Original Research

The Sustainable Supply Chain of CO_2 Emissions During the Coronavirus Disease (COVID-19) Pandemic

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Abstract
This investigation aims to demonstrate an application mathematical model of the sustainable closed-loop supply chain network (SCLSCN) during the COVID-19 pandemic. The suggested model can illustrate the trade-offs between environmental, economic, and social dimensions. The costs of this study include the normal costs and the hygienic costs. The novelty social aspects of this model include the average number of lost days caused by COVID-19 damage and the number of created new job opportunities related to COVID-19. The total cost was increased in the COVID-19 pandemic by 25.14 %. The average number of lost days caused by damages increased by 51.64 % during COVID-19. The CO_2 emissions were decreased by17.42 %. This paper presents a multi-objective mixed-integer programming (MOMIP) problem. We use the weighted sum method (WSM) approach for the scalarization approach. To optimize the process, Lingo software has been used. Our contributions to this research are (i) Suggesting an application model of the sustainable supply chain (SSC) to show better the trade-offs between three aspects of sustainability in the COVID-19 pandemic and lockdown periods, (ii) Designing the hygienic and safe SC for employees and employers, (iii) Developing the social and economic indicators, (iv) We have found the negative and positive impacts of COVID-19 and lockdowns on SC, (v) Finally, we analyze the mathematical model and discuss managerial implications. Therefore, this investigation tries to fill this gap in the COVID-19 condition disaster. This research's novelty is to simultaneously present a MOMIP model, COVID-19 issues, and hygienic rules, in a closed-loop supply chain (CLSC) framework.

Keywords: Sustainability; Closed-loop Supply Chain Network; COVID-19 Pandemic; Lockdowns; Multi-objective Mixed-Integer Programming

I INTRODUCTION

The natural catastrophic event faced by the global world started in the Wuhan city of China that comes with breathing problems and those affected are admitted to the hospital; then, this virus spread in a significantly shorter period in the country and it triggered around the globe [77]. COVID-19 can be transmitted rapidly from person to person [18]. Outbreaks cause chaotic situations in the supply chain (SC) all around the world [24]. One of the principles against the COVID-19 virus is the policy of lockdown, quarantine, and reducing physical contact [26]. The context of COVID-19 on SC in the early stages [78]. A closed-loop supply chain (CLSC) is a new logistics approach to stand environmental destruction and resource scarcity. The target of CLSC is to control the flow of materials, reduce emissions and waste, and be able to produce at a low cost [27]. The COVID-19 pandemic can have a basic impact on gas emissions [1]. With the emergence of urgent environment protection, reducing

CO_2 emissions has become the basic objective of supply chain design (SCD) [29]. A decrease in CO_2 emissions is reported in China during the COVID-19 lockdowns [31]. Big companies have expressed worry about their SC with environmental and social sustainability and catastrophic events and trade disputes, even before the COVID-19 [2]. Recently, SCs have become answerable for their activities' environmental and social effects [10]. The sustainability of SC depends upon how SCM, considers benefit, humans, and our planet, simultaneously, the three aspects of sustainability. In terms of the social aspect of SC in the COVID-19 pandemic, it is very important that SC, under the pressure of items such as safety, medical, food, and beverages chains, ensure the health and defense of their main workers [3]. The sustainable supply chain network design (SSCND) is specified as simultaneous attention to economic, environmental, and social aspects of SCs and logistics due to information management [79]. The global COVID-19 epidemic has severely damaged the SC [80]. The COVID-19 epidemic has affected global SCs at an unexampled speed and scale [85]. Along with all aspects of sustainability, creating a reverse flow for handling returned products is a problem that must be addressed [82]. Yet, the boundaries between sustainable and green SC are not defined [83]. With all demotion of sustainability, creating a backflow for the returned products is a problem that needs to be considered [82]. In the meantime, the effective method of increasing benefits and competition is increasing the social effects of networks [81]. COVID-19 has made the strongest impact on SCs in the recent pandemic and is the reason for the biggest disruptions in the history of humanity [11]. Before going into details of our study, it is very important to say that to perform all the activities of a SC, the hygienic principles and protocols related to COVID-19 must be considered for all the people and all places involved in the SC. For this issue, we have prepared Table 1, which meets the health needs of our SC.

To develop the efficiency of SC, the mathematical model of this investigation has been designed by incorporating economic, environmental, and social performance indicators into the SSCND in the COVID-19 condition. Therefore, this research tries to manage a new model of SSC focusing on CO_2 emissions. The multi-echelons model described above is considered to provide five types of facilities. Three hybrid centers such as:1) Manufacture / Remanufacture/Refurbish Centers (Factories)*;* 2) Collection/Distribution Centers, and 3) Recycling / Landfill/Incineration Centers and two simple centers included Suppliers Centers and Customers. The forward flow begins with the extraction of raw materials from suppliers and consigning them to the first hybrid facilities for manufacturing a new product. A manufactured, remanufactured, or refurbished product is transferred along the forward flow to satisfy the customer's demands. In the reverse flow, the returned products are collected from customers and sent to the collection/distribution centers. when the returned products are examined and classified, which are suitable for remanufacturing and refurbishing, sent to the factories, and others are sent to the recycling /landfill/incineration centers. Finally, the recycled materials are returned to the desired suppliers.

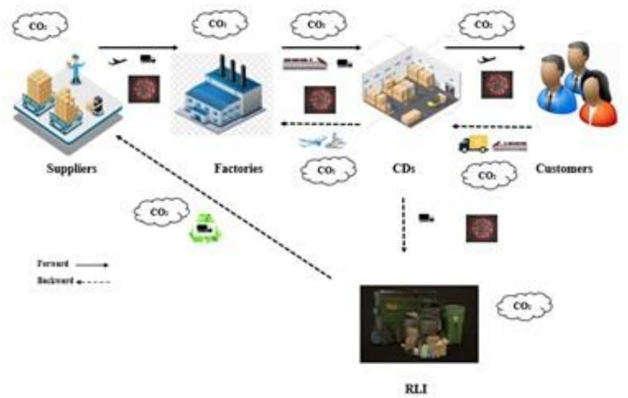

FIGURE1
SCHEMATIC OF CLSC NETWORK

2. LITERATURE REVIEW

This section surveys the related works; it is divided into three groups. The first category deals with carbon issues in the SC, the second is the effect of COVID-19 restrictions on CO_2 emissions, and the last is considering the SC in the COVID-19 pandemic. We mainly study three concepts of CO_2 emissions: Carbon Tax, Carbon Cap, and Cap-and-Trade (CAT).

2.1 Survey on related research

2.1.1 Carbon tax

Paksoy and Özceylan suggested a model for greenhouse gas (GHG) emissions in the supply chain network (SCN) [25]. Zeballos *et al* dealt with different types of transportation costs in connection with real needs in CLSC design [20]. Considered emissions from manufacturing inventory, recycling, and disposing of in the CLSC by [22]. Based on Australia's environmental policy, a tax rate was imposed on trade in CO_2 emissions from the SCD [21]. Considering tax rate effects on SCND by [30]. The role of a carbon tax in a SC and encouraging the manufacturer and the retailer to reduce emissions [53]. Investigation for optimization of CO_2 emissions in SC considering carbon tax [37].

2.1.2. Carbon cap

This policy is commonly specified as the upper bound of CO_2 emissions and should be implemented. The common carbon cap policy has been considered for the SCND in some studies. Many researchers set a limitation in the production, inventory, shipping, and recycling [35], [48], [33], [30], [52], [42], [22]. In control of CO_2 emissions during shipping, determine a maximum of CO_2 emissions for each producing and final recycling. Other scholars consider the periodic or global carbon cap during the SCND [38], [39], [40], [41], [23].

2.1.3 Cap-and-trade

All papers relevant to the cap-and-trade include shipping emissions, including raw material, open facilities, producing, distribution centers, and electricity consumption. Chaabane *et al*. and Rezaee *et al*., present a model, which contacts the CO_2 emissions of shipping and manufacturing with the scale of production [43], [49], [48], [75], [62], [45]. Kannan *et al.* minimize the footprint of CO_2 in open facilities for backward logistics [75]. Consideration of outsourcing issues in SC under the cap-and-trade [62]. Decision and coordination SC considering cap-and-trade [61].

