent)

Conversion rate	Value	Reference
α^1	0.35	(Brittaine and Lutaladio, 2010)
α^2	0.95	Assumption
β^1, β^2	0.83	(Fukuda et al., 2001; Achten et al., 2008)

In this article, two modes of transportation (road and rail) are considered. The distance between the cities (facilities), for the road mode from Ministry of Roads & Urban Development (www.mrud.ir), and for the rail mode from Asia Seir Aras Company (www.asiaseiraras.com), are achieved. Transportation costs between the facilities are obtained by multiplying the unit transportation cost (taken from (An et al., 2011b, 2011c)) in the distance between them. Quantities of WCO supplied from the cities are achieved from the IFCO (www.ifco.ir), which are shown in Table 2.

Table 2 The quantity of WCO supplied from the different cities; W_gt (ton).

City	Year									
	1	2	3	4	5	6	7	8	9	10
Tabriz	11130	11180	11229	11280	11331	11380	11430	11482	11533	11584
Uromieh	9205	9246	9288	9331	9370	9413	9455	9496	9539	9581
Ardabil	3731	3748	3764	3780	3798	3815	3832	3849	3867	3883
Isfahan	14581	14647	14712	14777	14843	14908	14975	15042	15108	15176
Ilam	1666	1676	1681	1688	1697	1705	1712	1720	1727	1732
Bushehr	3087	3102	3115	3130	3143	3155	3171	3182	3199	3213
Tehran	36408	36570	36732	36897	37061	37226	37391	37558	37725	37893
Chahar Mahaal and Bakhtiari	2676	2688	2700	2712	2725	2735	2748	2762	2772	2784
Khorasan J.	1979	1988	1998	2006	2016	2024	2033	2042	2051	2064
Khorasan R.	17914	17994	18072	18154	18232	18316	18397	18479	18564	18643
Khorasan Sh.	2593	2604	2617	2628	2639	2652	2664	2676	2688	2700
Khozestan	13542	13603	13663	13725	13786	13847	13908	13970	14033	14095
Zanjan	3036	3050	3064	3075	3091	3104	3118	3130	3146	3159
Semnan	1888	1894	1903	1912	1921	1929	1938	1946	1955	1965
Sistan va Balochestan	7574	7608	7643	7676	7709	7744	7778	7814	7848	7883
Fars	13738	13798	13858	13921	13982	14046	14108	14171	14232	14296
Gazvin	3591	3608	3623	3638	3655	3671	3688	3705	3720	3738
Gom	3444	3457	3473	3488	3504	3519	3536	3550	3568	3582
Kurdistan	4465	4482	4504	4524	4545	4564	4584	4604	4626	4647
Kerman	8783	8821	8863	8901	8941	8979	9019	9061	9101	9141
Kermanshah	5814	5839	5866	5893	5916	5944	5970	5996	6024	6050
Kohgiluyeh and Boyer-Ahmad	1968	1977	1986	1996	2004	2014	2021	2030	2039	2050
Golestan	5311	5334	5358	5381	5405	5430	5455	5478	5501	5527
Gilan	7414	7447	7479	7514	7546	7581	7613	7648	7682	7717
Lorestan	5244	5266	5289	5314	5337	5361	5384	5408	5432	5455
Mazandaran	9188	9227	9268	9308	9351	9393	9432	9477	9518	9563
Markazi	4226	4246	4264	4283	4300	4320	4339	4358	4379	4398
Hormozgan	4717	4738	4758	4780	4800	4822	4843	4866	4888	4908

Hamadan	5254	5278	5300	5325	5349	5371	5397	5421	5445	5468
Yazd	3212	3226	3240	3254	3268	3283	3298	3314	3327	3343

Table 3 The demand of biodiesel in the cities; D_{mt} (ton)

City	Year									
	1	2	3	4	5	6	7	8	9	10
Tabriz	21847	22633	23310	35832	36566	61977	94291	95436	128590	129791
Uromieh	25024	25924	26699	27362	41883	42594	43201	72876	73645	74333
Isfahan	67995	105662	108823	185871	189676	289344	391290	396043	600331	605936
Bushehr	25044	25945	26721	27384	41917	42629	43237	72936	73706	74394
Tehran	74700	116081	119553	204199	208379	317875	429872	435095	659527	665684
Khorasan R.	44209	45800	47170	72510	73994	125418	190807	193125	260216	262646
Khozestan	58320	60418	62225	95654	97612	165448	251709	254767	343272	346477
Sistan va Balochestan	48438	50181	51682	79446	81073	137415	209060	211600	285109	287771
Fars	56051	58067	59804	91932	93814	159011	241915	244853	329915	332995
Gazvin	24260	25133	25885	26527	40605	41295	41883	70653	71399	72065
Kurdistan	11656	12075	12436	12745	19508	19840	20122	33945	34303	34623
Kerman	46520	48193	49635	50866	77862	79183	80312	135479	136908	138186
Kermanshah	18464	19128	19700	20189	30902.9	31428	31875	53771	54338	54846
Lorestan	12460	12909	13295	13625	20855.1	21209	21511	36288	36671	37013
Markazi	22053	22846	23530	24114	36910.8	37538	38072	64225	64902	65508
Hormozgan	37587	38939	40104	41099	62910.7	63979	64890	109465	110619	111652
Hamadan	12130	12567	12943	13264	20302.7	20647	20942	35327	35699	36033
Yazd	25127	26031	26810	27475	42055.5	42770	43379	73177	73949	74639

