Journal of Optimization in Industrial Engineering
Vol.15, Issue 2, Summer & Autumn 2022, 201- 226
Doi: 10.22094/joie.2022.1953244.1941

Research Article

A Scenario-Based Robust Compromise Programming Approach for Design of Bioethanol and Electricity Supply Chain in Iran

Babak Rostami-Ranjbar[a], **Mohammad Saidi-Mehrabad**[a,*]

[a] *Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*

Received 21 February 2022; Revised 27 June 2022; Accepted 06 July 2022

Abstract

Concerning global warming and the Greenhouse gas (GHG) effect, clean energy resources have captured researchers' interest recently. Biomass materials are among important biofuels and bioenergy production resources that have the potential to replace fossil fuels. Using biomass materials leads to a decline in GHG emission and air pollution levels, not being dependent on fossil fuels, and provide energy security. Due to the importance of bioenergy and biofuels, a multi-product, multi-period, and green mathematical model has been developed to improve economic and environmental objectives for bioethanol and the electricity supply chain. It includes the following decisions: determining production centers' location and capacity, technology selection, determining inventory holding level, biomass type selection, allocation, amount of material flow, and determining transportation modes. In this study, a scenario-based robust compromise programming approach (SRCP) is developed for the bi-objective solution of the provided mathematical model and determining Pareto optimal points under uncertain conditions. Finally, the performance and effectiveness of SRCP are provided, and the results obtained from the case study in Iran are analyzed. According to the results, Annual electricity and bioethanol production capacity are at least 8000 million kWh and 1250 kton, respectively, satisfying 10% of electricity and 5% of gasoline demand in 6 provinces of Iran. The sensitivity analysis also shows that equal weight for both objectives can be more logical for decision makers.

Keywords: Biomass Supply Chain; Scenario-based Robust Optimization; Compromise Programming; Greenhouse gas emission, Electricity generation

1. Introduction

Global energy consumption encountered an abrupt increase in 1973 and a rise of 5.6% in 2010 (Sharma et al., 2013). Besides, according to the International Energy Agency (IEA) published information, oil and petroleum products accounted for major energy consumption worldwide until 2018. Thereby, it is obvious that there is an ascending trend in fossil fuels consumption and also CO2 gas emissions worldwide. In this regard, electrical energy, one of the main needs of human beings, and liquid fuels, such as gasoline and diesel, the most important energy source in the transportation network, are also of paramount importance. Besides, fossil fuel sources decline, and the increase in detrimental impacts of their burning bring about global warming, air pollution, climate change, acid rain, respiratory diseases, and countries' dependence on oil. These issues have led countries to expand the scope of research on fossil fuels replacement. In this regard, biomass materials are also among clean and renewable energy resources. Biomass is an organic, non-fossil material that is originated from plants or animals and is converted into clean energies after undergoing several processes. Biomass materials are categorized into three generations, among which the second generations are inedible and lignocellulosic materials (Sharma et al., 2013). Due to its availability, desert greening capability, and not competing with foods, agricultural residues, e.g., wheat straw among second-generation biomass materials, are considered in this study. In their study, Wang et al., (2013) and Tian et al., (2018) examined various preprocessing techniques and bioethanol production and power generation methods via a wheat straw. In addition, Sarkar et al., (2011) examined the technologies of lignocellulosic materials conversion, such as wheat and rice straw, bagasse, and corn stover, into ethanol.

Bioethanol is one of the most important and typical liquid biofuels worldwide, having the potential to be blended with gasoline due to its chemical and physical structure. The blending ratio varies in each country: there is the possibility of 5% to 25% bioethanol blending with gasoline. The gasoline-ethanol ratio is 10% in the USA and 22% in Brazil (An et al., 2011; Wyman et al., 1994). According to Najafi et al., (2009), the gasoline-bioethanol ratio has been estimated to be 25%; a ratio of 5% would be the best alternative for automobile engines.

The supply chain includes a network comprising suppliers, production facilities, distribution centers, and demand zones. Various decisions can be made in biomass supply chain design, including strategic, tactical, and

---

*Corresponding author Email address: mehrabad@iust.ac.ir operational decisions. Strategic decisions are carried out in the long-term, made by top-level managers, and are more of a leading aspect of tactical and operational decisions. All decisions must be made in accordance with an improvement in the objectives of the biomass supply chain network. These objectives are categorized into economic, environmental, and social objectives. The review studies conducted by Sharma et al., (2013); Ghaderi et al., (2016) and Malladi et al., (2018) have categorized the pertinent subjects to biomass supply chain and various optimization approaches.

In a case study in Canada, Razik et al., (2019) developed a linear, single-objective mathematical model for designing an electricity and bioethanol supply chain. The provided model is developed under a certain condition, not consistent with the real-world situation, and merely pertinent to material flows decisions. Furthermore, environmental effects are not considered in their supply chain design, which is an important issue in energy supply chain networks. In accordance with the study of Razik et al., (2019), a bi-objective, multi-period, and multi-product mathematical model is developed under uncertain conditions in this study whose main intention is to satisfy the electricity demands of Iran and produce bioethanol with the least costs and GHG emissions. Location and allocation problems are among the important decisions in this study. Also, decisions like technology selection, transportation mode, determining biomass type, dynamic determining of facilities capacity and inventory level in storage, and material flow rate between supply chain levels are made in this study.

2. Literature Review

Various investigations have been conducted in bioethanol supply chain design so far, where bioethanol production is considered solely or together with final products, such as biodiesel and electricity. Most studies pertinent to the biomass supply chain have considered using agricultural residues, which are among second-generation biomass materials, for ethanol or other biofuels production. Tan et al., (2017) provided a mixed-integer non-linear programming MINLP model for electricity generation using agricultural residues and forest biomass materials. Ghani et al., (2018) used corn stover, and Kostin et al., (2018) employed sugarcane for bioethanol production. Besides, Razm et al., (2019) designed a forest and agricultural residues biomass supply chain to produce bioethanol and intermediate products. Huang et al., (2019) used corn stover for Jet fuel and developed a mixed-integer linear programming (MILP) model. Esmaeili et al., (2020) employed the linear programming (LP) model to maximize profits (with and without emission penalties) to motivate the use of second-generation (corn stover) biomass instead of first-generation (corn) bioethanol producers. Due to its desert greening capability and being inedible, such biomass materials are of paramount importance among researchers.

The research background results indicate that we can set different objectives in biomass supply chain networks. Regarding the corn supply chain and its conversion into bioethanol, Dal-Mas et al., (2011) simultaneously optimized risk and cost factors, using a multi-objective model to maximize profit and minimize unexpected loss objectives under unfavorable conditions. In addition, Kelloway et al., (2013) considered the net present value (NPV) maximization objective for the biodiesel supply chain network. Tan et al., (2017) considered profit and social welfare maximization objectives in their study. An et al., (2011) conducted their research on urban waste and switchgrass to maximize the profit resulting from the lignocellulosic materials supply chain. Egieya et al., (2016) developed a mathematical model aiming to maximize economic profit for biogas production and power generation.

Studies with economic objectives are also classified based on cost types, including investment, operational, biomass purchase, inventory holding, and transportation costs. In this regard, Andersen et al., (2012) optimized the NPV objective, considering investment costs, production costs, biomass purchase costs, inventory holding costs, and transportation costs. Furthermore, Shabani et al., (2014) investigated the electricity supply chain and its generation via forest biomass materials. They used an optimization approach to achieve risk minimization and profit maximization objectives. The developed model is multi-period, including transportation, inventory, biomass supply, and production costs.

Taking account of environmental impacts in the design of the biomass supply chain is another issue that has captured researchers' interest. In this regard, Wu et al., (2017) developed a mathematical model with the MINLP approach, aiming to minimize the effects of GHG for power and biodiesel supply chain from microalgae biomass. Besides, the importance of environmental objectives in the investigation conducted by Babazadeh et al., (2017) and Jiang and Zhang, (2016) is sensible. In addition, Trujillo et al., (2019) considered two objectives of the benefit maximization and saving maximization of GHG emissions in their investigation. Moreover, Ghani et al., (2018) proposed an LP model with a profit maximization objective for the bioethanol supply chain from corn stover. They provided the model results once considering the CO2 emission costs and once without considering the CO2 emission costs. In addition, Zirngast et al., (2019) conducted an investigation into the biomass supply chain and biogas and power generation from agricultural products and manure feedstocks in the Republic of Slovenia. Their method was a MILP model aiming to maximize economic index and biological profit. In addition, Rabbani et al., (2020) developed a multi-objective mathematical model for the bioethanol supply chain from wastewater sludge. Their objective included minimizing the system's costs and environmental impacts and maximizing the created job opportunities. Furthermore, Ghaderi et al., (2018) employed a MILP model in the design of bioethanol supply chain from switchgrass biomass. Their model is a multi-period and multi-objective mathematical model aiming to minimize the system's costs and the environmental impacts and maximize social welfare.

Different decisions are made in the design of supply chain networks, which are categorized into two categories: strategic and tactical. The strategic decisions include locating, determining capacity, selecting technology, selecting the type of biomass, and selecting the transportation modes. The tactical decisions include determining the production rate, determining inventory holding level, and determining the material transportation (Sharma et al., 2013). Bairamzadeh et al., (2016) proposed a mathematical model with a MILP approach for the bioethanol supply chain from lignocellulosic materials. Their mathematical model is capable of making the decisions, including location, determining capacity, selection of technology, allocation, and select biomass type with respect to economic, environmental, and social objectives. Besides, Kostin et al., (2018) considered the NPV as an objective function. Their proposed model is developed based on the decisions, including location and allocation, selection of transportation modes, selection of technology, and determining capacity of sugarcane and molasses supply chain with respect to three transportation modes (heavy truck, medium truck, and tanker truck for liquid products), two kind of warehouse (for solid products and liquid products), and three option for exports. In addition, Sharma et al., (2019) tried to optimize the system's total costs with an optimization approach in the bioethanol supply chain network. They proposed a MILP model, and the essential decisions in their research include the location of centers and allocation of material flows among these centers. Furthermore, Akhtari et al., (2018) proposed a multi-product and multi-period model aiming to maximize the NPV for forest biomass materials. Their model includes the strategic decisions with an annual time horizon for determining capacity, facility location, technology type, and tactical decisions with a monthly horizon for determining the amount of biomass transportation, inventory level, and selection of biomass type. Marvin et al., (2012) also proposed a robust optimization model in which location and allocation of material flow among supply chain levels are the most important decisions in the design of the bioethanol supply chain. In location problems, MCDM or geographic information system (GIS) can be employed to determine candidate locations. The obtained results can be used as the inputs of the mathematical model (Zhang et al., 2017; Durmaz et al., 2020).

Another result that is obtained from the literature review is the programming under uncertainty, which is more useful than programming under certainty for the results to get closer to the real world. Besides, Dal-Mas et al., (2011) employed a scenario-based stochastic optimization approach in their research and considered parameters of biomass purchase costs and ethanol prices to be uncertain. Additionally, in their investigation, Shabani et al., (2014) employed a two-stage stochastic programming approach for the electricity supply chain. Ghane and Tavakkoli-Moghadam, (2018) also developed a stochastic optimization model for a location allocation problem. O'Neill et al., (2022) developed an integrated stochastic model for biofuel supply chain optimization under biomass yield uncertainty. Zhang and Jiang, (2017) proposed a robust mathematical model based on uncertain intervals for the biodiesel supply chain. In addition, Arabi et al., (2019) considered the uncertainty of the parameters pertinent to drying and harvesting microalgae for the biobutanol supply chain as an epistemic uncertainty and defined Fuzzy numbers for these parameters. Moreover, Khishtandar, (2019) employed the Fuzzy approach for uncertainty in the parameters, including biomass price, workforce availability, demand, and biomass availability in the biogas supply chain. Babazadeh et al., (2017) employed robust possibilistic programming for the biomass supply chain. In their research, they considered environmental parameters uncertain. In another investigation, Bairamzadeh et al., (2018) used a robust and Fuzzy hybrid approach to deal with uncertain parameters in their research. They categorized uncertain parameters based on uncertainty degree and employed different approaches for each parameter. They employed Mulvey robust and stochastic programming method for conversion rate parameter, robust possibilistic programming method for biomass yield parameter, and robust convex optimization approach for the demand parameter. This investigation is conducted on the bioethanol supply chain to reduce the total costs of a system. Additionally, Habib et al., (2021) used a robust possibilistic programming approach for the design of a biodiesel supply chain from animal fat. They considered biodiesel demand and biomass supply as an epistemic uncertainty with Fuzzy numbers. Darestani and Pourasadollah, (2019) used a fuzzy mathematical programming approach to convert multi-objective model into a single objective. Jana et al., (2022) developed a bi-criteria optimization model and considered some parameters as the variables in type-2 fuzzy logic. Additionally, Ghelichi et al., (2018) conducted a case study for Jatropha plant supply chain and biodiesel production in Iran. In this investigation, an adjustable and uncertain mathematical model was proposed, in which the biodiesel demand and yielding rate of trees at each cultivation region were considered uncertain. They used the minimization approach of the Maximum relative regret (MRR) to deal with uncertainty. Trujillo et al., (2020) developed a scenario-based non-linear mathematical model with a conditional value-at-risk (CVAR) approach for the biogas supply chain, in which the biogas demand and availability of biomass are considered uncertain. In their research, Sharma et al., (2020) used a two-stage stochastic programming approach in which the yield of switchgrass is assumed to be uncertain. They also proposed two different models for deciding on neutral risk and risk aversion, with the first model minimizing expected costs and the second model minimizing Value-at-Risk (VAR) and CVAR criteria .