2.1.4 Impact of COVID-19 restrictions on CO_2 emissions

Global reports illustrate that GHG emissions increased a record a couple of years ago. CO_2 emissions in the last five years are above five years ago [46]. It is evaluated that the emissions over the last few days from China (the world's biggest carbon producer) lowered by about 25% more than during the Pre-COVID-19 epidemic [44]. The international energy agency (IEA) has forecasted that CO_2 emissions can fall by 8% during the lockdown periods [47]. Some predictions show that emissions could fall by over 5% in 2020. This is the biggest yearly reduction so far [47]. The analysis reduced CO_2 emissions in the current epidemic with pandemics' past important events. The maximum reduction in CO_2 emissions during COVID-19 has been observed so far. Lockdowns helped to control the transmission rate of COVID-19, but they also ultimately to a severe decrease in human activities [31]. The lockdown restrictions have temporarily stopped the projected harvest of trees, leading to a decrease in CO_2 emissions Because of the current lockdown situation, all main transportation activities have stopped, and it can be predicted that a major part of emissions may be decreased in this outbreak [36].

2.1.5 Considering SC during COVID-19

This section gives a brief history of the considering COVID-19 pandemic in SC, in brief: Design a disaster relief SC with a multi-objective (MO), multi-product, and multi-period model for the PPE demands satisfaction during the COVID-19 [54]. Utilizing IoT for designing a relief SCN during COVID-19 [55]. Designing a sustainable SC considering multi-objective, multi-level, multi-period, and multi-product problems for medical issues during COVID-19 [56]. Designing a stochastic model for optimization of the blood SC based on simulation during COVID-19 by [57]. Designing a sustainable blood SC with a bi-objective approach [51]. Considering uncertainty in designing a network for sustainable-resilience healthcare during COVID-19 [58]. Proposing a multi-level model for optimizing the location of the medical centers during the COVID-19 [59]. Design a SCLSCN for a face mask and solve it with meta-heuristic algorithms during COVID-19 [60]. Ranking of hospitals during COVID-19 for patient satisfaction criteria [63]. The CS vulnerability by COVID-19 [12]. Food SCs during the COVID-19 by [8]. Efficient logistics and SCM during / after COVID-19 [13]. COVID-19 and SC resilience [5]. Rowan &Laffey investigated the shortage of supply chain PPE during the COVID19 epidemic [6]. Using the blockchain technology in SC during COVID-19 [14]. The future effect of the COVID-19 pandemic on global SC [7]. Investigating intertwined supply networks during COVID-19 [11]. A risk model for managing the SC in the COVID-19 condition [15]. The research on SCD can be grouped into single objective (SO), multi-objective (MO), open-loop (OL), and closed-loop (CL). The related works are illustrated in Tables 2 and 3.

2.2 Purpose, research gap, innovation, and objectives of the investigation:

Because of the novelty of the COVID-19 pandemic, there are still many research gaps. In summary, the suggested paper shows some concerns that cover the literature gaps, and innovation can be categorized as follows:

1) Designing a safe and hygienic SC for anyone involved in the chain.

2) Designing a SSC considering, pandemic issues:

a. Developing the economic aspects by adding hygienic costs to the normal condition.

b. Developing the social aspects, concerning COVID-19 damages society (COVID-19 hospitalization-COVID-19 mental illness).

3) Finding the positive, and negative impacts of COVID-19 and lockdown on the SC.

4) Analyzing the mathematical model and discussing managerial implications.

5)In this paper, we have three hybrid centers for preventing physical contact with employees, employers, and customers during the COVID-19 outbreak.

So this investigation simultaneously presents a MOMIP model and COVID-19 pandemic issues in the CLSC framework to fill the gap in the COVID-19 disaster.

3. Proposed Problem

The SSC covers three aspects of sustainability. The CLSC integrates a forward flow with a reverse flow. In our research, the simple centers merged with other centers to make hybrid centers for these reasons: reducing costs, environmental pollution, and CO_2 emission, and observing social distancing.

Based on the idea of stability, our objective functions (OFs) are considered for economic, environmental, and social dimensions.

The mathematical model described above is considered to provide five types of echelons:

- Suppliers centers (S)
- Manufacturing/Remanufacturing/Refurbishing centers (Factories) (F)
- Collection / Distribution centers (CD)
- Customers (V)
- Recycling / Landfill / Incineration centers (RLI)

The forward flow starts with extracting raw materials from supplier centers and consigning them to the factories for manufacturing a new product. A new/remanufactured/ refurbished product is transferred along the forward way (Factories to CDs and CDs to Customers) to meet customer needs. In the reverse flow, the returned products are collected from customers and shipped to the CDs, where the returned products are examined and classified, as suitable for remanufacturing and refurbishing, which are sent to the factories others sent to the RLIs. Eventually, the recycled materials are returned to the suppliers.

3.1 *Research assumptions*

For making the model, our research assumptions are as follows:

- The COVID-19 pandemic is considered in the SC thoroughly.
- The distribution center is merged with the collection center for observance of customers' social distancing.
- For the emergency COVID-19 situation, all demands of customers were always satisfied.
- It is supposed that a determined percentage of the total demand is recycled, landfilled, and incinerated.
- It is supposed that a determined percentage of the returned products is remanufactured/ refurbished.
- All returned products to be disposed of that enter an RLIs are always successfully incinerated and landfilled with the COVID-19 hygiene protocol.
- The locations of Fs, CDs and RLIs centers are potential.
- The locations of suppliers and customers are fixed.
- Distances between echelons should be feasible.
- the network is multi-objective (MO), multi-echelon, multimodal transport (e.g. road (truck) , rail(train), air (cargo plane), sea (ship), etc), and closed-loop (CL).
- Job opportunities are categorized into two types: normal Job opportunities and COVID-19 Job opportunities.
- The health and safety of workers are measured by workday lost and can be classified into two types: The average number of lost days caused by normal damages (e.g. accidents, normal hospitalizations), etc) and the average number of lost days caused by COVID-19 damages (e.g. mental illness during the coronavirus, coronavirus hospitalization, etc).

3.2 *Model components*

The mathematic model includes the sets, parameters, and variables described below:

The sets S, F, G, L, and V contain the suppliers, the factories, the CDs, the RLIs, and the customers. The sets TS, TF, TG, TL, and TV include the transportation options from suppliers, factories, CDs, RLIs, and customers. The model's parameters are technical parameters, economic, environmental, and social parameters. Binary and continuous decision variables are applied to implement the goals of the model.

The verbal explanation of the model:

Minimization of Total Cost during the pandemic =*Fixed costs +Variable costs +Shipping costs+ Hygienic costs****;***

Minimization of Environmental Impact during the pandemic = *CO_2 emissions due to the SC activates+ CO_2 emissions by shipping between echelons of SC****;***

Minimization of Social Impact during the pandemic = *Weighting factor for normal damages (Averages number of lost days by normal damages) +Weighting factor for COVID-19 damages (Averages number of lost days by COVID-19 damages)-Weighting factor for normal job opportunities (Created normal job Opportunities)-Weighting factor for COVID-19 job opportunities (Created COVID-19 job Opportunities)****;***

Subject to: Constraints

3.3 *Formulation process*

The formulation of the mathematical model is separated into two parts: objective functions (OFs) and constraints. The mathematical model has three objectives to minimize the total cost (economic aspect), minimize CO_2 emissions (environmental aspect), and minimize the bad social effect (social aspect) during the COVID-19 and lockdowns condition throughout the CLSC.

Notations

Indices:

s: Index of fixed supplier centers $s \in S = \{1,2,3...,s\}$;

f: Index of potential factories $f \in F = \{1,2,3...,f\}$;

g: Index of potential CD centers $g \in G = \{1,2,3...,G\}$;

l: Index of potential RLI centers $l \in L = \{1,2,3...,L\}$;

v: Index of fixed customers $v \in V = \{1,2,3...,v\}$;

ts: Index of transportation options from supplier centers $ts \in TS = \{1,2,3...,ts\}$;

tf: Index of transportation options from factories $tf \in TF = \{1,2,3...,tf\}$;

tg: Index of transportation options from CD centers $tg \in TG = \{1,2,3...,tg\}$;

tv: Index of transportation options from customers $tv \in TV = \{1,2,3...,tv\}$;

tl: Index of transportation options from RLI centers $tl \in TL=\{1,2, 3..., tl\}$;

Technical parameters:

(Demand)

d_v : Customers' demand;

(Maximum Capacity)

M_f : Maximum manufacturing capacity;

M_g : Maximum distribution capacity;

M_l : Maximum recycling / landfilling / incineration capacity;

Mr_f Maximum remanufacturing/refurbishing capacity;

Mr_g Maximum collection capacity;

(Limit of the returned product)

$N_{dismanteld}$: Minimum percentage of the unit of the returned product to be remanufactured/refurbished;

$N_{disposed-recycled}$: Minimum percentage of the unit of the returned product to be recycled, landfilled, and incinerated;

(Distances)