Table 4 Optimal values of the objective function components according to Iran currency (MIRR)

Fixed establishing costs (FC)	Inventory holding costs (IC)	Variable establishing costs (VC)	Production costs (PC)	Transportation costs (TC)	Total Costs
6184867	263814300	2998731000	2733996000	200301900	6203028067

Note: MIRR: Million Iranian Rials.

Since there is no data on biodiesel demand in the country, diesel demand data (extracted from https://niordc.ir/) has been used to estimate their values. According to the level of air pollution and diesel demand in these areas, based on some percentages (between 2 to 15%), their biodiesel demands are estimated. Table 3 shows the biodiesel demand for each of these cities in different periods. In this study, a 10 years planning horizon for implementing the proposed model is considered. 11 locations compatible with climate of Iran are selected as candidate areas for JCL cultivation. Besides, as stated in this section, considering the demand for diesel and the air pollution problem of the cities, 18 cities are selected as biodiesel consumers. Therefore, in this model, 11 potential areas for cultivating JCL, 30 potential WCO suppliers, 30 candidate areas for JCL oil extraction facilities, 30 candidate areas for biorefineries, 18 areas for biodiesel consumers, and 2 transportation modes are considered. The optimal values of the objective function components are presented in Table 4. As shown in Table 4, the maximum costs are related to variable establishing costs and production costs. The best areas for cultivating JCL and their capacities are shown in Figure 2. As shown in Figure 2, Chahar Mahaal and Bakhtiari has the highest capacity of JCL cultivation. The rest cities have almost the same JCL cultivation capacity. The selected areas for JCL oil extraction facilities and their capacities in different periods are shown in Table 5. As shown in this table, the total capacity of JCL oil extraction facilities increases almost linearly over time.

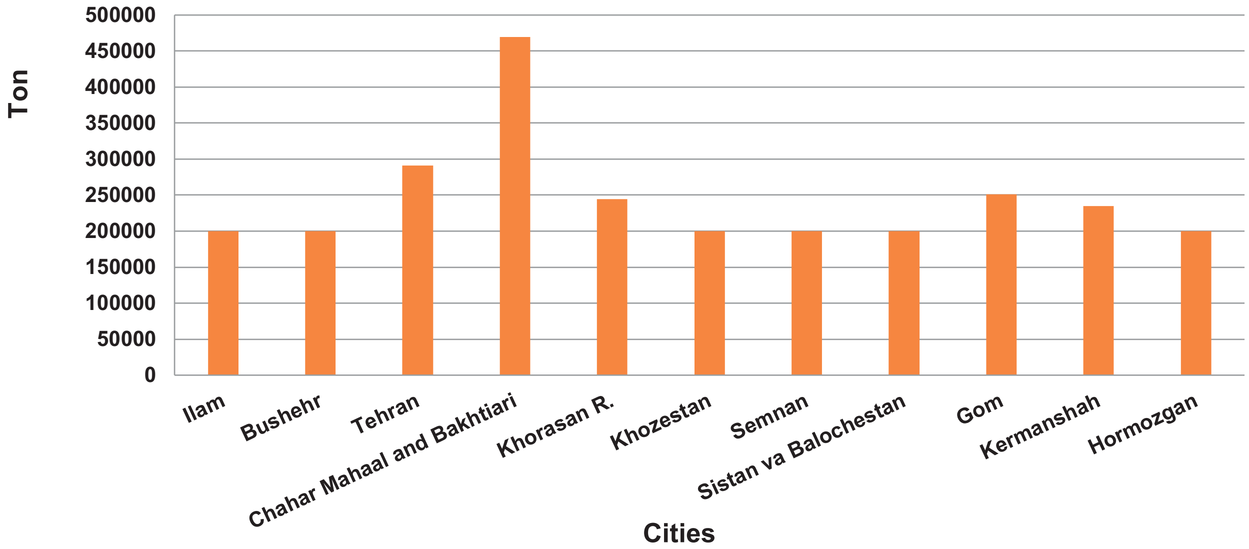

Figure 2: Selected areas for cultivating JCL

Table 5 Capacity of selected JCL oil extraction facilities (ton)