In case the dimensions of the problem increase in the design of supply chain networks, solving the mathematical model will be time-consuming. Accordingly, accurate solving methods are less useful. Therefore, meta-heuristic algorithms can be used to solve models (Saghaei et al., 2020; Gonela et al., 2015; Billal and Hossain, 2020; Reyes-Barquet et al., 2022).

In the following, we will address research gaps and weaknesses of conducted investigations.

- A vast majority of conducted researches have taken account of the decisions, including location and allocation in the biomass supply chain, and less attention has been paid to other decisions.
- Few studies have been conducted on uncertain optimization models, which leads to the unsustainability of the model and getting away from reality. Besides, in uncertain models, identifying parameters' uncertainty degree and the approach (Fuzzy, stochastic, and robust) that is suitable for dealing with uncertainty has not been paid attention to.
- Because of having integer variables, supply chain models are often of high complexity. Accordingly, the solving approach of the model is of paramount importance, and accurate solving methods might be time-consuming and inappropriate. Few investigations have been conducted into solution approach for optimization models.
- There are a lesser number of conducted investigations into multi-objective models. Besides, compared to economic objectives, lesser attention has been paid to environmental and social objectives, including social welfare and employment index.
- Lesser attention has also been paid to multi-product and simultaneous power generation and biodiesel and bioethanol production.
- A limited number of studies have employed simulation and decision-making approaches and their combination with optimization problems.
- The biomass supply chain models that have been investigated have limited levels in the design phase of the supply chain network. However, more levels can be considered in raw material supply to distribution and delivery to customers for easiness of supply chain management and its integrity.

According to research gaps, considering different technologies at different levels of the supply chain network as well as the ability to integrate network levels or establish centers separately, simultaneous generation of electricity, bioethanol, and intermediate products, the importance of environmental and economic factors, strategic and tactical decisions, dynamic production capacity and utilization, several types of biomass will increase the flexibility of the designed supply chain network. The use of the SRCP conservative approach also gets the results closer to the real world.

3. Problem Statement

This study is a bi-objective, multi-period, and green mathematical model for electricity and bioethanol supply chain under uncertain conditions. The provided model includes six levels; the first level is pertinent to the biomass cultivation centers, the second level is related to the preprocessing centers, the third to fifth level pertains to the intermediate and final products production centers, and the sixth level is pertinent to the demand zones (Figure. 1). Each supply chain level has a particular product; the produced products can be transferred as raw materials to the next level, dispatched to demand zones, or stored in warehouses. At the strategic level of the problem, we aim to determine the optimal location for biomass cultivation and production centers, select the technology type for each production center, production centers capacity, transportation mode, and specify the required vehicles for transportation purchase. In addition, in a short-term horizon and at the tactical level of the problem, the production level of each product, the quantity of materials transfer between supply chain levels, product sales level, inventory holding level, and the number of required vehicles to be rent is determined. It is also worth mentioning that if the proposed points for establishing production centers are alike, the mathematical model can decide to separately establish production centers at each level or integrate several levels.

4. Model Formulation

The developed mathematical model is modeled by a MILP approach. According to the aforementioned assumptions, this model is proposed to design an electricity and bioethanol supply chain. First, indexes, technical parameters, cost parameters, environmental parameters, and decision variables of the mathematical model are defined. Ultimately, the objective functions and mathematical model constraints are explained. Table (1) to (7)

4.1 Scenario-based robust optimization with MMR approach

The proposed model is a scenario-based robust mathematical model with a minimization MRR approach that aims to provide maximum safety for dealing with uncertainty. The maximum regret was first introduced by Aghezzaf et al., (2010). In this approach, the maximum difference of the objective function from its optimal value among all scenarios is minimized. Besides, to make the mathematical model flexible under uncertainty, the soft approach is the worst developed case such that the scenarios will be applied to the computations until their probability threshold is met. The probability threshold is determined by decision-makers and designers as the input parameter. Thereby, several scenarios can be eliminated to make decision-making easier. (Ghelichi et al., 2018)

4.2 Linearize objective functions with a CP approach

The compromise programming (CP) approach was employed to solve the model in a multi-objective way and determine the Pareto optimal points. This method seeks to minimize the difference of objective functions from their optimum value. In order to normalize the objective functions, this discrepancy is divided by the difference between the optimal value and the worst value of the objective function. This approach was developed by Zelany in 1974. The objective functions of the problem can convert into one objective using this approach.

For p=1, the distance is orthogonal, and for p=∞, the distance is chebyshev. In addition, according to the importance degree of each objective function, ω_i is considered as the weight of each objective function.

$$LD = \sum \left(\left| \omega_i \frac{Z_i - Z_i^*}{Z_{i*} - Z_i^*} \right|^p \right)^{\frac{1}{p}} \tag{1}$$

Table 1
Indexes

g	The related index to biomass materials
h	The related index to proposed points for preprocessing centers
i	The related index to products from preprocessing centers
j	The related index to proposed points for the first level production centers
k	The related index to products from the first level production centers
l	The related index to proposed points for the second level production centers
m	The related index to products from the second level production centers
n	The related index to proposed points for the third level production centers
o	The related index to products from the third level production centers
sp	The related index to proposed points for biomass cultivation centers
t	The related index to the time period
fh	The related index to the technologies of preprocessing centers
fj	The related index to the technologies of the first level centers
fl	The related index to the technologies of the second level centers
fn	The related index to the technologies of the third level centers
dz	The related index to product demand zones
tm	The related index to transportation modes
$tms \subset tm$	Solid materials transportation modes via roads (medium and heavy trucks)
$tml \subset tm$	Liquid materials transportation modes
$tmg \subset tm$	Gas materials transportation modes
$tme \subset tm$	Electric Power Transmission modes
s	The related index to the scenarios

Table 2
Cost parameters (Million Rial)

$CTG_{g,sp,h,t,tm}$	Biomass g transportation cost from center sp to center h in period t by transportation mode tm
$CTI_{i,h,j,t,tm}$	Preprocessing product i transportation cost from center h to center j in period t by transportation mode tm
$CTK_{k,j,l,t,tm}$	First level product k transportation cost from center j to center l in period t by transportation mode tm
$CTM_{m,l,n,t,tm}$	Second level product m transportation cost from center l to center n in period t by transportation mode tm
$CSI_{h,dz,i,t,tm}$	Preprocessing product i transportation cost from center h to demand zone dz in period t by transportation mode tm
$CSK_{j,dz,k,t,tm}$	First level product k transportation cost from center j to demand zone dz in period t by transportation mode tm
$CSM_{l,dz,m,t,tm}$	Second level product m transportation cost from center l to demand zone dz in period t by transportation mode tm
$CSO_{n,dz,o,t,tm}$	Third level product o transportation cost from center n to demand zone dz in period t by transportation mode tm
$CPG_{g,sp,t}$	Biomass g cultivation cost at location sp in period t
$CPI_{i,g,h,fh,t}$	Preprocessing product i production cost from biomass g at center h with technology fh in period t
$CPK_{k,i,j,fj,t}$	First level product k production cost from the product i at center j with technology fj in period t
$CPM_{m,k,l,fl,t}$	Second level product m production cost from product k at center l with technology fl in period t
$CPO_{o,m,n,fn,t}$	Third level product o production cost from product m at center n with technology fn in period t
$CFH_{fh,h}$	The establishment fixed cost of technology fh at center h
$CFJ_{fj,j}$	The establishment fixed cost of technology fj at center j
$CFL_{fl,l}$	The establishment fixed cost of technology fl at center l
$CFN_{fn,n}$	The establishment fixed cost of technology fn at center n
$CF_{g,sp}$	The cultivation fixed cost of biomass g at center sp
CSP_{sp}	The fixed cost of purchase and set up at center sp
CH_h	The fixed cost of purchase and set up at center h
CJ_j	The fixed cost of purchase and set up at center j
CL_l	The fixed cost of purchase and set up at center l
CN_n	The fixed cost of purchase and set up at center n
$CCAPEFH_{i,fh,t}$	The capacity expansion cost for each product i by technology fh in period t
$CCAPEFJ_{k,fj,t}$	The capacity expansion cost for each product k by technology fj in period t
$CCAPEFL_{m,fl,t}$	The capacity expansion cost for each product m by technology fl in period t
$CCAPEFN_{o,fn,t}$	The capacity expansion cost for each product o by technology fn in period t

$CINVG_{g,sp,t}$	Inventory holding cost of biomass g at center sp in period t
$CINVI_{i,h,t}$	Inventory holding cost of preprocessing products i at center h in period t
$CINVK_{k,j,t}$	Inventory holding cost of first level products k at center j in period t
$CINVM_{m,l,t}$	Inventory holding cost of second level products m at center l in period t
$CINVO_{o,n,t}$	Inventory holding cost of third level products o at center n in period t
CVP_{tm}	Vehicle type tm purchase cost
$CVR_{tm,t}$	Vehicle type tm renting cost in period t

Table 3
Technical parameters

VC_{tm}	The capacity of solid and liquid materials transportation mode (kton)
$XI_{fh,g,i}$	The conversion factor of product i from biomass g by technology fh
$XK_{fj,i,k}$	The conversion factor of product k from the product i by technology fj
$XM_{fl,k,m}$	The conversion factor of product m from product k by technology fl
$XO_{fn,m,o}$	The conversion factor of product o from product m by technology fn
$A_{g,sp}$	The maximum capacity of biomass g production at center sp (kton)
$UBI_{fh,i,t}$	The maximum of production capacity expansion of product i by technology fh in period t (kton)
$UBK_{fj,k,t}$	The maximum of production capacity expansion of product k by technology fj in period t (kton)
$UBM_{fl,m,t}$	The maximum of production capacity expansion of product m by technology fl in period t (kton - million kWh)
$UBO_{fn,o,t}$	The maximum of production capacity expansion of product o by technology fn in period t (kton - million kWh)
$DUBI_{fh,i,t}$	The allowed deviation from the maximum production capacity expansion of product i with technology fh in period t (kton)
$DUBK_{fj,k,t}$	The allowed deviation from the maximum production capacity expansion of product k with technology fj in period t (kton)
$DUBM_{fl,m,t}$	The allowed deviation from the maximum production capacity expansion of product m with technology fl in period t (kton - million kWh)
$DUBO_{fn,o,t}$	The allowed deviation from the maximum production capacity expansion of product o with technology fn in period t (kton - million kWh)
$DI_{i,dz,t}$	Product i demand in demand zone dz in period t (kton)
$DK_{k,dz,t}$	Product k demand in demand zone dz in period t (kton)
$DM_{m,dz,t,s}$	Product m demand in demand zone dz in period t under scenario s (kton - million kWh)
$DO_{o,dz,t,s}$	Product o demand in demand zone dz in period t under scenario s (kton - million kWh)
NFH	The maximum number of technologies allowed to be established at center h

$UBNH$	The maximum number of centers h allowed to be established
NFJ	The maximum number of technologies allowed to be established at center j
$UBNJ$	The maximum number of centers j allowed to be established
NFL	The maximum number of technologies allowed to be established at center l
$UBNL$	The maximum number of centers l allowed to be established
NFN	The maximum number of technologies allowed to be established at center n
$UBNN$	The maximum number of centers n allowed to be established
NSP	The maximum number of biomass materials allowed to be produced at center SP
$UBNSP$	The maximum number of centers SP allowed to be established
BN	A large number
$\lambda g_{g,tm}$	A binary parameter that if it is possible to transport biomass g with transportation mode tm (1), otherwise (0)
$\lambda i_{i,tm}$	A binary parameter that if it is possible to transport product i with transportation mode tm (1), otherwise (0)
$\lambda k_{k,tm}$	A binary parameter that if it is possible to transport product k with transportation mode tm (1), otherwise (0)
$\lambda m_{m,tm}$	A binary parameter that if it is possible to transport product m with transportation mode tm (1), otherwise (0)
$\lambda o_{o,tm}$	A binary parameter that if it is possible to transport product o with transportation mode tm (1), otherwise (0)
ω_1	The first objective function weight (economic)
ω_2	The second objective function weight (environmental)
ω_3	The expected value coefficient in the objective of SRCP model
π_s	Scenario s probability
Ω	Probability threshold
α	The degree of satisfaction of constraints (parametric programming for the capacity parameter)