δ_{sf} :Distance between supplier center *s* and factory *f;*

δ_{fg} : Distance between factory *f* and CD center *g;*

δ_{gf} : Distance between CD center *g* and factory *f;*

δ_{gv} : Distance between CD center *g* and customer *v;*

δ_{vg} : Distance between customer *v* and CD center *g;*

δ_{gl} : Distance between CD center *g* and RLI center *l;*

δ_{ls} : Distance between RLI center *l* and supplier center *s;*

(Weighting factor):

$W_{n_{ld}}$: Weighting factor of the total number of lost days caused by work's normal damages;

$W_{COVID-19_{ld}}$: Weighting factor of the total number of lost days caused by work's COVID-19 damages;

W_{jo} : Weighting factor of the total number of normal job opportunities; $W_{COVID-19_{jo}}$: Weighting factor of the total number of COVID-19 job opportunities;

***Economic parameters*:**

(Fixed costs)

θ_f : Fixed costs for establishing (e.g., design, construction, equipment costs, and etc) factory *f;*

θ_g : Fixed costs for establishing (e.g., design, construction, equipment costs, and etc) CD center *g;*

θ_l : Fixed costs for establishing (e.g., design, construction, equipment costs, and etc)RLI center *l;*

(Variable Costs)

Vs: Variable costs for extracting a unit of raw material from the supplier *s;*

V_f: Variable costs for manufacturing a unit of product in the factory *f;*

V_g: Variable costs for distribution of a unit of product in the CD center *g;*

V_{rg}: Variable costs for collecting, inspecting, consolidating, and sorting a unit of the returned product in the CD center *g;*

V_l: Variable costs for recycling, incinerating, and landfilling a unit of the returned product in the RLI center *l;*

V_{rf}: Variable costs for remanufacturing and refurbishing a unit of the returned product in the factory *f;*

(Transportation Cost)

TCO_{sf}^{ts}: Transportation cost of a unit of raw material from the supplier *s* to factory *f* with transportation option *ts;*

TCO_{fg}^{tf}: Transportation cost of a unit product from factory *f* to CD center *g* with transportation option *tf;*

TCO_{gv}^{tg}: Transportation cost of a unit of product from CD center *g* to customer *v* with transportation option *tg;*

TCO_{vg}^{tv}: Transportation cost of a unit of the returned product is collected from customer *v* to CD center *g* with transportation option *tv;*

TCO_{gf}^{tg}: Transportation cost of a unit of the returned product is available for remanufacturing and refurbishing from CD center *g* to factory *f* with transportation option *tg;*

TCO_{gl}^{tg}: Transportation cost of a unit of returned product that is unsuitable for remanufacturing and refurbishing, from CD center *g* to RLI center *l* with transportation option *tg;*

TCO_{ls}^{tl}: Transportation cost of a unit of recycled materials from RLI center *l* to supplier *s* with transportation option *tl;*

(Hygienic Costs)

HV_s: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during extracting a unit of raw material from the supplier *s;*

HV_f: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during a producing a unit of product in the factory *f*;

HV_g: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during distributing a unit of product from the CD center *g*;

HVr_g: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during collecting inspecting consolidating, and sorting a unit of the returned products in the CD center *g*;

HV_l: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during recycling, incinerating, and landfilling a unit of the returned product in RLI center *l;*

HVr_f: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during remanufacturing and refurbishing a unit of the returned product in the factory *f;*

HTC_{sf}^{ts}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of raw material from the supplier *s* to the factory *f* with transportation options *ts;*

HTC_{fg}^{tf}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of product from factory *f* to CD center *g* with transportation option *tf;*

HTC_{gv}^{tg}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of product from CD center *g* to customer *v* with transportation option *tg;*

HTC_{gf}^{tg}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of the returned product is available for remanufacturing and refurbishing from CD center *g* to factory *f* with transportation option *tg;*

HTC_{gl}^{tl}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of the returned product that is unsuitable for remanufacturing and refurbishing from CD center *g* to RLI center *l* with transportation option *tl;*

HTC_{vg}^{tv}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of returned product from customer *v* to CD center *g* with transportation option *tv;*

HTC_{ls}^{tl}: Hygienic costs (e.g., disinfection, sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, and etc) during the transporting of a unit of recycled materials from RLI center *l* to supplier *s* with transportation option *tl;*

***Environmental parameters*:**

(CO_2 emissions from the activities)

e_s : Rate of CO_2 emissions to extracting a unit of raw material in supplier *s* during COVID-19 and lockdown periods*;*

e_f : Rate of CO_2 emissions for manufacturing one unit of product in factory *f* during COVID-19 and lockdown periods*;*

e_g :Rate of CO_2 emissions for handling and distributing one unit of product in the CD center *g* during COVID-19 and lockdown periods*;*

er_g : Rate of CO_2 emissions for collecting, inspecting consolidating, and sorting one unit of the returned product in the CD center *g* during COVID-19 and lockdown periods*;*

er_f : Rate of CO_2 emissions for refurbishing / remanufacturing one unit of the returned product in the factory *f* during COVID-19 and lockdown periods*;*

e_l : Rate of CO_2 emissions for recycling, incinerating, and landfilling one unit of the returned product in RLI center *l* during COVID-19 and lockdown periods*;*

(CO_2 released by shipping)

ETC_{sf}^{ts}:CO_2 emissions by transportation option *ts* to send a unit of raw material from supplier *s* to factory *f* for a unit distance during COVID-19*;*

ETC_{fg}^{tf}:CO_2 emissions by transportation option *tf to* send a unit of product from factory *f* to CD center *g* for a unit distance during COVID-19*;*

ETC_{gv}^{tg}:CO_2 emissions by transportation option *tg* to send a unit of product from CD center *g* to customer *v* for a unit distance during COVID-19*;*

$ETCR_{vg}^{tv}$: CO_2 emissions by transportation option *tv* to collect a unit of returned production from customer center *v* to CD center *g* for a unit distance during COVID-19*;*

$ETCR_{gf}^{tg}$: CO_2 emissions by transportation option *tg* to send a unit of the returned product to be remanufactured from CD center *g* to factory *f* for a unit distance during COVID-19*;*

$ETCR_{gl}^{tg}$:CO_2 emissions by transportation option *tg* to send a unit of returned production from CD center *g* to RLI center *l* for a unit distance during COVID-19*;*

ETC_{ls}^{tl}: CO_2 emissions by transportation option *tl* to send a unit of recycled materials from RLI center *l* to supplier s for a unit distance during COVID-19*;*

***Social parameters*:**

(The averages number of lost days):

LD_f: The average number of lost days caused by normal damages (e.g. accidents, normal hospitalizations, and etc) during the COVID-19 pandemic if factory *f* is opened;

LD_g: The average number of lost days caused by normal damages (e.g. accidents, normal hospitalizations, and etc) during the COVID-19 pandemic if CD center *g* is opened;

LD_l: The average number of lost days caused by normal damages (e.g. accidents, normal hospitalizations, and etc) during the COVID-19 pandemic if RLI center l is opened;

$LD\text{-}COVID_f$: The average number of lost days caused by COVID-19 damages (e.g. mental illness during the coronavirus, coronavirus hospitalization, and etc) during the COVID-19 pandemic if factory f is opened;

$LD\text{-}COVID_g$: The average number of lost days caused by COVID-19 damages (e.g. mental illness during the coronavirus, coronavirus hospitalization, and etc) in the COVID-19 pandemic if CD center g is opened;

$LD\text{-}COVID_l$: The average number of lost days caused by COVID-19 damages (e.g. mental illness during the coronavirus, coronavirus hospitalization, and etc) during the COVID-19 pandemic if RL l is opened;

(The number of created job opportunities):

JO_f: The number of created normal job opportunities if factory f is opened;

JO_g: The number of created normal opportunities if CD center g is opened;

JO_l: The number of created normal opportunities if RLC center l is opened;

$JO\text{-}COVID_f$: The number of created new job opportunities related to *COVID-19* during manufacturing, remanufacturing and refurbishing, if factory f is opened;

$JO\text{-}COVID_g$: The number of created new job opportunities related to *COVID-19* during distributing and collecting if CD center g is opened;

$JO\text{-}COVID_l$: The number of created new job opportunities related to *COVID-19* during recycling, incinerating, and landfilling if RLC center l is opened;

***Variables*:**

Binary:

x_f: If factory f is established, equal 1; otherwise 0;

x_g: If CDC center g is established, equal 1; otherwise 0;

x_l: If RLC center l is established, equal 1; otherwise 0;

Amount of product and returned product:

Y_{sf}^{ts}: Quantity of units of raw material sent from supplier s to factory f with transportation ts;

Y_{fg}^{tf}: Quantity of units of product sent from factory f to CD center g with transportation tf;