City	Year									
	1	2	3	4	5	6	7	8	9	10
Isfahan	20000	20000	543185	1535679	2997482	3754478	4495578	5236677	5600000	5600000
Ilam	100000	300000	600000	800000	1000000	1201728	1800000	2800000	3800000	4800000
Bushehr	160000	600000	797590	797590	797590	1520000	2456189	2862360	3420788	4800000
Tehran	145364	416092	697292	697292	1570409	2301332	2890053	3336587	4146360	5600000
Chahar Mahaal and Bakhtiari	234655	683964	884743	884743	884743	1589550	1605446	1605446	2453454	4800000
Khorasan J.	20000	164594	201817	201817	201817	201817	201817	201817	201817	201817
Khorasan R.	122284	366852	733705	988251	1846384	2527784	2984370	3433255	4377159	5600000
Khozestan	160000	600000	1000000	1200000	1956531	2626603	3069197	3435878	4080000	5600000
Semnan	100000	300000	600000	800000	1000000	1288610	1967456	2800000	3800000	4800000
Sistan va Balochestan	160000	435406	962777	1200000	1520000	2040340	2413220	2892257	3280000	4800000
Gazvin	20000	20000	194893	660513	660513	660513	660513	660513	660513	660513
Gom	125395	376186	732373	732373	823530	1850166	2172685	2292091	3546045	4800000
Kurdistan	20000	85955	524226	1197375	2371764	2371764	2371764	2371764	2371764	2371764

City	Year									
	1	2	3	4	5	6	7	8	9	10
Kermanshah	117439	266362	266362	266362	266362	1440750	2102427	2451223	3625611	4800000
Kohgiluyeh and Boyer-Ahmad	20000	20000	202410	604820	1327230	1327230	1327230	1327230	1327230	1327230
Markazi	20000	20000	20000	290791	721216	721216	721216	721216	721216	721216
Hormozgan	160000	600000	1000000	1200000	1520000	1977194	2425317	2730649	3280000	4800000
Total	1705137	5275411	9961372	14057605	21465571	29401076	35664477	41158963	50691957	66082540

Table 6 Capacity of selected locations for biorefineries (ton)

City	Year									
	1	2	3	4	5	6	7	8	9	10
Tabriz	56000	106000	156000	206000	256000	306000	356000	406000	456000	506000
Isfahan	120000	220000	320000	420000	520000	620000	720000	820000	920000	1020000
Bushehr	20000	25000	30000	35000	40000	45000	50000	55000	60000	65000
Tehran	55000	105000	155000	205000	255000	305000	355000	405000	455000	505000
Khorasan R.	55000	105000	155000	205000	255000	305000	355000	405000	455000	505000
Khozestan	61000	116000	171000	226000	281000	336000	391000	446000	501000	556000
Semnan	55000	105000	155000	205000	255000	305000	355000	405000	455000	505000
Sistan va Balochestan	110000	160000	210000	260000	310000	360000	410000	460000	510000	560000
Fars	55000	105000	155000	205000	255000	305000	355000	405000	455000	505000
Gom	55000	105000	155000	205000	255000	305000	355000	405000	455000	505000
Kermanshah	55000	105000	155000	205000	255000	305000	355000	405000	455000	505000
Hormozgan	80000	130000	180000	230000	280000	330000	380000	430000	480000	530000
Total	777000	1387000	1997000	2607000	3217000	3827000	4437000	5047000	5657000	6267000

Table 6 shows the capacity of selected biorefineries in different periods. Like the JCL oil extraction facilities' capacities, the total capacity of biorefineries increases almost linearly over time. As illustrated in Figure 2 and Tables 5 and 6, JCL oil extraction facilities are established in the selected cultivation locations and industrial cities. Besides, biorefineries are nearly established in the chosen locations of cultivating JCL and big cities. Moreover, the number and dispersion of JCL oil extraction facilities are more than other facilities.

6. CONCLUSION

Though Iran has high reserves of fossil energy sources, it shouldn't rely on these types of sources, and it must create policies for the development of renewable energies. Replacement of diesel with biodiesel can reduce the air pollution problem in Iran's big cities. Moreover, development of biofuels provides the opportunity to export fossil fuels that improves the international position of Iran. The potential for renewable energy resources, especially biomass, is high in the country. The high costs of renewable energies are the main challenges of applying these energies in the country. While biomass is relatively cheap, the logistic costs are essential component of fuel supply costs. In this article, a MILP model is presented to integrate tactical and strategic decisions in biofuel supply chain networks. The presented method was implemented for 10 years planning horizon in Iran. The proposed MILP model determines the optimum strategic decisions, such as the location, number, and capacity of the centers of JCL cultivating, oil extraction, and biorefineries. It also determines tactical decisions, including the amount of production, inventory, and transportation of materials in different periods.

The proposed supply chain model is in accordance with the actual conditions and geographical features of the case study to bring it closer to the real world. Since Iran imports most of its edible oils consumption and the high cost of producing from these sources, utilizing sources of edible oils for producing biodiesel in Iran is irrational. Therefore, in this paper, non-edible biomass, including WCO and JCL, are regarded as sources of producing biodiesel. Besides, motivated by the shortcomings in literature, the capacities of refineries are considered as discrete decision variables. The results of this research can help policymakers, energy planners, private industry, and others to make the right tactical and strategic decisions in designing and planning the BSCN. The proposed model could be investigated under uncertainty of parameters in the future. Also, considering other non-edible biomass in planning the supply chain will strengthen its flexibility in supplying the required biomass

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