Table 4
Environmental parameters (in tons)

$EITG_{g,sp,\boldsymbol{h},\boldsymbol{tm}}$	The environmental effect of biomass g transportation from center sp to center h via transportation mode tm
$EITI_{i,h,j,tm}$	The environmental effect of preprocessing product i transportation from center h to center j via transportation mode tm
$EITK_{k,j,l,tm}$	The environmental effect of the first level product k transportation from center j to center l via transportation mode tm
$EITM_{m,l,n,tm}$	The environmental effect of the second level product m transportation from center l to center n via transportation mode tm
$EISI_{h,dz,i,tm}$	The environmental effect of product i transportation from center h to demand zone dz via transportation mode tm
$EISK_{j,dz,k,tm}$	The environmental effect of product k transportation from center j to demand zone dz via transportation mode tm

$EISM_{l,dz,m,tm}$	The environmental effect of product m transportation from center l to demand zone dz via transportation mode tm
$EISO_{n,dz,o,tm}$	The environmental effect of product o transportation from center n to demand zone dz via transportation mode tm
$EIPG_{g,sp}$	The environmental effect of biomass g production at center sp
$EIPI_{i,g,h,fh}$	The environmental effect of product i production from biomass g at center h by technology fh
$EIPK_{k,i,j,fj}$	The environmental effect of product k production from the product i at center j by technology fj
$EIPM_{m,k,l,fl}$	The environmental effect of product m production from product k at center l by technology fl
$EIPO_{o,m,n,fn}$	The environmental effect of product o production from product m at center n by technology fn
$EIF_{g,sp}$	The environmental effect of biomass g cultivation at center sp
$EIFH_{fh,h}$	The environmental effect of technology fh establishment at center h
$EIFJ_{fj,j}$	The environmental effect of technology fj establishment at center j
$EIFL_{fl,l}$	The environmental effect of technology fl establishment at center l
$EIFN_{fn,n}$	The environmental effect of technology fn establishment at center n
$EISP_{sp}$	The environmental effect from the activation of center sp
EIH_h	The environmental effect from the activation of center h
EIJ_j	The environmental effect from the activation of center j
EIL_l	The environmental effect from the activation of center l
EIN_n	The environmental effect from the activation of center n

Table 5
binary decision variables

$XSPG_{g,sp}$	If biomass g is produced at center sp (1), otherwise (0)
$X_{fh,h}$	If technology fh is established at center h (1), otherwise (0)
$Y_{fj,j}$	If technology fj is established at center j (1), otherwise (0)
$Z_{fl,l}$	If technology fl is established at center l (1), otherwise (0)
$W_{fn,n}$	If technology fn is established at center n (1), otherwise (0)
XH_h	If the preprocessing center h is selected (1), otherwise (0)
YJ_j	If the first level production center j is selected (1), otherwise (0)
ZL_l	If the second level production center l is selected (1), otherwise (0)
WN_n	If the third level production center n is selected (1), otherwise (0)
XSP_{sp}	If center sp is selected for biomass cultivation (1), otherwise (0)
WS_s	In the case, scenario s is covered (1), otherwise (0)

Table 6
Continuous decision variables

$FTG_{g,sp,h,fh,i,t,tm,s}$	Transport level of biomass g which is required for the production of the product i by technology fh from sp centers to centers h at period t by the transportation mode tm under scenario s
$FTI_{i,h,j,fj,k,t,tm,s}$	Transport level of product i that is required for the production of product k by technology fj from centers h to centers j at period t by the transportation mode tm under scenario s
$FTK_{k,j,l,fl,m,t,tm,s}$	Transport level of product k that is required for the production of product m by technology fl from centers j to centers l at period t by the transportation mode tm under scenario s
$FTM_{m,l,n,fn,o,t,tm,s}$	Transport level of product m that is required for the production of product o by technology fn from centers l to centers n at period t by the transportation mode tm under scenario s
$FPG_{g,sp,t,s}$	The cultivation level of biomass g at the center sp at period t under scenario s
$FPI_{i,g,h,fh,t,s}$	The production level of product i from biomass g at the center h by technology fh at period t under scenario s
$FPK_{k,i,j,fj,t,s}$	The production level of product k from the product i at the center j by the technology fj at period t under scenario s
$FPM_{m,k,l,fl,t,s}$	The production level of product m from product k at the center l by the technology fl at period t under scenario s
$FPO_{o,m,n,fn,t,s}$	The production level of product o from product m at the center n by the technology fn at period t under scenario s
$FSI_{h,dz,i,t,tm,s}$	The transport level of product i from the center h to the demand zone dz at period t by the transportation mode tm under scenario s
$FSK_{j,dz,k,t,tm,s}$	The transport level of product k from the center j to the demand zone dz at period t by the transportation mode tm under scenario s
$FSM_{l,dz,m,t,tm,s}$	The transport level of product m from the center l to the demand zone dz at t period t by the transportation mode tm under scenario s
$FSO_{n,dz,o,t,tm,s}$	The transport level of product o from the center n to the demand zone dz at period t by the transportation mode tm under scenario s
$INVG_{g,sp,t,s}$	The inventory holding level of the biomass g at the center sp at period t under scenario s
$INVI_{i,h,t,s}$	The inventory holding level of the product i at the center h at period t under scenario s
$INVK_{k,j,t,s}$	The inventory holding level of product k at center j at period t under scenario s
$INVM_{m,l,t,s}$	The inventory holding level of product m at the center l at period t under scenario s
$INVO_{o,n,t,s}$	The inventory holding level of product o at the center n at period t under scenario s
$CAPFH_{i,fh,h,t,s}$	The production capacity for the product i by the technology fh at the center h at period t under scenario s
$CAPEFH_{i,fh,h,t,s}$	The expansion of the production capacity of the product i by the technology fh at the center h at period t under scenario s
$CAPFJ_{k,fj,j,t,s}$	The production capacity for the product k by the technology fj at the center j at period t under scenario s
$CAPEFJ_{k,fj,j,t,s}$	The expansion of the production capacity of the product k by the technology fj at the center j at period t under scenario s
$CAPFL_{m,fl,l,t,s}$	The production capacity for the product m by the technology fl at the center l at period t under scenario s
$CAPEFL_{m,fl,l,t,s}$	The expansion of the production capacity of the product m by the technology fl at the center l at period t under scenario s

$CAPFN_{o,fn,n,t,s}$	The production capacity for the product o by the technology fn at the center n at period t under scenario s
$CAPEFN_{o,fn,n,t,s}$	The expansion of the production capacity of the product o by the technology fn at the center n at period t under scenario s
TTC_s	Sum of the transportation costs under the scenario s (million rials)
$TTVC_s$	Sum of the purchasing and renting vehicles costs under the scenario s (million rials)
TPC_s	Sum of the production costs under the scenario s (million rials)
TIC_s	Sum of the inventory holding costs under the scenario s (million rials)
TFC	Sum of the fixed costs (million rials)
TEC_s	Sum of the capacity expansion costs under the scenario s (million rials)
TTE_s	Sum of the GHG emissions caused by transportation system under the scenario s (tons)
TPE_s	Sum of the GHG emissions caused by production system under the scenario s (tons)
TFE	Sum of the GHG emissions caused by the establishment of center and technology (tons)
REG	Maximum relative regret (MRR)
Z_1^s	Sum of the system costs for the scenario s (million rials)
Z_2^s	Sum of the GHG emissions for the scenario s (tons)
LD_s	The objective function of the CP approach for each scenario
θ_s	Artificial variable for linearization

Table 7
Integer decision variables

NPV_{tm}	The number of the vehicles via transportation mode tm that must be purchased
$NVR_{tm,t,s}$	The number of the vehicles via transportation mode tm that must be rented at Period t under scenario s

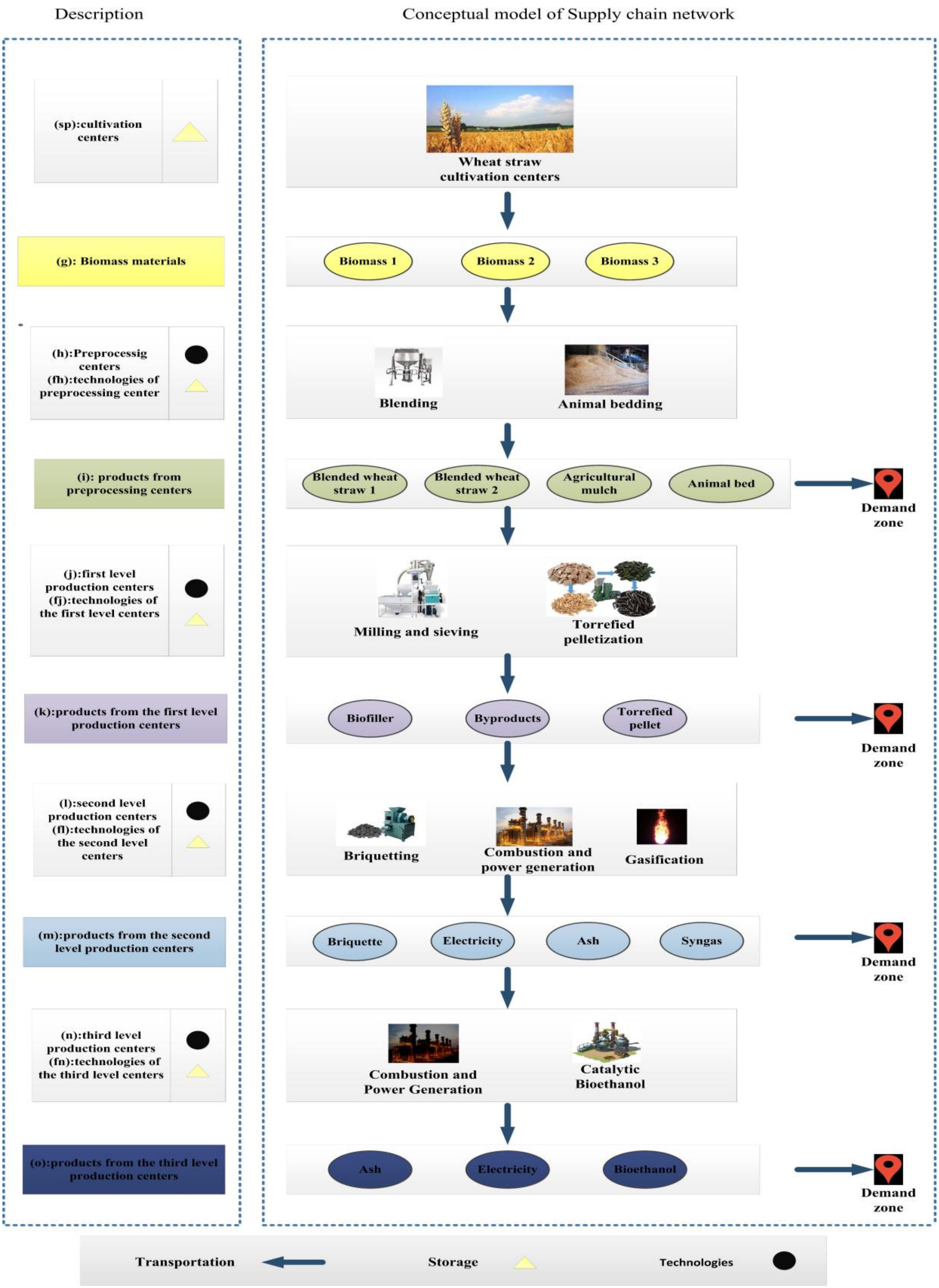

Fig. 1. Conceptual model (Razik et al., 2019)

4.3 Objective functions

The proposed mathematical model is a bi-objective mathematical model that consists of economic and environmental objectives. The first objective of this investigation is to minimize total system costs, and the second objective of the proposed mathematical model is to minimize total GHG emissions.