Y_{gv}^{tg}: Quantity of units of product sent from CD center g to customer v with transportation tg;

Y_{vg}^{tv}: Quantity of units of returned product collected from customer v to CD center g with transportation option tv;

Y_{gf}^{tg}: Quantity of units of returned product available for remanufacturing and refurbishing sent from CD center g to factory f with transportation option tg;

Y_{gl}^{tg}: Quantity of units of returned product unsuitable for remanufacturing and refurbishing sent from CD center g to RLI center l with transportation option tg;

Y_{ls}^{tl}: Quantity of units of recycled product sent from RLC l to supplier s with transportation tl;

Objective functions of supply chain network:

$$\text{Min } Z_1 = \sum_{f=1}^{F}\theta_f x_f + \sum_{g=1}^{G}\theta_g x_g + \sum_{l=1}^{L}\theta_l x_l \quad (1)$$

(2)

$$\sum_{s=1}^{S}V_s\sum_{f=1}^{F}\sum_{ts=1}^{TS}Y_{sf}^{ts} + \sum_{f=1}^{F}V_f\sum_{g=1}^{G}\sum_{tf=1}^{TF}Y_{fg}^{tf} + \sum_{g=1}^{G}V_g\sum_{v=1}^{V}\sum_{tg=1}^{TG}Y_{gv}^{tg}$$
$$+\sum_{g=1}^{G}Vr_g\sum_{v=1}^{V}\sum_{tv=1}^{TV}Y_{vg}^{tv} + \sum_{f=1}^{F}Vr_f\sum_{g=1}^{G}\sum_{tg=1}^{TG}Y_{gf}^{tg} + \sum_{l=1}^{L}V_l\sum_{g=1}^{G}\sum_{tg=1}^{TG}Y_{gl}^{tg}$$

(3)

$$\sum_{s=1}^{S}\sum_{f=1}^{F}\sum_{ts=1}^{TS}TCO_{sf}^{ts}Y_{sf}^{ts} + \sum_{f=1}^{F}\sum_{g=1}^{G}\sum_{tf=1}^{TF}TCO_{fg}^{tf}Y_{fg}^{tf} + \sum_{g=1}^{I}\sum_{v=1}^{V}\sum_{tg=1}^{TG}TCO_{gv}^{tg}Y_{gv}^{tg}$$
$$+\sum_{v=1}^{V}\sum_{g=1}^{G}\sum_{tv=1}^{TV}TCO_{vg}^{vg}Y_{vg}^{tv} + \sum_{g=1}^{G}\sum_{f=1}^{F}\sum_{tg=1}^{TG}TCO_{gf}^{tg}Y_{gf}^{tg} + \sum_{g=1}^{G}\sum_{l=1}^{L}\sum_{tg=1}^{TG}TCO_{gl}^{tg}Y_{gl}^{tg}$$
$$+\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{tl=1}^{TL}TCO_{ls}^{tl}Y_{ls}^{tl}$$

(4)

$$\sum_{s=1}^{S}HV_s\sum_{f=1}^{F}\sum_{ts=1}^{TS}Y_{sf}^{ts} + \sum_{f=1}^{F}HV_f\sum_{g=1}^{G}\sum_{tf=1}^{TF}Y_{fg}^{tf} + \sum_{g=1}^{G}HV_g\sum_{v=1}^{V}\sum_{tg=1}^{TG}Y_{gv}^{tg}$$
$$+\sum_{g=1}^{G}HVr_g\sum_{v=1}^{V}\sum_{tv=1}^{TV}Y_{vg}^{tv} + \sum_{f=1}^{F}HVr_f\sum_{g=1}^{G}\sum_{tg=1}^{TG}Y_{gf}^{tg} + \sum_{l=1}^{L}HV_l\sum_{g=1}^{G}\sum_{tg=1}^{TG}Y_{gl}^{tg}$$
$$+$$
$$\sum_{s=1}^{S}\sum_{f=1}^{F}\sum_{ts=1}^{TS}HTCO_{sf}^{ts}Y_{sf}^{ts} + \sum_{f=1}^{F}\sum_{g=1}^{G}\sum_{tf=1}^{TF}HTCO_{fg}^{tf}Y_{fg}^{tf} + \sum_{g=1}^{G}\sum_{v=1}^{V}\sum_{tg=1}^{TG}HTCO_{gv}^{tg}Y_{gv}^{tg}$$
$$+\sum_{v=1}^{V}\sum_{g=1}^{G}\sum_{tv=1}^{TV}HTCO_{vg}^{tv}Y_{vg}^{tv} + \sum_{g=1}^{G}\sum_{f=1}^{F}\sum_{tg=1}^{TG}HTCO_{gf}^{tg}Y_{gf}^{tg} + \sum_{g=1}^{G}\sum_{l=1}^{L}\sum_{tg=1}^{TG}HTCO_{gl}^{tg}Y_{gl}^{tg}$$
$$+\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{tl=1}^{TL}HTCO_{ls}^{tl}Y_{ls}^{tl}$$

(5)

$$\text{Min} Z_2 = \sum_{s=1}^{S}e_s\sum_{f=1}^{F}\sum_{ts=1}^{TS}Y_{sf}^{ts} + \sum_{f=1}^{F}e_f\sum_{g=1}^{G}\sum_{tf=1}^{TF}Y_{fg}^{tf} + \sum_{g=1}^{G}e_g\sum_{v=1}^{V}\sum_{tg=1}^{TG}Y_{gv}^{tg}$$
$$+\sum_{g=1}^{G}er_g\sum_{v=1}^{V}\sum_{tv=1}^{TV}Y_{vg}^{tv} + \sum_{f=1}^{F}er_f\sum_{g=1}^{G}\sum_{tg=1}^{TG}Y_{gf}^{tg} + \sum_{l=1}^{L}e_l\sum_{g=1}^{G}\sum_{tg=1}^{TG}Y_{gl}^{tg} +$$
$$\sum_{s=1}^{S}\sum_{f=1}^{F}\sum_{ts=1}^{TS}ETC_{sf}^{ts}Y_{sf}^{ts}\delta_{sf}^{ts} + \sum_{f=1}^{F}\sum_{g=1}^{G}\sum_{tf=1}^{TF}ETC_{fg}^{tf}Y_{fg}^{tf}\delta_{fg}^{tf} + \sum_{g=1}^{G}\sum_{v=1}^{V}\sum_{tg=1}^{TG}ETC_{gv}^{tg}Y_{gv}^{tg}\delta_{gv}^{tg}$$
$$+\sum_{v=1}^{V}\sum_{g=1}^{G}\sum_{tv=1}^{TV}ETCR_{vg}^{tv}Y_{vg}^{tv}\delta_{vg}^{tv} + \sum_{g=1}^{G}\sum_{f=1}^{F}\sum_{tg=1}^{TG}ETCR_{gf}^{tg}Y_{gf}^{tg}\delta_{gf}^{tg} + \sum_{g=1}^{G}\sum_{l=1}^{L}\sum_{tg=1}^{TG}ETC_{gl}^{tg}Y_{gl}^{tg}\delta_{gl}^{tg}$$
$$+\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{tl=1}^{TL}ETCR_{ls}^{tl}Y_{ls}^{tl}\delta_{ls}^{tl}$$

(6)

Min Z3 = [$W_{n_{ld}}$ (LD$_f$. x_f+ LD$_g$. x_g + LD$_l$. x_l + $W_{COVI-19_{ld}}$ (*LD-COVID$_f$. x_f + LD-COVID$_g$. x_g + LD-COVID$_l$. x_l*]-[W_{jo} (JO$_f$. x_f +JO$_g$ x_g +JO$_l$. x_l)+ $W_{COVID-19_{jo}}$ (JO-COVID$_f$. x_f +JO-COVID$_g$. x_g +JO-COVID$_l$. x_l)]

Constraints of supply chain network:

$$\sum_{s\in S}\sum_{ts\in TS} Y_{sf}^{ts} \le M_f x_f \quad \forall f\in F \quad (7)$$

$$\sum_{f\in F}\sum_{tf\in TF} Y_{fg}^{tf} \le M_g x_g \quad \forall g\in G \quad (8)$$

$$\sum_{g\in G}\sum_{tg\in TG} Y_{gl}^{tg} \le M_l x_l \quad \forall l\in L \quad (9)$$

$$\sum_{g\in G}\sum_{tg\in TG} Y_{gf}^{tg} \le Mr_f x_f \quad \forall f\in F \quad (10)$$

$$\sum_{v\in V}\sum_{tv\in TV} Y_{vg}^{tv} \le Mr_g x_g \quad \forall g\in G \quad (11)$$

$$\sum_{g\in G}\sum_{tf\in TF} Y_{fg}^{tf} \le \sum_{f\in F}\sum_{ts\in TS} Y_{sf}^{ts} \quad \forall f\in F \quad (12)$$

$$\sum_{v\in V}\sum_{tg\in TG} Y_{gv}^{tg} \le \sum_{g\in G}\sum_{tf\in TF} Y_{fg}^{tf} \quad \forall g\in G \quad (13)$$

$$\sum_{l\in L}\sum_{tg\in TG} Y_{gl}^{tg} \le \sum_{g\in G}\sum_{tf\in TF} Y_{fg}^{tf} \quad \forall g\in G \quad (14)$$

$$\sum_{f\in F}\sum_{tg\in TG} Y_{gf}^{tg} \le \sum_{g\in G}\sum_{tf\in TF} Y_{fg}^{tf} \quad \forall g\in G, \forall f\in F \quad (15)$$

$$\sum_{i\in I}\sum_{tc\in TC} Y_{vg}^{tv} \le \sum_{v\in V}\sum_{tg\in TG} Y_{gv}^{tg} \quad \forall g\in G, \forall v\in V \quad (16)$$

$$d_v \le \sum_{g=1}^{G}\sum_{tg=1}^{TG} Y_{gv}^{tg} \quad \forall v\in V \quad (17)$$

$$\sum_{v=1}^{V}\sum_{tv=1}^{TV} Y_{vg}^{tv} \le d_v \quad \forall v\in V \quad (18)$$

$$N_{disposed-recycled}.dv \le \sum_{g=1}^{G}\sum_{tv=1}^{TV} Y_{vg}^{tv} \quad \forall v\in V \quad (19)$$

$$\sum_{f\in F}\sum_{tg\in TG} Y_{gf}^{tg} \ge N_{dismanteld}\sum_{v\in V}\sum_{tg\in TG} Y_{vg}^{tg} \quad \forall g\in G \quad (20)$$

$$Y_{sf}^{ts}, Y_{fg}^{tf}, Y_{gv}^{tg}, Y_{vg}^{tv}, Y_{gf}^{tg}, Y_{gl}^{tg}, Y_{ls}^{tl} \ge 0 \quad \forall s\in S, \forall f\in F, \forall g\in G, \forall l\in L, \forall v\in V, \forall ts\in TS, \forall tf\in TF, \forall tg\in TG, \forall tl\in TL, \forall tv\in TV \quad (21)$$

$$X_f, X_g, X_l \in \{0,1\} \quad \forall f\in F, \forall g\in G, \forall l\in L \quad (22)$$

The OFs:

The OFs are described in Eqs (1) - (6). The total cost is the summation of the total fixed cost, the total variable cost, the total hygienic cost, and the total shipping cost. The total emissions of CO_2 are calculated by adding the total CO_2 due to extracting raw materials, manufacturing, remanufacturing, refurbishing, recycling, incinerating, and landfilling, and the total CO_2 emissions due to transporting. The total bad social impact is computed by subtracting the number of lost days and created job opportunities throughout SC during the coronavirus disease pandemic. All the current SC social effects are formulated as follows by giving weight to each component; the weighting factor of the total number of lost days caused by work's normal and COVID-19 damages, the weighting factor of the total number of produced normal and COVID-19 job opportunities.

The Constraints:

The constraints of the mathematical model are given below, Eqs (7) - (22):

7) The total number of row materials units that enter a factory from any suppliers via any transportation options should be lower or equal to the maximum capacity of the respective factory.

8) The total number of product units that enter a CD center from any factories via any transportation options should be lower or equal to the maximum capacity of the respective CD center.

9) The total number of returned product units to be recycled, incinerated, and landfilled collected from any customers to an RLI center via any transportation options should be lower or equal to the maximum capacity of the respective RLI center.

10) The total number of returned product units shipped from a CD center to any factories via any transportation options should be lower or equal to the maximum remanufacturing and refurbishing capacity of the respective factory.

11) The total number of returned product units shipped from a customer to any CD centers via any transportation options should be lower or equal to the maximum collecting capacity of the respective factory.

12) The total number of product units shipping from a factory to any CD centers via any transportation options should be lower or equal to the total number of raw material units shipping from a supplier to any factories.

13) The total number of product units shipping from a CD center to any customers via any transportation options should be lower or equal to the total number of products shipping from a factory to any CD centers.

14) The total number of product units shipping from a CD center to any RLI centers via any transportation options should be lower or equal to the total number of products shipping from a factory to any CD centers.

15) The total number of returned product units shipping from a CD center to any factories via any transportation options should be lower or equal to the total number of products units shipping from a factory to any CD centers.

16)The total number of returned product units shipping from a customer to any CD centers via any transportation options

should be lower or equal to the total number of products units shipping from a CD center to any customers.
17) The total number of product units distributed from any CD centers via any transportation options to satisfy the demand of a customer should be higher or equal to the respective demand of the customer.
18) The total number of returned products units collected from a customer to any CD centers via any transportation options should be lower than the respective customer demand.
19) The total number of product units to be recycled, incinerated, and landfilled sent to any RLI centers via any transportation options from a customer should be higher or equal to the minimum percentage of restitution from the total number of demands of the respective customer.
20) The total number of products units to be refurbished and remanufactured delivered to any factories from a CD center via any transportation options should be greater or equal to the minimum percentage of units of product to be remanufactured from the total amount of units of returned product.
21) The total number of raw material, products, and returned products flowed from a supplier to a factory via transportation options, a factory to a CD center via transportation options, a CD center to a customer center via transportation options, a customer center to a CD center via transportation options and CD center to RLI center and a factory via transportation options should be higher or equal to zero.
22) Binary number which is used to describe the existence of facilities (factories, CD centers, and RLI centers).

3.4 Multi-objective (MO)methodology

The multi-objective optimization problems (MOOPs) consist of more than one objectives functions that must be minimized or maximized. The non-dominant group of fully possible decision space is named the Pareto-optimal set (POS). In the POS, the specified bounder of the collection of all mapped points is named the Pareto-optimal front (POF).

Scalarization Methods:

The traditional way to solve MOOP is scalarization, which engages in formulating a SOOP that is associated with the MOOP [19].

$$\min_{x \in X} (f_1(x) \ldots, f_p(x))$$

The weighted sum method (WSM) uses the vector of weights $\lambda \in R^p \geq$ as a parameter [19].

$$\min_{x \in X} \sum_{k=1}^{p} \lambda_k f_k(x)$$

A way to managing WSM is to weigh each aspect and minimize the weighted sum of all aspects. The excellence of this method is to solve MOP with SO approaches [74].

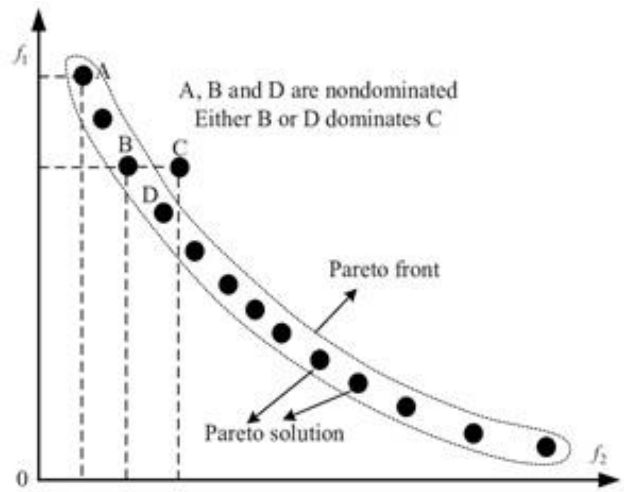

FIGURE2
GRAPHICAL PRESENTATION OF THE PARETO SOLUTIONS [50]

The model for solving three OFs with WSM:

Minimize $w_1 f_1 + w_2 f_2 + w_3 f_3$

Subject to:

Eqs (7) to (22)

where $w_1 \geq 0$, $w_2 \geq 0$, and $w_3 \geq 0$ are weights such that $w_1 + w_2 + w_3 = 1$; f_1, f_2 and f_3 the OFs.

4. Implementation And Evaluation (Case Study)

The first affected of COVID-19 was announced in Iran on 19 February 2020. The validity of the model and the performance of the solution method are evaluated through the data for the considered case study. We surveyed real companies in Iran and collected information from the manager of SC. A real case study evaluated the results of the model. At last, it must be referenced that the proposed model is a reliable and responsive closed-loop SCND model. The network in this investigation is made of five types of facilities, namely suppliers (S), factories (Fs), collection /distribution centers (CDs), recycling /landfill/incineration centers (RLIs), and customers (Vs). Potential location of supply chain facilities: Fs, CDs, RLIs, and fixed location S and V are given. we focus on CO_2 emissions for environmental impact then, the total emissions of CO_2 are calculated by adding the total CO_2 gases due to extracting raw materials, producing, remanufacturing, refurbishing, recycling, landfilling, and the total CO_2 gases due to transporting. The hygienic costs of the network included: disinfection & sterilization, PPE, COVID-19 test, COVID-19 education, vaccine, vaccination, medicine, etc. Tables 4-10 demonstrate the essential data for modeling.