In order to model the problem under uncertainty and also obtain Pareto optimal points, first, the problem is converted to a single-objective problem using CP. Then, the problem with a new objective function is modeled under uncertainty conditions. Similar to this method, a method was used by Habibi et al., (2017), while they used Weighted Sum Method to convert their objective functions into one objective function. After converting two objective functions to one, the new objective function of the problem for each scenario and for p=1 will be expressed as Equation (2):

$$LD_s = \omega_1\left(\frac{Z_1^{\,s}-Z_1^*}{Z_{1*}-Z_1^*}\right)+\omega_2\left(\frac{Z_2^{\,s}-Z_2^*}{Z_{2*}-Z_2^*}\right) \qquad (2)$$

Furthermore, for adjustable and scenario-based robust programming, the final objective function is modeled in the form of Equation (3):

$$\text{Min objective}=\omega_3\sum_s \pi_s LD_s ws_s + \max_{s\in S}\left(\frac{LD_s-LD_s^*}{LD_s^*}\right) \qquad (3)$$

In the first part of Equation (3), because the continuous variable LD_s is multiplied by a binary variable, WS_s are converted to non-linear form. In order to linearize the problem, the artificial variable θ_s is defined. The maximum regret (REG) variable is also defined to linearize the second part of Equation (3). The final form of the problem will be as follows:

$$\text{Min objective}=\omega_3\sum_s \pi_s \theta_s + REG \qquad (4)$$

$$\sum_s \pi_s ws_s \ge \Omega \qquad (5)$$

$$\left[\frac{LD_s-LD_s^*}{LD_s^*}\right]-\left[BN(1-WS_S)\right]\le REG \quad \forall s \qquad (6)$$

$$\theta_s \le BN.\, ws_s \quad \forall s \qquad (7)$$

$$\theta_s \ge BN.\,(ws_s-1)+LD_s \quad \forall s \qquad (8)$$

$$Z_1^s = \mathrm{TTC}_s + TPC_s + TFC + TIC_s + TEC_s + TTVC_s \quad \forall s \qquad (9)$$

$$Z_2^s = \mathrm{TTE}_s + TPE_s + TFE \quad \forall s \qquad (10)$$

$$\begin{aligned}
TTC_s = {} & \sum_{g}\sum_{sp}\sum_{h}\sum_{fh}\sum_{t}\sum_{tm}\sum_{i} CTG_{g,sp,h,t,tm}FTG_{g,sp,h,fh,i,t,tm,s} \\
& +\sum_{i}\sum_{h}\sum_{j}\sum_{fj}\sum_{t}\sum_{tm}\sum_{k} CTI_{i,h,j,t,tm}FTI_{i,h,j,fj,k,t,tm,s} \\
& +\sum_{k}\sum_{j}\sum_{l}\sum_{fl}\sum_{t}\sum_{tm}\sum_{m} CTK_{k,j,l,t,tm}FTK_{k,j,l,fl,m,t,tm,s} \\
& +\sum_{m}\sum_{l}\sum_{n}\sum_{fn}\sum_{t}\sum_{tm}\sum_{o} CTM_{m,l,n,t,tm}FTM_{m,l,n,fn,o,t,tm,s} \\
& +\sum_{h}\sum_{i}\sum_{t}\sum_{dz}\sum_{tm} CSI_{h,dz,i,t,tm}FSI_{h,dz,i,t,tm,s} \\
& +\sum_{j}\sum_{k}\sum_{t}\sum_{dz}\sum_{tm} CSK_{j,dz,k,t,tm}FSK_{j,dz,k,t,tm,s} \\
& +\sum_{l}\sum_{m}\sum_{t}\sum_{dz}\sum_{tm} CSM_{l,dz,m,t,tm}FSM_{l,dz,m,t,tm,s} \\
& +\sum_{n}\sum_{o}\sum_{t}\sum_{dz}\sum_{tm} CSO_{n,dz,o,t,tm}FSO_{n,dz,o,t,tm,s} \quad \forall s
\end{aligned} \qquad (11)$$

$$\begin{aligned}
\mathrm{TPC}_s = {} & \sum_{g}\sum_{sp}\sum_{t} CPG_{g,sp,t}FPG_{g,sp,t,s} \\
& +\sum_{i}\sum_{g}\sum_{h}\sum_{fh}\sum_{t} CPI_{i,g,h,fh,t}FPI_{i,g,h,fh,t,s} \\
& +\sum_{k}\sum_{i}\sum_{j}\sum_{fj}\sum_{t} CPK_{k,i,j,fj,t}FPK_{k,i,j,fj,t,s} \\
& +\sum_{m}\sum_{k}\sum_{l}\sum_{fl}\sum_{t} CPM_{m,k,l,fl,t}FPM_{m,k,l,fl,t,s} \\
& +\sum_{o}\sum_{m}\sum_{n}\sum_{fn}\sum_{t} CPO_{o,m,n,fn,t}FPO_{o,m,n,fn,t,s} \quad \forall \mathrm{s}
\end{aligned} \qquad (12)$$

$$\begin{aligned}
\mathrm{TFC} = {} & \sum_{g}\sum_{sp} CF_{g,sp}XSPG_{g,sp} + \sum_{fh}\sum_{h} CFH_{fh,h}X_{fh,h} \\
& +\sum_{fj}\sum_{j} CFJ_{fj,j}Y_{fj,j} + \sum_{fl}\sum_{l} CFL_{fl,l}Z_{fl,l} \\
& +\sum_{fn}\sum_{n} CFN_{fn,n}W_{fn,n} + \sum_{sp} CSP_{sp}XSP_{sp} + \sum_{h} CH_h XH_h \\
& +\sum_{j} CJ_j YJ_j + \sum_{l} CL_l ZL_l + \sum_{n} CN_n WN_n
\end{aligned} \qquad (13)$$

$$\mathrm{TTVC}_s = \sum_{tm} NVP_{tm}CVP_{tm} + \sum_{t}\sum_{tm} NVR_{tm,t,s}CVR_{tm,t} \quad \forall \mathrm{s} \qquad (14)$$

$$\begin{aligned}
\mathrm{TIC}_s = {} & \sum_{g}\sum_{sp}\sum_{t} CINVG_{g,sp,t}INVG_{g,sp,t,s} \\
& +\sum_{i}\sum_{h}\sum_{t} CINVI_{i,h,t}INVI_{i,h,t,s} \\
& +\sum_{k}\sum_{j}\sum_{t} CINVK_{k,j,t}INVK_{k,j,t,s} \\
& +\sum_{m}\sum_{l}\sum_{t} CINVM_{m,l,t}INVM_{m,l,t,s} \\
& +\sum_{o}\sum_{n}\sum_{t} CINVO_{o,n,t}INVO_{o,n,t,s} \quad \forall \mathrm{s}
\end{aligned} \qquad (15)$$

$$\begin{aligned}
\mathrm{TEC}_s = {} & \sum_{i}\sum_{fh}\sum_{h}\sum_{t} CCAPEFH_{i,fh,t}CAPEFH_{i,fh,h,t,s} \\
& +\sum_{k}\sum_{fj}\sum_{j}\sum_{t} CCAPEFJ_{k,fj,t}CAPEFJ_{k,fj,j,t,s} \\
& +\sum_{m}\sum_{fl}\sum_{l}\sum_{t} CCAPEFL_{m,fl,t}CAPEFL_{m,fl,l,t,s} \\
& +\sum_{o}\sum_{fn}\sum_{n}\sum_{t} CCAPEFN_{o,fn,t}CAPEFN_{o,fn,n,t,s} \quad \forall \mathrm{s}
\end{aligned} \qquad (16)$$

$$
\begin{aligned}
\mathrm{TTE}_s = {} & \sum_{g}\sum_{sp}\sum_{h}\sum_{fh}\sum_{t}\sum_{tm}\sum_{i} EITG_{g,sp,h,tm} FTG_{g,sp,h,fh,i,t,tm,s} \\
& + \sum_{i}\sum_{h}\sum_{j}\sum_{fj}\sum_{t}\sum_{tm}\sum_{k} EITI_{i,h,j,tm} FTI_{i,h,j,fj,k,t,tm,s} \\
& + \sum_{k}\sum_{j}\sum_{l}\sum_{fl}\sum_{t}\sum_{tm}\sum_{m} EITK_{k,j,l,tm} FTK_{k,j,l,fl,m,t,tm,s} \\
& + \sum_{m}\sum_{l}\sum_{n}\sum_{fn}\sum_{t}\sum_{tm}\sum_{o} EITM_{m,l,n,tm} FTM_{m,l,n,fn,o,t,tm,s} \\
& + \sum_{h}\sum_{i}\sum_{t}\sum_{dz}\sum_{tm} EISI_{h,dz,i,tm} FSI_{h,dz,i,t,tm,s} \\
& + \sum_{j}\sum_{k}\sum_{t}\sum_{dz}\sum_{tm} EISK_{j,dz,k,tm} FSK_{j,dz,k,t,tm,s} \\
& + \sum_{l}\sum_{m}\sum_{t}\sum_{dz}\sum_{tm} EISM_{l,dz,m,tm} FSM_{l,dz,m,t,tm,s} \\
& + \sum_{n}\sum_{o}\sum_{t}\sum_{dz}\sum_{tm} EISO_{n,dz,o,tm} FSO_{n,dz,o,t,tm,s} \qquad \forall s
\end{aligned} \tag{17}
$$

$$
\begin{aligned}
\mathrm{TPE}_s = {} & \sum_{g}\sum_{sp}\sum_{t} EIPG_{g,sp} FPG_{g,sp,t,s} \\
& + \sum_{i}\sum_{g}\sum_{h}\sum_{fh}\sum_{t} EIPI_{i,g,h,fh} FPI_{i,g,h,fh,t,s} \\
& + \sum_{k}\sum_{i}\sum_{j}\sum_{fj}\sum_{t} EIPK_{k,i,j,fj} FPK_{k,i,j,fj,t,s} \\
& + \sum_{m}\sum_{k}\sum_{l}\sum_{fl}\sum_{t} EIPM_{m,k,l,fl} FPM_{m,k,l,fl,t,s} \\
& + \sum_{o}\sum_{m}\sum_{n}\sum_{fn}\sum_{t} EIPO_{o,m,n,fn} FPO_{o,m,n,fn,t,s} \qquad \forall \mathrm{s}
\end{aligned} \tag{18}
$$

$$
\begin{aligned}
\mathrm{TFE} = {} & \sum_{g}\sum_{sp} EIF_{g,sp} XSPG_{g,sp} + \sum_{fh}\sum_{h} EIFH_{fh,h} X_{fh,h} \\
& + \sum_{fj}\sum_{j} EIFJ_{fj,j} Y_{fj,j} + \sum_{fl}\sum_{l} EIFL_{fl,l} Z_{fl,l} + \sum_{fn}\sum_{n} EIFN_{fn,n} W_{fn,n} \\
& + \sum_{sp} EISP_{sp} XSP_{sp} + \sum_{h} EIH_h XH_h + \sum_{j} EIJ_j YJ_j \\
& + \sum_{l} EIL_l ZL_l + \sum_{n} EIN_n WN_n
\end{aligned} \tag{19}
$$

Constraint (5) indicates that scenarios can be selected until their probability threshold is met. Constraint (6) indicates the MRR. Besides, constraints (7) and (8) are pertinent to the linearization of Equation (3). Constraint number (9) is the total system costs and is related to the economic objective function, and Constraint (10) is the total GHG emissions and is pertinent to the environmental objective function. Constraints (11) to (16) indicate transportation costs, production costs, fixed costs, purchase or renting costs of the transportation system, inventory holding costs, and the capacity expansion costs of production centers, respectively. Constraints (17) to (19) indicate GHG emissions caused by transportation, production, and fixed activities, respectively.

4.4 Conversion constraints

Constraints (20) to (23) are pertinent to the conversion rate of productions from each level to the next. In other words, the production rate of each product must correspond to its conversion rate and the level of the products received from the previous level.

$$
\begin{aligned}
& xi_{fh,g,i} \sum_{tm}\sum_{sp} \lambda g_{g,tm} FTG_{g,sp,h,fh,i,t,tm,s} \\
& = FPI_{i,g,h,fh,t,s} \qquad \forall \mathrm{i,g,fh,h,t,s}
\end{aligned} \tag{20}
$$

$$
\begin{aligned}
& xk_{fj,i,k} \sum_{tm}\sum_{h} \lambda i_{i,tm} FTI_{i,h,j,fj,k,t,tm,s} \\
& = FPK_{k,i,j,fj,t,s} \qquad \forall \mathrm{k,i,fj,j,t,s}
\end{aligned} \tag{21}
$$

$$
\begin{aligned}
& xm_{fl,k,m} \sum_{tm}\sum_{j} \lambda k_{k,tm} FTK_{k,j,l,fl,m,t,tm,s} \\
& = FPM_{m,k,l,fl,t,s} \qquad \forall \mathrm{m,k,fl,l,t,s}
\end{aligned} \tag{22}
$$

$$
\begin{aligned}
& xo_{fn,m,o} \sum_{tm}\sum_{l} \lambda m_{m,tm} FTM_{m,l,n,fn,o,t,tm,s} \\
& = FPO_{o,m,n,fn,t,s} \qquad \forall \mathrm{o,m,fn,n,t,s}
\end{aligned} \tag{23}
$$

4.5 Demand constraints

Constrain (24) implies that the transport level of the product i through any transportation modes from all production centers h to demand center dz for any time period and under any scenario must supply the demand of the zone dz at time period t. Similarly, constraints (25) to (27) are pertinent to supplying product demands of the network's next levels. Additionally, supplying the demand of the second and third levels is conditional upon selecting that scenario.

$$
\sum_{tm}\sum_{h} \lambda i_{i,tm} FSI_{h,dz,i,t,tm,s} = DI_{i,dz,t} \qquad \forall \mathrm{i,t\ ,dz,s} \tag{24}
$$

$$
\sum_{tm}\sum_{j} \lambda k_{k,tm} FSK_{j,dz,k,t,tm,s} = DK_{k,dz,t} \qquad \forall k\mathrm{,t,dz,s} \tag{25}
$$

$$
\begin{aligned}
& \sum_{tm}\sum_{l} \lambda m_{m,tm} FSM_{l,dz,m,t,tm,s} \\
& = DM_{m,dz,t,s} \mathrm{WS}_s \qquad \forall m\mathrm{,t,dz,s}
\end{aligned} \tag{26}
$$

$$
\begin{aligned}
& \sum_{tm}\sum_{n} \lambda o_{o,tm} FSO_{n,dz,o,t,tm,s} \\
& = DO_{o,dz,t,s} \mathrm{WS}_s \qquad \forall o\mathrm{,t,dz,s}
\end{aligned} \tag{27}
$$

4.6 Balancing constraints

Constraints (28) to (32) strike a balance among production level of each product, transport rate of each product to the next level, transport rate of each product to the demand zones, and the level of the stored inventory of each product for each center at any time period and under any scenario; For instance, Constrain (28) that is pertinent to cultivation level of biomass implies that the sum of biomass production g at the center sp and the g biomass inventory at the end of the previous period at the center sp must be equal to g biomass transport rate to all centers h and the g biomass inventory at the end of the period at the center sp. Similarly, Constraints (29) to (32) are considered for the next levels of the network.

$$
\begin{aligned}
& FPG_{g,sp,t,s} + INVG_{g,sp,t-1,s} \\
& = \sum_{h}\sum_{fh}\sum_{tm}\sum_{i} \lambda g_{g,tm} FTG_{g,sp,h,fh,i,t,tm,s} \\
& + INVG_{g,sp,t,s} \qquad \forall \mathrm{g,sp,t,s}
\end{aligned} \tag{28}
$$

$$\sum_{g}\sum_{fh} FPI_{i,g,h,fh,t,s} + INVI_{i,h,t-1,s} = \sum_{j}\sum_{fj}\sum_{tm}\sum_{k} \lambda i_{i,tm} FTI_{i,h,j,fj,k,t,tm,s} + \sum_{dz}\sum_{tm} \lambda i_{i,tm} FSI_{h,dz,i,t,tm,s} + INVI_{i,h,t,s} \quad \forall \text{i,h,t,s} \tag{29}$$

$$\sum_{i}\sum_{fj} FPK_{k,i,j,fj,t,s} + INVK_{k,j,t-1,s} = \sum_{l}\sum_{fl}\sum_{tm}\sum_{m} \lambda k_{k,tm} FTK_{k,j,l,fl,m,t,tm,s} + \sum_{dz}\sum_{tm} \lambda k_{k,tm} FSK_{j,dz,k,t,tm,s} + INVK_{k,j,t,s} \quad \forall k,j,t,s \tag{30}$$

$$\sum_{k}\sum_{fl} FPM_{m,k,l,fl,t,s} + INVM_{m,l,t-1,s} = \sum_{n}\sum_{fn}\sum_{tm}\sum_{o} \lambda m_{m,tm} FTM_{m,l,n,fn,o,t,tm,s} + \sum_{dz}\sum_{tm} \lambda m_{m,tm} FSM_{l,dz,m,t,tm,s} + INVM_{m,l,t,s} \quad \forall m,l,\text{t,s} \tag{31}$$

$$\sum_{m}\sum_{fn} FPO_{o,m,n,fn,t,s} + INVO_{o,n,t-1,s} = \sum_{dz}\sum_{tm} \lambda o_{o,tm} FSO_{n,dz,o,t,tm,s} + INVO_{o,n,t,s} \quad \forall o,\text{n,t,s} \tag{32}$$

4.7 Capacity bound and capacity expansion constraints

In this investigation, the capacity of the network's production centers is considered dynamic. In other words, the capacity of the production centers in the time horizon can be developed so that in the case of an increase in demand, the demand can be supplied. Constraint (33) implies that the level of biomass g production at the center sp must be lesser than the maximum allowed production capacity of biomass g at the center sp. Constraints (34) to (37) are pertinent to the capacity of production centers that are considered dynamic. Constraints (38) to (41) are related to the expansion of the production centers' capacity at the time horizon. Besides, constraints (42) to (45) ensure that at each time period, the increase in the production capacity of any product by any technology at any production center is lesser than the defined upper bound, given that these constraints are conditional upon the relevant technology being established at particular production center. In addition, an allowed deviation is considered for the upper bound parameter, which is defined by α the parameter.

$$FPG_{g,sp,t,s} \le XSPG_{g,sp} \mathrm{A}_{g,sp} \quad \forall g,sp,t,s \tag{33}$$

$$\sum_{g} FPI_{i,g,h,fh,t,s} \le CAPFH_{i,fh,h,t,s} \quad \forall \text{i,fh,h,t,s} \tag{34}$$

$$\sum_{i} FPK_{k,i,j,fj,t,s} \le CAPFJ_{k,fj,j,t,s} \quad \forall k,\text{fj,j,t,s} \tag{35}$$

$$\sum_{k} FPM_{m,k,l,fl,t,s} \le CAPFL_{m,fl,l,t,s} \quad \forall m,\text{fl,l,t,s} \tag{36}$$

$$\sum_{m} FPO_{o,m,n,fn,t,s} \le CAPFN_{o,fn,n,t,s} \quad \forall o,\text{fn,n,t,s} \tag{37}$$

$$CAPFH_{i,fh,h,t,s} = CAPFH_{i,fh,h,t-1,s} + CAPEFH_{i,fh,h,t,s} \quad \forall \text{i,fh,h,t,s} \tag{38}$$

$$CAPFJ_{k,fj,j,t,s} = CAPFJ_{k,fj,j,t-1,s} + CAPEFJ_{k,fj,j,t,s} \quad \forall k,\text{fj,j,t,s} \tag{39}$$

$$CAPFL_{m,fl,l,t,s} = CAPFL_{m,fl,l,t-1,s} + CAPEFL_{m,fl,l,t,s} \quad \forall \text{m,fl,l,t,s} \tag{40}$$

$$CAPFN_{o,fn,n,t,s} = CAPFN_{o,fn,n,t-1,s} + CAPEFN_{o,fn,n,t,s} \quad \forall \text{o,fn,n,t,s} \tag{41}$$

$$CAPEFH_{i,fh,h,t,s} \le (UBI_{fh,i,t} + (1-\alpha)DUBI_{fh,i,t})X_{fh,h} \quad \forall i,fh,h,t,s \tag{42}$$

$$CAPEFJ_{k,fj,j,t,s} \le (UBK_{fj,k,t} + (1-\alpha)DUBK_{fj,k,t})Y_{fj,j,} \quad \forall \text{k,fj,j,t,s} \tag{43}$$

$$CAPEFL_{m,fl,l,t,s} \le (UBM_{fl,m,t} + (1-\alpha)DUBM_{fl,m,t})Z_{fl,l} \quad \forall \text{m,fl,l,t,s} \tag{44}$$

$$CAPEFN_{o,fn,n,t,s} \le (UBO_{fn,o,t} + (1-\alpha)DUBO_{fn,o,t})W_{fn,n} \quad \forall \text{o,fn,n,t,s} \tag{45}$$

4.8 The allocation of technology to production centers constraints

Constraints (46) to (49) imply that the number of different technologies established at each production center must be lesser than the defined allowed number.

$$\sum_{fh} X_{fh,h} \le NFH.\,\mathrm{XH}_{h} \quad \forall h \tag{46}$$

$$\sum_{fj} Y_{fj,j} \le NFJ.\,\mathrm{YJ}_{j} \quad \forall j \tag{47}$$

$$\sum_{fl} Z_{fl,l} \le NFL\,.\,\mathrm{ZL}_{l} \quad \forall l \tag{48}$$

$$\sum_{fn} W_{fn,n} \le NFN.\,\mathrm{WN}_{n} \quad \forall n \tag{49}$$

4.9 The maximum number of allowed production centers constraints

Constrains (50) to (53) and Constraints (55) imply that at any supply chain level, the number of established centers must be less than the defined allowed number. Besides, Constraint (54) implies that several types of biomass can be produced at each biomass production center.

$$\sum_{h} XH_{h} \le UBNH \tag{50}$$

$$\sum_{\mathrm{j}} \mathrm{YJ}_{\mathrm{j}} \le \mathrm{UBNJ} \tag{51}$$

$$\sum_{l} ZL_{l} \le UBNL \tag{52}$$

$$\sum_{n} WN_{n} \le UBNN \tag{53}$$

(54)

$$\sum_{g} XSPG_{g,sp} \le NSP \;.\; \mathrm{XSP}_{SP} \qquad \forall sp$$

$$\sum_{sp} XSP_{sp} \le UBNSP \tag{55}$$

4.10 Transportation Constraints

According to Constraints (56) to (63), the purchased or rented trucks for solid products at any time period must be adapted to the maximum level of material transportation between any two centers. Similarly, this compatibility must be taken into account for liquid productions according to Constraint (64).

$$\sum_{g}\sum_{fh}\sum_{i} \lambda g_{g,tm} FTG_{g,sp,h,\,fh,i,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall sp,h,t,s,tm \in \mathrm{tms} \tag{56}$$

$$\sum_{i}\sum_{fj}\sum_{k} \lambda i_{i,tm} FTI_{i,h,\,j,\,fj,k,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall h,\mathrm{j,t,s,tm} \in \mathrm{tms} \tag{57}$$

$$\sum_{i} \lambda i_{i,tm} FSI_{h,dz,i,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall h,\mathrm{dz,t,s,tm} \in \mathrm{tms} \tag{58}$$

$$\sum_{k}\sum_{fl}\sum_{m} \lambda k_{k,tm} FTK_{k,\,j,l,\,fl,m,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall j,\mathrm{l,t,s,tm} \in \mathrm{tms} \tag{59}$$

$$\sum_{k} \lambda k_{k,tm} FSK_{j,dz,k,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall j,\mathrm{dz,t,s,tm} \in \mathrm{tms} \tag{60}$$

$$\sum_{m}\sum_{fn}\sum_{o} \lambda m_{m,tm} FTM_{m,l,n,\,fn,o,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall l,\mathrm{n,t,s,tm} \in \mathrm{tms} \tag{61}$$

$$\sum_{m} \lambda m_{m,tm} FSM_{l,dz,m,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall l,\mathrm{dz,t,s,tm} \in \mathrm{tms} \tag{62}$$

$$\sum_{o} \lambda o_{o,tm} FSO_{n,dz,o,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall n,\mathrm{dz,t,s,tm} \in \mathrm{tms} \tag{63}$$

$$\lambda o_{o,tm} FSO_{n,dz,o,t,tm,s} \le VC_{tm}(NVR_{tm,t,s} + NVP_{tm}) \quad \forall o,n,\mathrm{dz,t,s,tm} \in \mathrm{tml} \tag{64}$$

4.11 Other constraints

Constraints (65) to (68) prevent transporting products to the centers where the relevant technology is not established, or there is no at least one conversion rate by that technology for that product.

$$\sum_{sp}\sum_{tm}\sum_{i} \lambda g_{g,tm} FTG_{g,sp,h,\,fh,i,t,tm,s} \le X_{fh,h} \sum_{i} XI_{fh,g,i} BN \qquad \forall g,h,\,fh,t,s \tag{65}$$

$$\sum_{h}\sum_{tm}\sum_{k} \lambda i_{i,tm} FTI_{i,h,\,j,\,fj,k,t,tm,s} \le Y_{fj,\,j} \sum_{k} XK_{fj,i,k} BN \qquad \forall i,\,j,\,fj,t,s \tag{66}$$

$$\sum_{j}\sum_{tm}\sum_{m} \lambda k_{k,tm} FTK_{k,\,j,l,\,fl,m,t,tm,s} \le Z_{fl,l} \sum_{m} XM_{fl,k,m} BN \qquad \forall k,l,\,fl,t,s \tag{67}$$

$$\sum_{l}\sum_{tm}\sum_{o} \lambda m_{m,tm} FTM_{m,l,n,\,fn,o,t,tm,s} \le W_{fn,n} \sum_{o} XO_{fn,m,o} BN \qquad \forall m,n,\,fn,t,s \tag{68}$$

5. Solution Approach and Validation.

After declaring assumptions and mathematical modeling, the implementation steps must be carried out according to Figure. (2) in order to implement an SRCP approach.

In order to conduct a comparison between CP at the certain model and scenario-based robust model, the problem is solved with numerical examples with small dimensions during 32 tests and realism with Cplex optimization algorithm in GAMS software. Afterward, according to the probability of each scenario, the mathematical expectation values of economic, environmental, and LD linearized objective functions are calculated, and the obtained results are demonstrated in Table (8). As can be seen, the linearized objective function LD has a lower total mean and standard deviation in the scenario-based robust model compared to certain model. It means that in solving a multi-objective mathematical model, the linearized objective function LD, indicating the Sum of the orthogonal distance of each function from its optimal value, showed better performance in the SRCP model.