FIGURE 3
SCHEMATIC OF THE REAL SC DURING COVID-19 AND LOCKDOWNS

5. COMPUTATIONAL RESULTS

A numerical example is created to show and analyze the mathematical model's efficiency in small dimensions. The closed-loop network (CLN) in the numerical example is made of five types of facilities, namely Suppliers (Ss), Factories (F), Collection/Distribution Centers (CDs), Recycling/landfill Centers (RLIs), and Customers (Vs). The potential location of supply chain facilities (F, CD, RLI) and existing S and V are.{Existing Suppliers (s= 1, 2...7); Potential Factories (f = 1, 2,...10);Potential CDs (g = 1,2,...8);Existing Customers (v = 1, 2,...5);Potential RLIs (l = 1,2,3,4);Transportation options from suppliers (ts = 1, 2...6);Transportation options from factories (tf = 1,2,...9);Shipping alternatives from CDs (tg = 1,2);Transportation options from customers (tv = 1,2,3);Transportation options from RLIs (tl = 1,2)}.

The results of solving the sustainable SC model with different objective weights: If $W_{economic\ performance}=0.5396$, $W_{environmental\ performance}=0.2970$, $W_{social\ performance}=0.1634$ then the objective value is= 4006821. If $W_{economic\ performance}=0.2970$, $W_{environmental\ performance}=0.1634$, $W_{social\ performance}=0.5396$ then the objective value is= 2205365. If $W_{economic\ performance}=0.1634$, $W_{environmental\ performance}=0.5396$, $W_{social\ performance}=0.2970$ then the objective value is= 6939799.

So we conclude when the weight of the environment is greater the optimization value goes up:

$W_{economic\ performance} \geq W_{environmental\ performance} \geq W_{social\ performance} = Z_1^*$;

$W_{social\ performance} \geq W_{economic\ performance} \geq W_{environmental\ performance} = Z_2^*$;

$W_{environmental\ performance} \geq W_{social\ performance} \geq W_{economic\ performance} = Z_3^*$;

$$Z_3^* \geq Z_1^* \geq Z_2^*$$

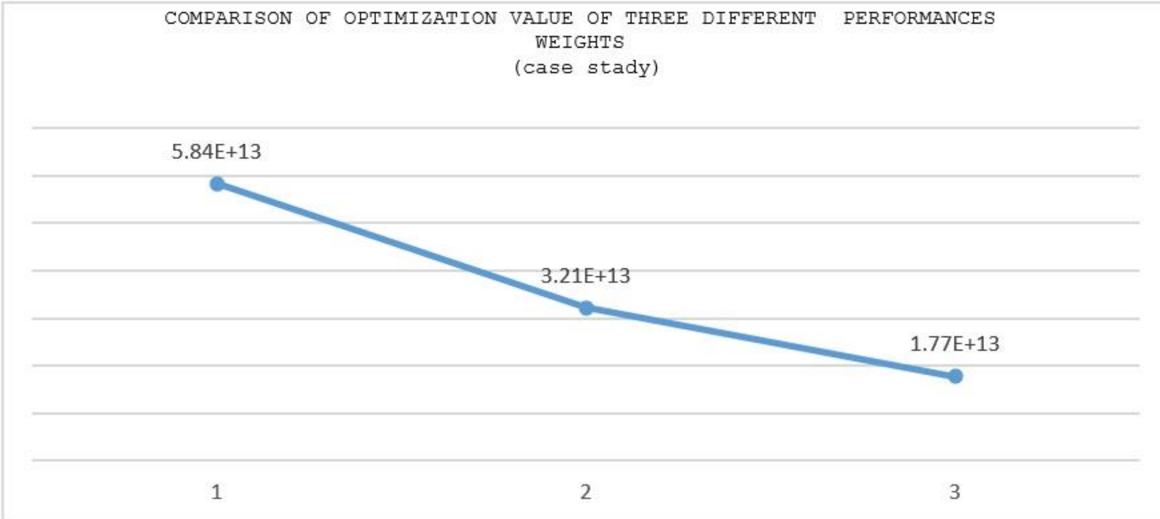

FIGURE 4
OPTIMIZATION RESULT OF CASE STUDY USING SCALARIZATION APPROACH

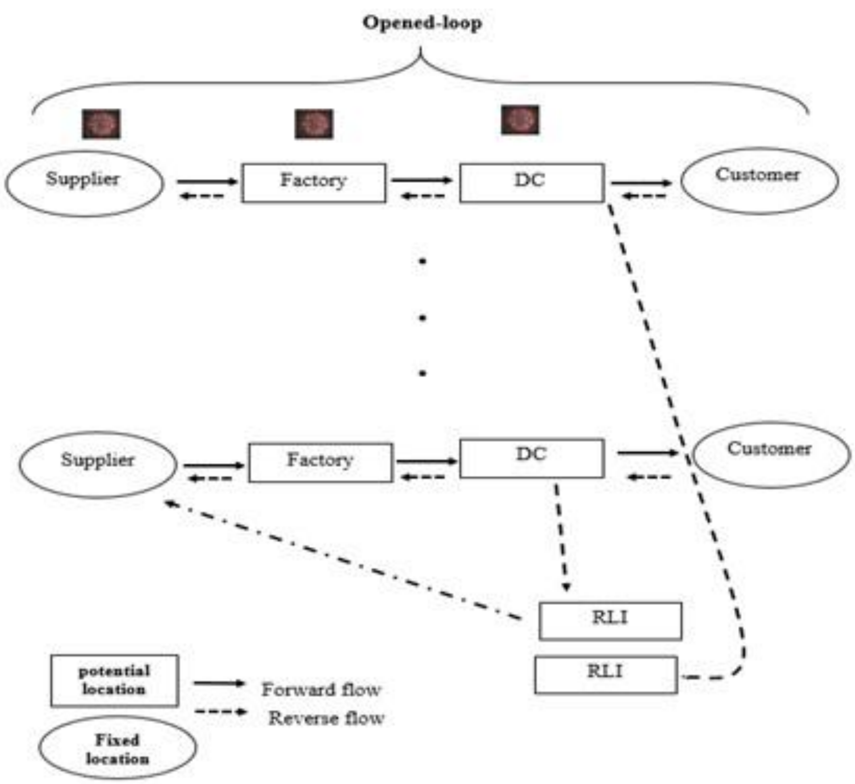

FIGURE 5
A CLOSED-LOOP NETWORK IN SMALL DIMENSION

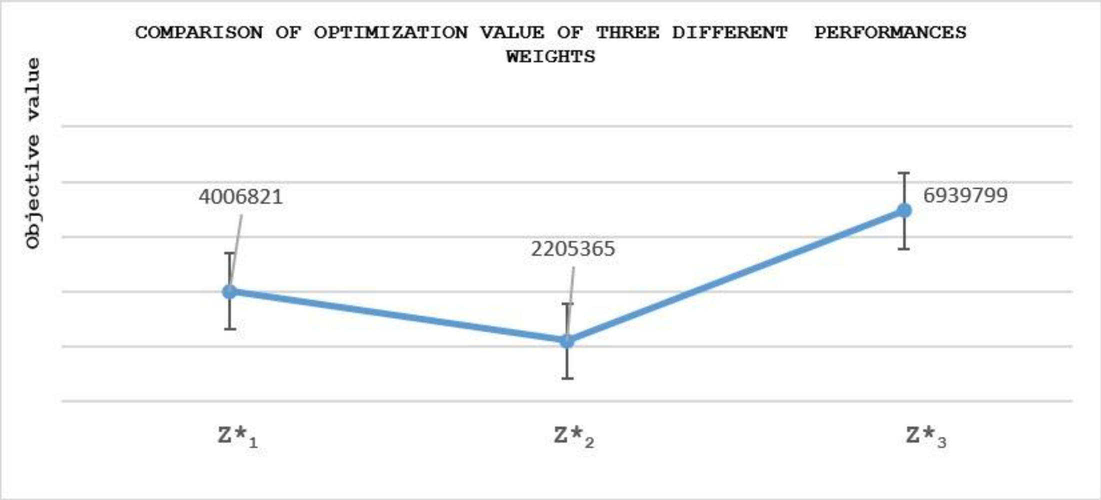

FIGURE 6
OPTIMIZATION VALUE OF NUMERICAL EXAMPLE

6. SENSITIVITY ANALYSIS

6.1 *Sensitivity Analysis of* w_i:

The computational process is conducted through lingo software. Different approximations to the POF are determined by the WSM. In this case, there are three weights (w_1, w_2, and w_3) because of three OFs. It is noticeable that $w_1, w_2, w_3 \geq 0$ and $w_1 + w_2 + w_3 = 1$.