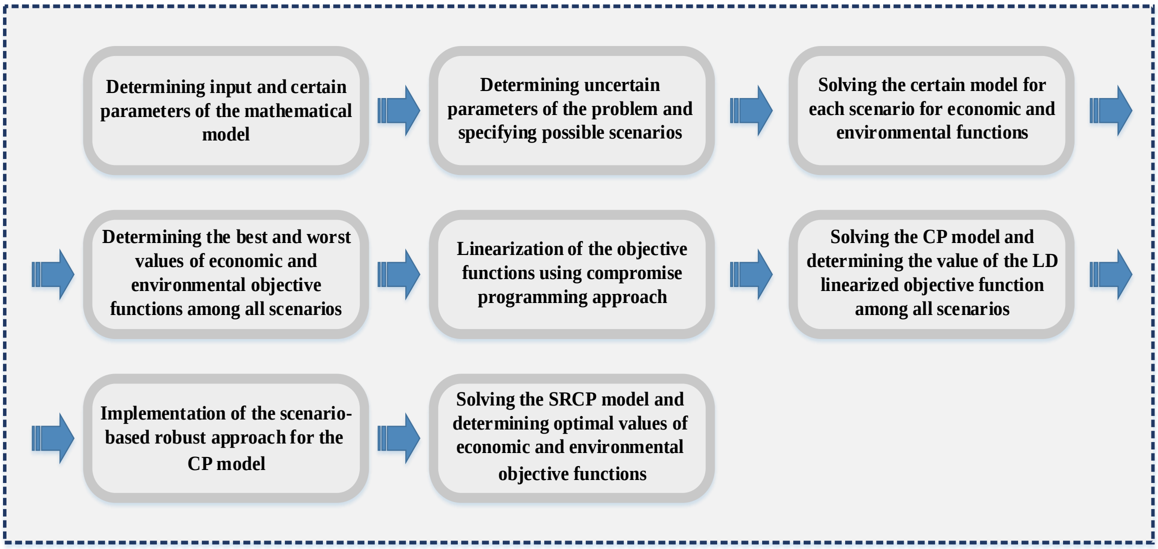

Fig. 2. Flow chart of a solution approach

Table 8
The results of comparing the mean and standard deviation of CP and SRCP models

Test $(\omega_1, \omega_2, \alpha)$	The mathematical expectation of linearized objective function		The mathematical expectation of economic objective function (Million Rials)		The mathematical expectation of environmental objective function (Ton)	
	CP	SRCP	CP	SRCP	CP	SRCP
	E(LD_s)	E(LD_s)	E(Z_1^s)	E(Z_1^s)	E(Z_2^s)	E(Z_2^s)
(0.25,0.75,1)	0.66389488	0.65852	137868784.8	136640034	3459824.04	3459811.1
(0.5,0.5,1)	0.66927457	0.66168	136117988	135227475.2	3462272.12	3462285.84
(0.5,0.5,0.75)	0.67796805	0.66574	135849366.8	134433530	3461607.8	3461646.41
(0.25,0.75,0.5)	0.66216083	0.65536	135883492	134352256.8	3459537.54	3459495.16
(0.5,0.5,0.5)	0.70119697	0.66508	138313781.2	134142936.8	3461040.96	3461135.23
(0.75,0.25,0.5)	0.68398084	0.6733	134790088	133985752	3467179.4	3467190.28
(0.75,0.25,0.25)	0.69282542	0.6733	135275012.4	133806156	3467502.9	3467437.6
(0.25,0.75,0)	0.66527628	0.6552	136193234	133909136.4	3459594.34	3459158.82
Total mean	0.67707223	0.6635225	136286468.4	134562159.7	3462319.89	3462270.06
Total standard deviation	0.01451422	0.007199726	1211047.127	950697.9278	3251.87435	3295.35282

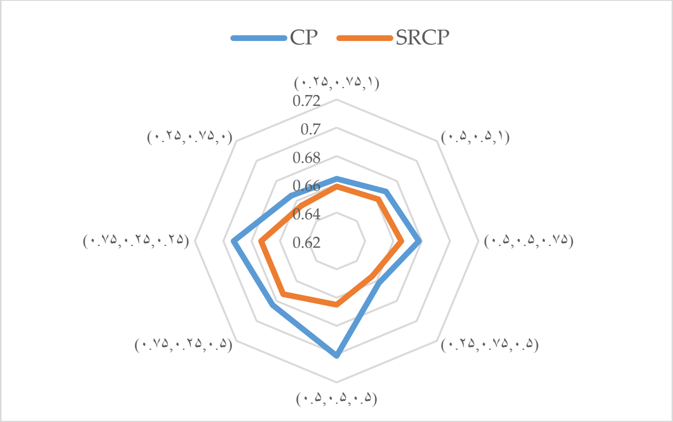

Fig. 3. Comparison of LD objective function in CP and SRCP models

The performance of LD linearized is demonstrated in Figure. (3). Besides, to make sure of the difference between the performance of LD linearized objective function in CP and SRCP models, the t-student statistical test at the significance level of 5% was carried out, and the obtained results are demonstrated in Table (9). As can be seen in Table (9), there is a difference between the mean of statistical populations. Since the p-value=0.007 is less than 5%, the null hypothesis that states the mean of CP and SRCP models are equal is refused. The validation method is obtained from the investigation conducted by Sahmoradi et al., (2016).

6. Case Study

6.1 System description and data gathering

This investigation considers wheat straw with three distinct qualities as biomass types 1, 2, and 3. Corn stover and soybean stalk can also be used similarly. The conversion factor of intermediate and final products is obtained from the study conducted by Razik et al., (2019). Table (10) demonstrates the proposed points for cultivation and production centers at different network levels and the maximum allowed number of centers for establishment. In this investigation, the developed mathematical model is considered for a 5-year time horizon. According to conducted studies, six important provinces of Iran are determined as demand zones of electricity and bioethanol. Bioethanol demand is collected through gasoline consumption data of provinces, provided by National Iranian Oil Refining & Distribution Company (www.niordc.ir) and is predicted using double exponential smoothing method in Minitab software. Besides, electricity demand is considered as 10% of the electricity consumption of six determined provinces. Electricity consumption data for each province are collected from the Tavanir Co. website (www.tavanir.org.ir). Four scenarios are considered for electricity demand in the second and third levels and bioethanol demand. The second scenario is the worst possible case, the third scenario is the best possible case, and the first and fourth scenarios are the possible cases. Table (11) presents details pertinent to each scenario. The production costs are obtained from the investigation of Razik et al. (2019). The inventory costs with an 18% inventory holding rate are taken into account in the finished cost. Other costs of systems and technical parameters are collected by expert opinion. Emissions of GHG caused by the transportation of trucks are collected according to the study conducted by Schoemaker et al., (1991). In addition, the GHG emissions caused by construction of building and industrial shed is also collected according to the investigation of Porhinčák et al., (2011).

6.2 Computational results and analyses

An attempt is made to address the importance of made decisions and analysis in this section. The developed mathematical model is solved in Gams software using the Cplex algorithm according to parameters and data that are determined in the data-gathering section for a case study in Iran. The SRCP mathematical model is solved for values of $(\omega_3 = 10, \omega_1 = 0.5, \omega_2 = 0.5)$ and a probability threshold of 0.9. ω_3 is the importance degree of the mathematical expectation value of the objective function is proportional to MRR and is determined by the decision-maker. All scenarios are covered by considering 0.9 for the probability threshold. The value of the objective function for each scenario is demonstrated in Table (12). Besides, the mathematical expectation value of the relevant decision variable is considered according to the probability of each scenario in order to analyze other decisions. Percentage of cost and GHG emission components are indicated in Figure (4) and Figure (5). Approximately 69% of costs are pertinent to production, and 17% are pertinent to transportation. Besides, according to Figure. (5), 60% of GHG emissions are pertinent to establishing production centers and relevant technologies. In order to obtain different values for the objective function, sensitivity analysis is carried out in problem parameters. Different values of economic and environmental objective functions for different values (ω_1, ω_2) and α=0 are indicated in Figure. (6). This Figure. demonstrates different optimal Pareto points according to different weights of the objective function. In addition, Figure. (7) demonstrates the variation of objective function according to upper bound variation in production capacity and $(\omega_1 = 0.5, \omega_2 = 0.5)$. The sensitivity analysis also shows that equal weight for both objectives can be logical for decision makers.

Iran is a rich country in fossil fuels and oil, making it highly dependent on crude oil. Nowadays, energy security is of paramount importance worldwide. Extreme dependence on fossil fuels and a high oil export share has made the country more vulnerable in terms of economy and energy security. Iran has various renewable resources. Motivation in the country must be created in order to replace fossil fuels with renewable resources. In this regard, according to the importance of gasoline in Iran, which is the essential fuel for transportation in the country, the production of bioethanol in combination with gasoline with the rate of 5% along with electricity generation is considered.

Among eight proposed provinces for biomass cultivation centers, Fars, Lorestan, Khuzestan, Markazi, Mazandaran, and Khorasan Razavi are selected. Cultivation centers and some of the essential established technologies at the selected provinces can be seen on the Iran map in Figure. (8).

As mentioned earlier, the capacity of production facilities is considered dynamic in this investigation. This capability allows the development of production capacity in case demand for a product increases. By the development of each facility's capacity, some costs will obviously be imposed on the system. The second and third levels have electricity generation capability. According to

Figure. (9), electricity generation capacity at each period is at least 4000 million kWh, which is produced in five provinces with different capacities. This production supply 10% of the annual demand of Tehran, Isfahan, and Razavi Khorasan provinces. Besides, according to Figure. (10), electricity generation at the third level supplies 10% of the annual electricity demand of East Azarbaijan, Fars, and Khuzestan. As can be concluded according to Figure. (9), the capacity of Khorasan Razavi, Tehran, Khuzestan, and Fars must increase after one year. Similarly, this increase must be considered at the third level of the network.

Table 9
Student-t test for LD linearized objective function

Paired T for SRCP - CP							
	N	Mean	Std deviation	Std error mean	95% CI for the mean difference	T	P-Value
Difference(CP-SRCP)	8	0.01355	0.01011	0.00357	(0.00510, 0.02200)	3.79	0.007
CP	8	0.67707	0.01451	0.00513			
SRCP	8	0.66352	0.0072	0.00255			

Table 10.
Proposed points for the establishment of cultivation and production centers at different network levels of the supply chain

Index	Center name	Candidate provinces	The maximum allowed number for selection
sp	Biomass cultivation centers	Fars, Lorestan, Ilam, Khuzestan, Markazi, Kordestan, Mazandaran, Razavi Khorasan	6
h	Pre-processing centers	Tehran, Isfahan, Fars, Razavi Khorasan, Khuzestan, Azerbaijan	4
j	First level production centers	Tehran, Isfahan, Fars, Razavi Khorasan, Khuzestan, Azerbaijan	4
l	Second level production center	Sistan and Baluchestan, Bushehr, Tehran, Isfahan, Fars, Razavi Khorasan, Khuzestan, Azerbaijan	5
n	Third level production centers	Sistan and Baluchestan, Bushehr, Tehran, Isfahan, Fars, Razavi Khorasan, Khuzestan, Azerbaijan	5

Table 11.
Presented details pertinent to each scenario

Scenario	electricity demand for second-level production center (variation)	electricity demand for third-level production center (variation)	bioethanol demand (variation)	Probability
Scenario 1	0%	0%	0%	34%
Scenario 2	20%	20%	20%	16%
Scenario 3	-20%	-20%	-20%	16%
Scenario 4	20%	20%	-20%	34%

Table 12.
Optimal value of objective functions

objective function	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total system cost(million rials)	21360948200	27720563360	16996290500	26362541930
Total GHG emission(ton)	39897039	54571726	32987485	53818433

Five provinces among eight candidate provinces are selected, where Bioethanol production refinery must be established. The Sum of production capacity at these refineries at each period is higher than 1250 kton bioethanol annually. This production capacity supplies 5% of gasoline demand at the six main provinces of Iran for the following five years. Besides, during this time horizon. Razavi Khorasan, Khuzestan, and Tehran require the development of production capacity (Figure. 11).

Figure. (12) demonstrates the production capacity of syngas, which is at least 1500 kton annually during the first period. Besides, after the first period, all syngas production centers require capacity development. Figure. (13) indicates that the production capacity of Briquette in the first period is at least 27500 kton annually. Among the selected provinces, Razavi Khorasan has had the greatest capacity increase for Briquette, such that its capacity increased from 5500 tons to 6000 kton in the second year. Besides, torrefied pellet production capacity at the first period is at least 30000 kton, as indicated in Figure. (14). One of the decisions that can be made in this investigation is determining the inventory level of each product at each period. The inventory level of bioethanol as one of the final products of the supply chain is indicated in Figure. (15). As can be seen, the greatest inventory level belongs to Isfahan province in the third period with 182 kton.