So we conclude when the weight of the environment is greater the optimization value goes up. The impact of COVID-19 on the environment is very important as other aspects of sustainability in our research.

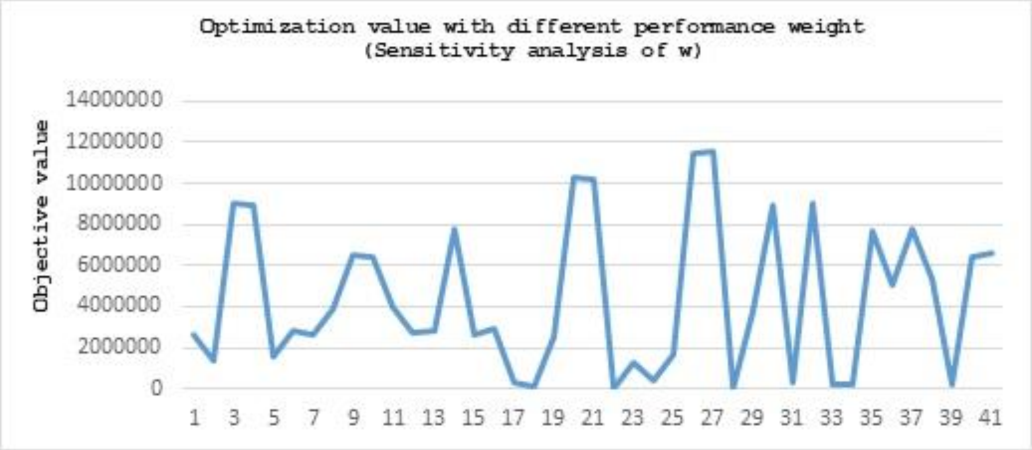

FIGURE 7
SENSITIVITY ANALYSIS

6.2. Comparison of optimization value of three different performances:

For the optimization value of performance, we compare of optimization value of economic, environmental, and social aspects separately. In each step, we allocated the weight of the function to other aspects. The environmental, economic and social had the highest optimal values, respectively during the COVID-19.

min $w_1f_1 + w_2f_2 + w_3f_3$

s. t. Eqs. (7) – (22)

where $w_1 \geq 0$, $w_2 \geq 0$ and $w_3 \geq 0$ are weights such that $w_1 + w_2 + w_3 = 1$, and f_1, f_2, f_3 the OFs.

1)If w_1=1 then:

min w_1f_1

s. t. Eqs. (7) – (22)

2) If w_2=1 then:

min w_2f_2

s. t. Eqs. (7) – (22)

3)If w_3=1 then:

min $w_3 f_3$
s. t. Eqs. (7) – (22)

6.3 Sensitivity analysis of objective value between normal and COVID-19 conditions:

The comparison of optimization value of the normal condition and COVID-19 condition model.
To understand more about this subject, you can refer to Tables 16,17 and 18. The optimization value of the performance of the mathematical model was more realistic during COVID-19.

To study the effects of the parameters of the model, a sensitivity analysis is done. We compare the value of the economic, environmental, and social objectives function under two different scenarios. We analyzed the optimization of the solutions to the changes in the conditions of the problem. The value of the economic, environmental, and social objectives functions under different scenarios such as figure 4.
The findings of the proposed network illustrated, that the SC has become sustainable in the environmental aspects. The optimization value of the environment OF under the COVID-19 scenario is better than the normal scenario. The optimization value of the economics OF under the normal scenario is better than in the COVID-19 scenario. The optimization value of the social OF under the normal scenario is better than in the COVID-19 scenario.
Now, by the designed model, we have analyzed the indicators of sustainability in the economy, environmental, and social aspects. You can see the perspective of the impacts of COVID- 19 on SC.
The indicators of the environmental dimension, have been positive, but the social and economic indicators were negative. We have found the negative and positive impacts of COVID-19 and lockdowns on SSC.

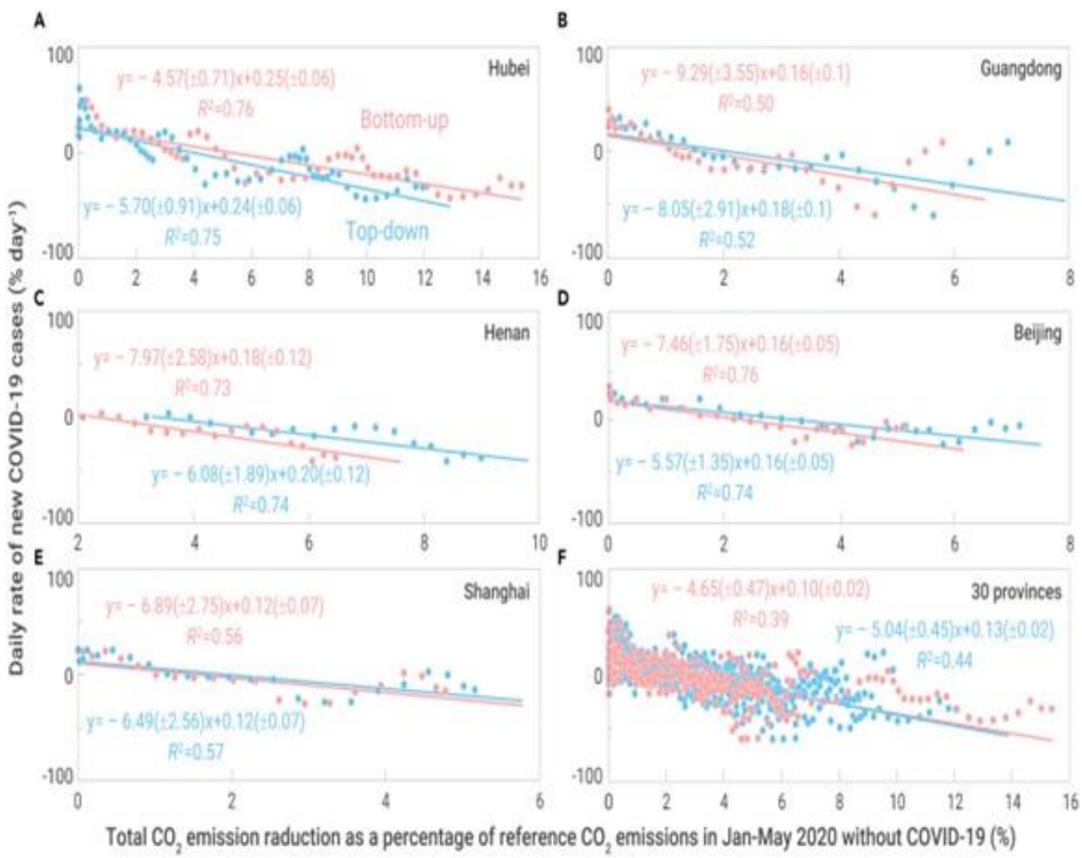

FIGURE 8
Relationship Between Total co2 Emissions And COVID-19 Pandemic [17]

7. Managerial Impactions And Insights

The implications of this investigation can provide useful policies for disaster management, especially in COVID-19 conditions, and help the relevant managers such as:

i. Managers of the SC should have accurate costs estimates and improve the economic performance during COVID-19 by considering the hygienic costs in their SC.
ii. Managers should have accurate social aspects estimates and improve the performance of social SC's processes during the pandemic by considering the damage of COVID-19 (Mental illness - Hospitalization) in their SC.
iii. Managers should have the potential ability for replacing their workers in emergency and disaster conditions of COVID-19.
iv. Managers should have provided financial relief to the employees involved in the SC during the COVID-19.
v. Managers should note to the psychological impact on the employees during the COVID-19.

The proposed model enables managers to make informed choices and determine the trade-off between costs, and emissions, and control bad social effects on the supply chain. Designing this CLSC can reduce waste generated, and optimize the total cost components. Finally, this study contributes to the performance of managing SC during the COVID-19 and lockdown periods.