7. Conclusion and Suggestions

Using biomass materials brings about energy security, lower dependence on fossil fuels, more job openings, the development of rural economy, desert greening, and GHG emissions decline. Concerning the mentioned biomass materials, we can replace fossil fuels with a reliable energy source. In this study, an electricity and bioethanol supply chain is designed, implemented as a case study in Iran. The proposed mathematical model is a green multi-period, multi-product model with economic and environmental objectives capable of making decisions at strategic and tactical levels in the supply chain. Ultimately, in order to get closer to real-world results, an SRCP approach is used. According to the results, in addition to reducing costs and environmental effects, the annual production capacity of at least 8,000 million kWh of electricity and 1250 kton of bioethanol along with the production of agricultural products and intermediate products will lead to the country's progress in energy and agriculture. In the following, concerning the structure of this research, it is suggested that by investigating other parameters of the problem and identifying the uncertainty degree in each parameter, stochastic, fuzzy, robust, or hybrid approaches could be used to deal with such uncertainty in other parameters. Besides, for more application of the provided research, we should consider social objectives, e.g., maximizing the number of open job positions along with the economic and environmental objectives, so that it is rational for the decision-makers at the macro scale.

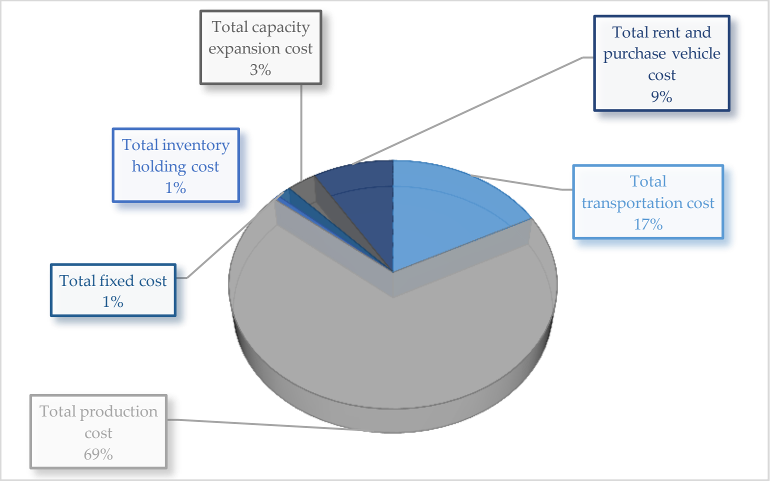

Fig. 4. Percentage of cost components

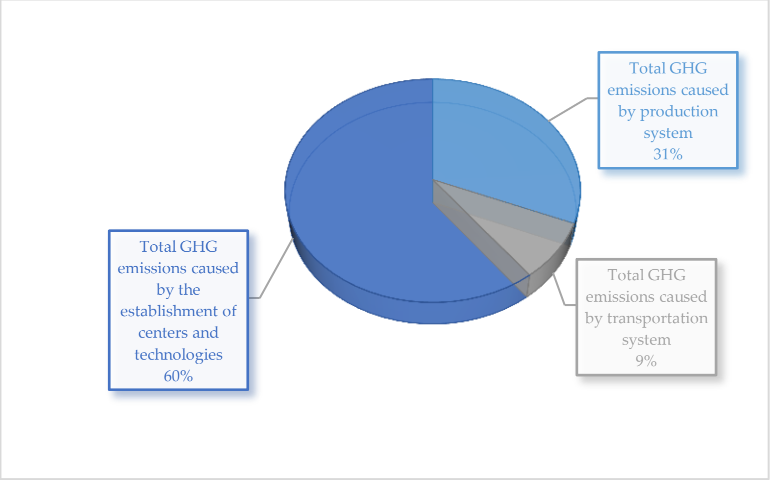

Fig. 5. Percentage of GHG components

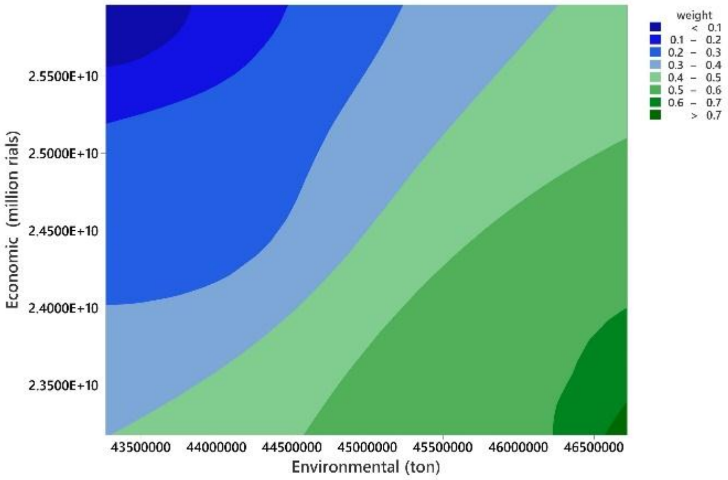

Fig. 6. Contour Plot of weight of Economic objective vs Economic objective, Environmental objective

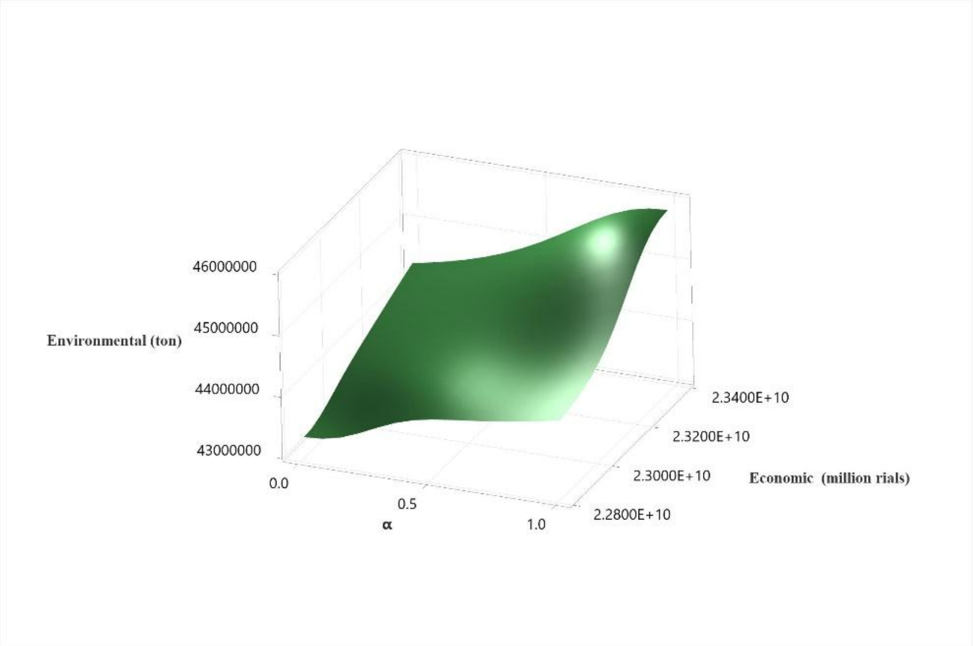

Fig. 7. Surface Plot of Environmental objective vs Economic objective, α

Fig. 8. Structure of selected cultivation center and some established technologies

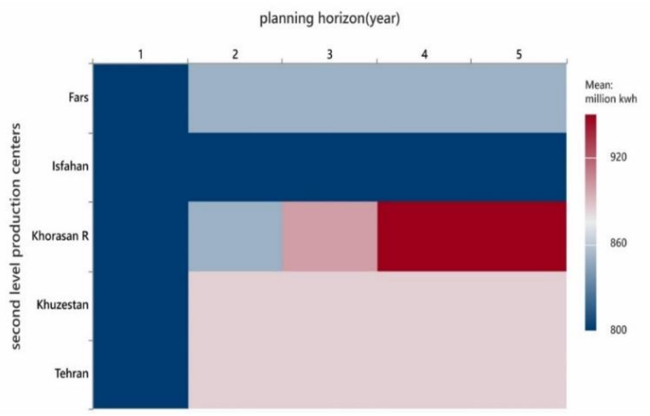

Fig. 9. Electricity generation capacity at the second level of network

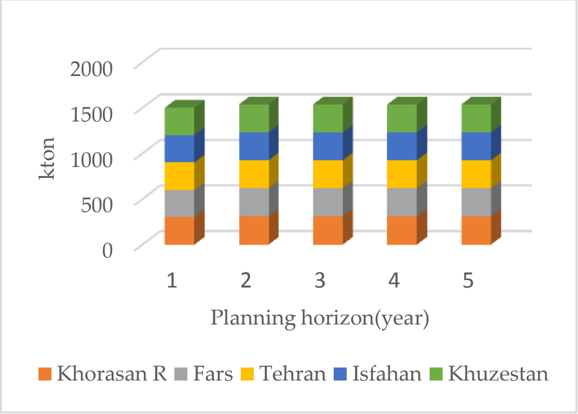

Fig. 12. Production capacity of syngas

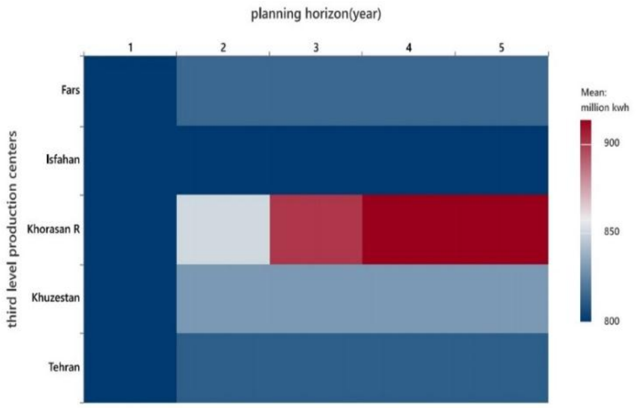

Fig. 10. Electricity generation capacity at the third level of the network

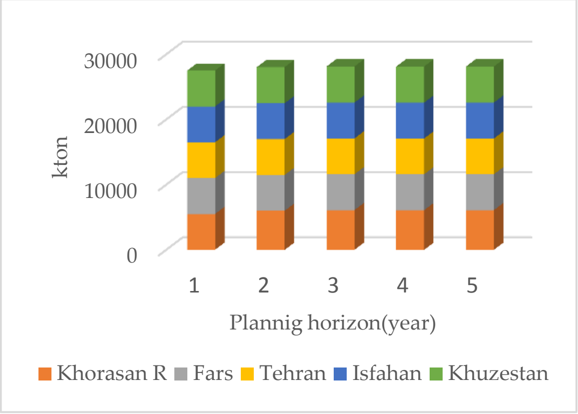

Fig. 13. Production capacity of Briquette

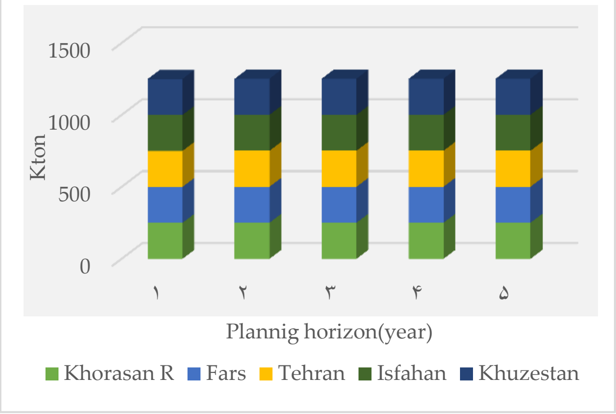

Fig. 11. Bioethanol production capacity

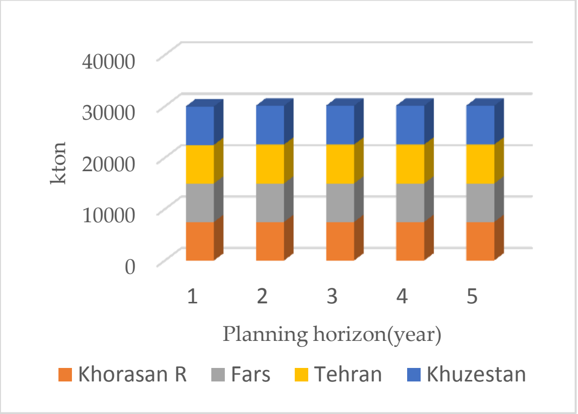

Fig. 14. Production capacity of the torrefied pellet

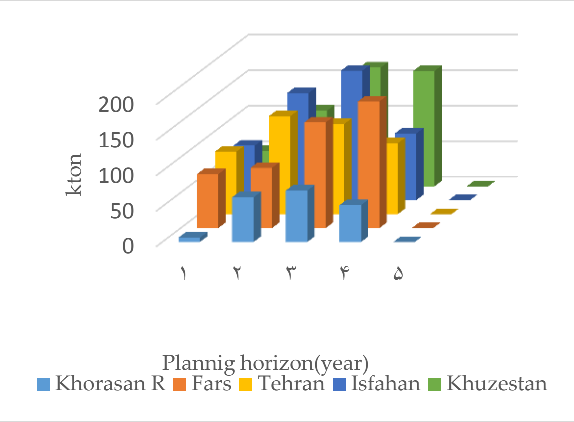

Fig. 15 Inventory level of bioethanol

Reference

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

Wang, L., Littlewood, J., & Murphy, R. J. (2013). Environmental sustainability of bioethanol production from wheat straw in the UK. Renewable and Sustainable Energy Reviews, 28, 715-725.

Tian, S. Q., Zhao, R. Y., & Chen, Z. C. (2018). Review of the pretreatment and bioconversion of lignocellulosic biomass from wheat straw materials. Renewable and Sustainable Energy Reviews, 91, 483-489.

Sarkar, N., Ghosh, S. K., Bannerjee, S., & Aikat, K. (2012). Bioethanol production from agricultural wastes: an overview. Renewable energy, 37(1), 19-27.

An, H., Wilhelm, W. E., & Searcy, S. W. (2011). A mathematical model to design a lignocellulosic biofuel supply chain system with a case study based on a region in Central Texas. Bioresource technology, 102(17), 7860-7870.

Wyman, C. E. (1994). Ethanol from lignocellulosic biomass: technology, economics, and opportunities. Bioresource Technology, 50(1), 3-15.

Najafi, G., Ghobadian, B., Tavakoli, T., & Yusaf, T. (2009). Potential of bioethanol production from agricultural wastes in Iran. Renewable and Sustainable Energy Reviews, 13(6-7), 1418-1427.

Ghaderi, H., Pishvaee, M. S., & Moini, A. (2016). Biomass supply chain network design: an optimization-oriented review and analysis. Industrial crops and products, 94, 972-1000.

Malladi, K. T., & Sowlati, T. (2018). Biomass logistics: A review of important features, optimization modeling and the new trends. Renewable and Sustainable Energy Reviews, 94, 587-599.

Razik, A. H. A., Khor, C. S., & Elkamel, A. (2019). A model-based approach for biomass-to-bioproducts supply Chain network planning optimization. Food and Bioproducts Processing, 118, 293-305.

Tan, Q., Wang, T., Zhang, Y., Miao, X., & Zhu, J. (2017). Nonlinear multi-objective optimization model for a biomass direct-fired power generation supply chain using a case study in China. Energy, 139, 1066-1079.

Ghani, N. M. A. M. A., Vogiatzis, C., & Szmerekovsky, J. (2018). Biomass feedstock supply chain network design with biomass conversion incentives. Energy policy, 116, 39-49.

Kostin, A., Macowski, D. H., Pietrobelli, J. M., Guillén-Gosálbez, G., Jiménez, L., & Ravagnani, M. A. (2018). Optimization-based approach for maximizing profitability of bioethanol supply chain in Brazil. Computers & Chemical Engineering, 115, 121-132.

Razm, S., Nickel, S., Saidi-Mehrabad, M., & Sahebi, H. (2019). A global bioenergy supply network redesign through integrating transfer pricing under uncertain condition. Journal of Cleaner Production, 208, 1081-1095.

Huang, E., Zhang, X., Rodriguez, L., Khanna, M., de Jong, S., Ting, K. C., … & Lin, T. (2019). Multi-objective optimization for sustainable renewable jet fuel production: A case study of corn stover based supply chain system in Midwestern US. Renewable and Sustainable Energy Reviews, 115, 109403.

Dal-Mas, M., Giarola, S., Zamboni, A., & Bezzo, F. (2011). Strategic design and investment capacity planning of the ethanol supply chain under price uncertainty. Biomass and bioenergy, 35(5), 2059-2071.

Kelloway, A., Marvin, W. A., Schmidt, L. D., & Daoutidis, P. (2013). Process design and supply chain optimization of supercritical biodiesel synthesis from waste cooking oils. Chemical Engineering Research and Design, 91(8), 1456-1466.

Egieya, J. M., Čuček, L., Zirngast, K., Isafiade, A. J., Pahor, B., & Kravanja, Z. (2019). Synthesis of biogas supply networks using various biomass and manure types. Computers & Chemical Engineering, 122, 129-151.

Andersen, F., Iturmendi, F., Espinosa, S., & Diaz, M. S. (2012). Optimal design and planning of biodiesel supply chain with land competition. Computers & Chemical Engineering, 47, 170-182.

Shabani, N., Sowlati, T., Ouhimmou, M., & Rönnqvist, M. (2014). Tactical supply chain planning for a forest biomass power plant under supply uncertainty. Energy, 78, 346-355.

Wu, W., Wang, P. H., Lee, D. J., & Chang, J. S. (2017). Global optimization of microalgae-to-biodiesel chains with integrated cogasification combined cycle systems based on greenhouse gas emissions reductions. Applied energy, 197, 63-82.

Babazadeh, R., Razmi, J., Pishvaee, M. S., & Rabbani, M. (2017). A sustainable second-generation biodiesel supply chain network design problem under risk. Omega, 66, 258-277.

Jiang, Y., & Zhang, Y. (2016). Supply chain optimization of biodiesel produced from waste cooking oil. Transportation Research Procedia, 12, 938-949.

Díaz-Trujillo, L. A., & Nápoles-Rivera, F. (2019). Optimization of biogas supply chain in Mexico considering economic and environmental aspects. Renewable energy, 139, 1227-1240.

Zirngast, K., Čuček, L., Zore, Ž., Kravanja, Z., & Pintarič, Z. N. (2019). Synthesis of flexible supply networks under uncertainty applied to biogas production. Computers & Chemical Engineering, 129, 106503.

Rabbani, M., Momen, S., Akbarian-Saravi, N., Farrokhi-Asl, H., & Ghelichi, Z. (2020). Optimal design for sustainable bioethanol supply chain considering the bioethanol production strategies: A case study. Computers & Chemical Engineering, 134, 106720.

Ghaderi, H., Moini, A., & Pishvaee, M. S. (2018). A multi-objective robust possibilistic programming approach to sustainable switchgrass-based bioethanol supply chain network design. Journal of cleaner production, 179, 368-406.

Bairamzadeh, S., Pishvaee, M. S., & Saidi-Mehrabad, M. (2016). Multiobjective robust possibilistic programming approach to sustainable bioethanol supply chain design under multiple uncertainties. Industrial & Engineering Chemistry Research, 55(1), 237-256.

Sharma, B. P., Yu, T. E., English, B. C., Boyer, C. N., & Larson, J. A. (2019). Stochastic optimization of cellulosic biofuel supply chain incorporating feedstock yield uncertainty. Energy Procedia, 158, 1009-1014.

Akhtari, S., Sowlati, T., & Griess, V. C. (2018). Integrated strategic and tactical optimization of forest-based biomass supply chains to consider medium-term supply and demand variations. Applied Energy, 213, 626-638.

Marvin, W. A., Schmidt, L. D., Benjaafar, S., Tiffany, D. G., & Daoutidis, P. (2012). Economic optimization of a lignocellulosic biomass-to-ethanol supply chain. Chemical Engineering Science, 67(1), 68-79.

Zhang, F., Wang, J., Liu, S., Zhang, S., & Sutherland, J. W. (2017). Integrating GIS with optimization method for a biofuel feedstock supply chain. Biomass and bioenergy, 98, 194-205.

Durmaz, Y. G., & Bilgen, B. (2020). Multi-objective optimization of sustainable biomass supply chain network design. Applied Energy, 272, 115259.

O'Neill, E. G., Martinez-Feria, R. A., Basso, B., & Maravelias, C. T. (2022). Integrated spatially explicit landscape and cellulosic biofuel supply chain optimization under biomass yield uncertainty. Computers & Chemical Engineering, 160, 107724.

Zhang, Y., & Jiang, Y. (2017). Robust optimization on sustainable biodiesel supply chain produced from waste cooking oil under price uncertainty. Waste management, 60, 329-339.

Arabi, M., Yaghoubi, S., & Tajik, J. (2019). A mathematical model for microalgae-based biobutanol supply chain network design under harvesting and drying uncertainties. Energy, 179, 1004-1016.

Khishtandar, S. (2019). Simulation based evolutionary algorithms for fuzzy chance-constrained biogas supply chain design. Applied energy, 236, 183-195.

Bairamzadeh, S., Saidi-Mehrabad, M., & Pishvaee, M. S. (2018). Modelling different types of uncertainty in biofuel supply network design and planning: A robust optimization approach. Renewable energy, 116, 500-517.

Habib, M. S., Asghar, O., Hussain, A., Imran, M., Mughal, M. P., & Sarkar, B. (2021). A robust possibilistic programming approach toward animal fat-based biodiesel supply chain network design under uncertain environment. Journal of Cleaner Production, 278, 122403.

Ghelichi, Z., Saidi-Mehrabad, M., & Pishvaee, M. S. (2018). A stochastic programming approach toward optimal design and planning of an integrated green biodiesel supply chain network under uncertainty: A case study. Energy, 156, 661-687.

Díaz-Trujillo, L. A., Fuentes-Cortés, L. F., & Nápoles-Rivera, F. (2020). Economic and environmental optimization for a biogas supply Chain: A CVaR approach applied to uncertainty of biomass and biogas demand. Computers & Chemical Engineering, 141, 107018.

Saghaei, M., Ghaderi, H., & Soleimani, H. (2020). Design and optimization of biomass electricity supply chain with uncertainty in material quality, availability and market demand. Energy, 197, 117165.

Gonela, V., Zhang, J., Osmani, A., & Onyeaghala, R. (2015). Stochastic optimization of sustainable hybrid generation bioethanol supply chains. Transportation research part e: Logistics and transportation review, 77, 1-28.

Billal, M. M., & Hossain, M. (2020). Multi-objective optimization for multi-product multi-period four echelon supply chain problems under uncertainty. Journal of Optimization in Industrial Engineering, 13(1), 1-17.

Reyes-Barquet, L. M., Rico-Contreras, J. O., Azzaro-Pantel, C., Moras-Sánchez, C. G., González-Huerta, M. A., Villanueva-Vásquez, D., & Aguilar-Lasserre, A. A. (2022). Multi-Objective Optimal Design of a Hydrogen Supply Chain Powered with Agro-Industrial Wastes from the Sugarcane Industry: A Mexican Case Study. Mathematics, 10(3), 437.

Aghezzaf, E. H., Sitompul, C., & Najid, N. M. (2010). Models for robust tactical planning in multi-stage production systems with uncertain demands. Computers & Operations Research, 37(5), 880-889.

Sharma, B. P., Yu, T. E., English, B. C., Boyer, C. N., & Larson, J. A. (2020). Impact of government subsidies on a cellulosic biofuel sector with diverse risk preferences toward feedstock uncertainty. Energy Policy, 146 , 111737.

Zelany, M. (1974). A concept of compromise solutions and the method of the displaced ideal. Computers & Operations Research, 1(3-4), 479-496.

Habibi, F., Asadi, E., Sadjadi, S. J., & Barzinpour, F. (2017). A multi-objective robust optimization model for site-selection and capacity allocation of municipal solid waste facilities: A case study in Tehran. Journal of Cleaner Production, 166, 816-834.

Shahmoradi-Moghaddam, H., Akbari, K., Sadjadi, S. J., & Heydari, M. (2016). A scenario-based robust optimization approach for batch processing scheduling. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230(12), 2286-2295.

Avakh Darestani, S., & Pourasadollah, F. (2019). A multi-objective fuzzy approach to closed-loop supply chain network design with regard to dynamic pricing. Journal of Optimization in Industrial Engineering, 12(1), 173-194.

Schoemaker, T. J., & Bouman, P. A. (1991). Facts and Figures on Evironmental Effects of Freight Transport in the Netherlands. In *Studies in Environmental Science* (Vol. 45, pp. 41-62). Elsevier.

Porhinčák, M., Eštoková, A., & Vilčeková, S. (2011). Comparison of environmental impact of building materials of three residential buildings. Pollack Periodica, 6(3), 53-62.

Esmaeili, S. A. H., Szmerekovsky, J., Sobhani, A., Dybing, A., & Peterson, T. O. (2020). Sustainable biomass supply chain network design with biomass switching incentives for first-generation bioethanol producers. *Energy policy*, *138*, 111222.

Ghane, M., & Tavakkoli-Moghaddam, R. (2018). A stochastic optimization approach to a location-allocation problem of organ transplant centers. Journal of Optimization in Industrial Engineering, 11(1), 103-111.

Jana, D. K., Bhattacharjee, S., Dostál, P., Janková, Z., & Bej, B. (2022). Bi-criteria optimization of cleaner biofuel supply chain model by novel fuzzy goal programming technique. Cleaner Logistics and Supply Chain, 4, 100044.

This article can be cited: Rostami-Ranjbar, B., & Saidi-Mehrabad, M. (2022). A Scenario-Based Robust Compromise Programming Approach for Design of Bioethanol and Electricity Supply Chain in Iran. *Journal of Optimization in Industrial Engineering*, *15*(2), 201-226.
Doi: 10.22094/joie.2022.1953244.1941