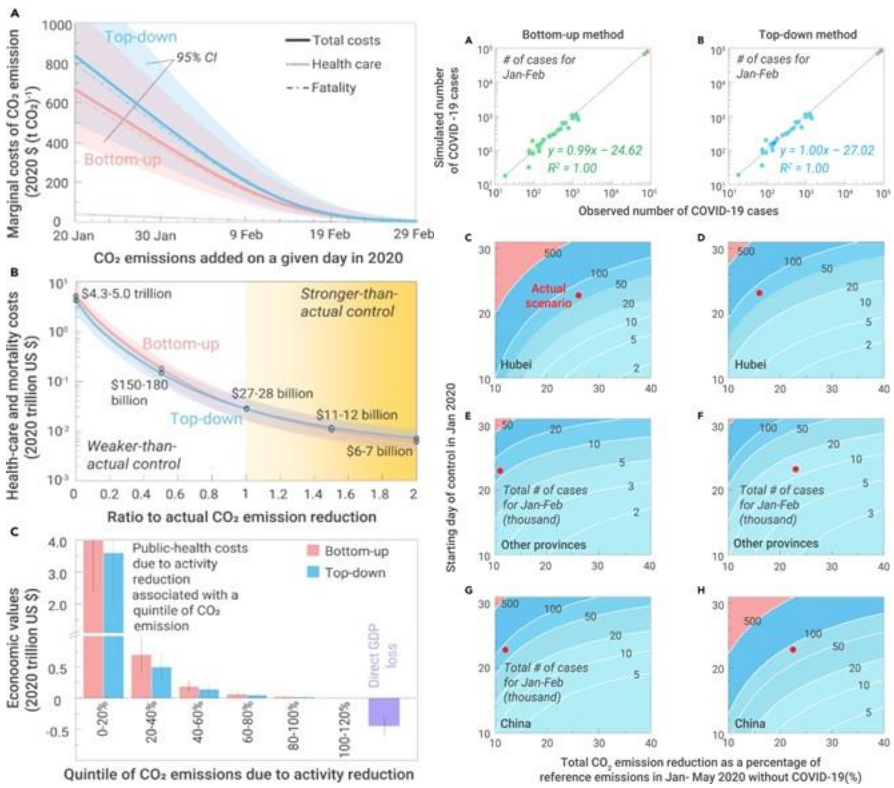

FIGURE 9
Relationship Between Total CO_2 Emissions Due And COVID-19 Pandemic [17]

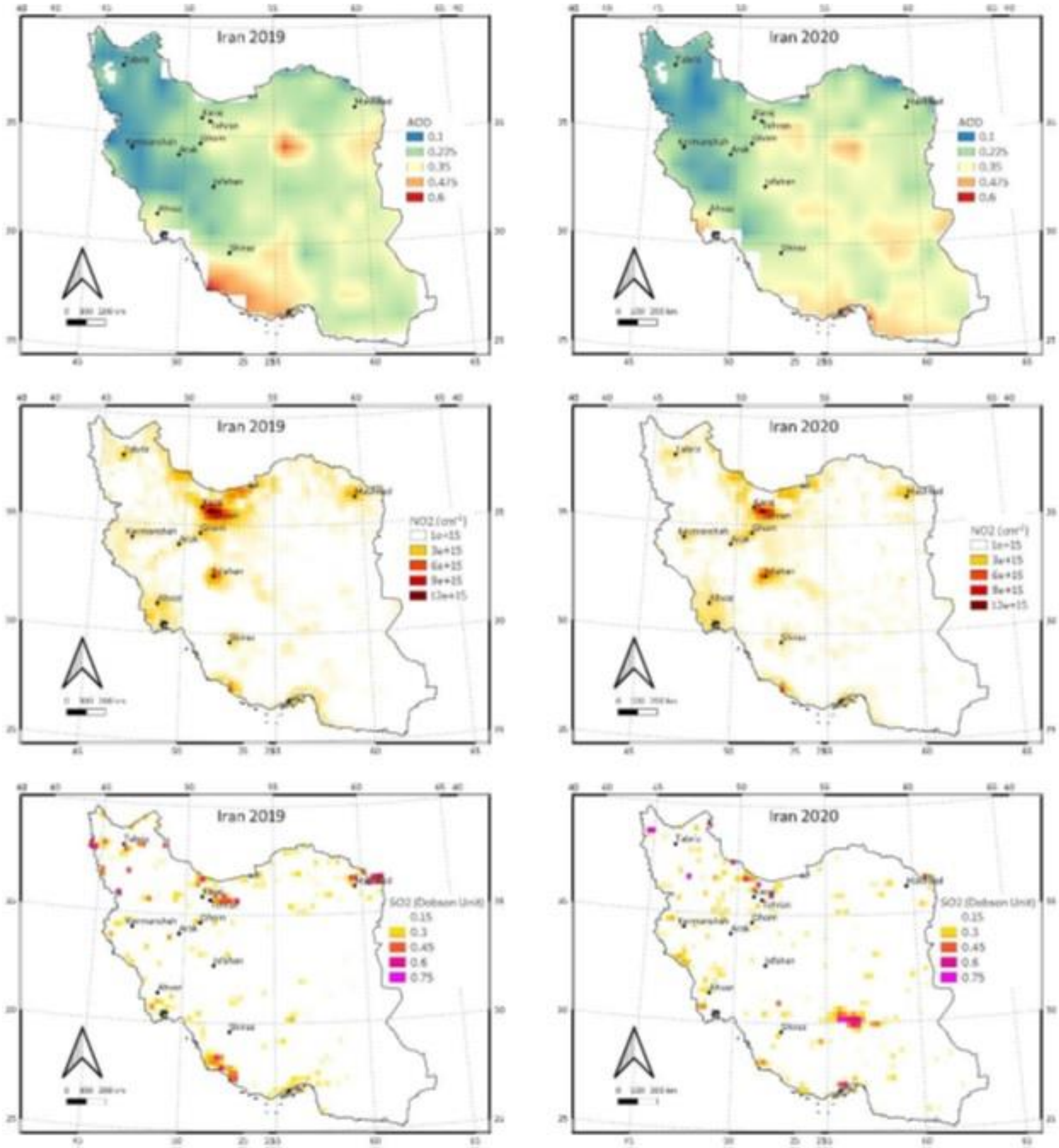

FIGURE 10
THE AVERAGE VALUE OF GHG IN IRAN (21 MARCH -21 APRIL, 2019-2020) [76]

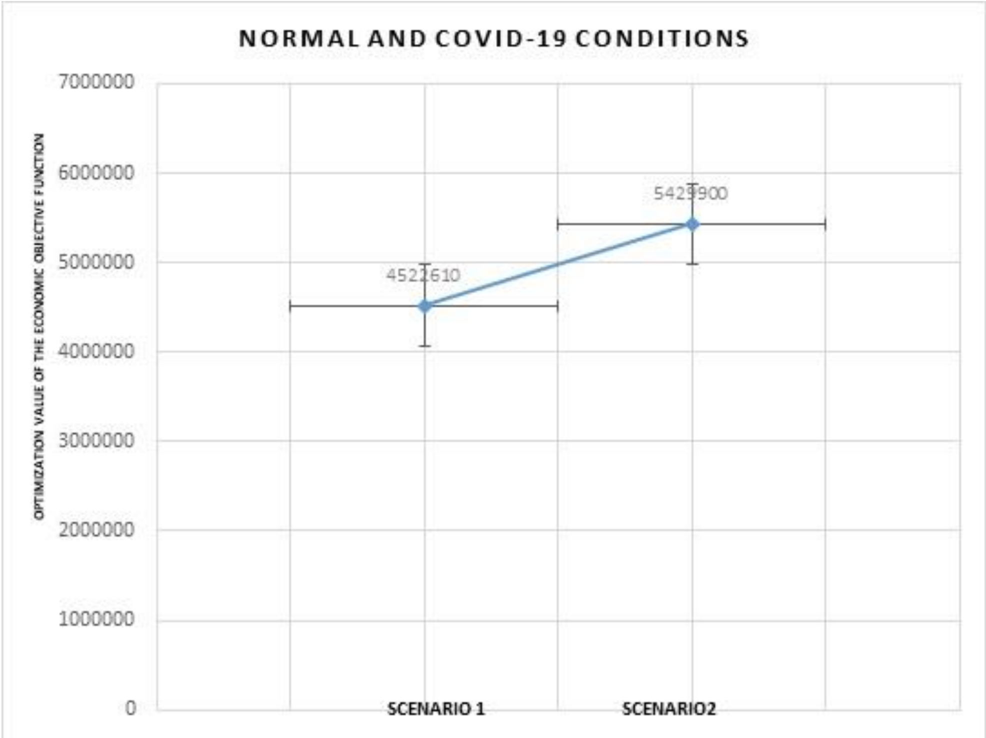

FIGURE 11
SENSITIVITY ANALYSIS OF ECONOMY ASPECTS

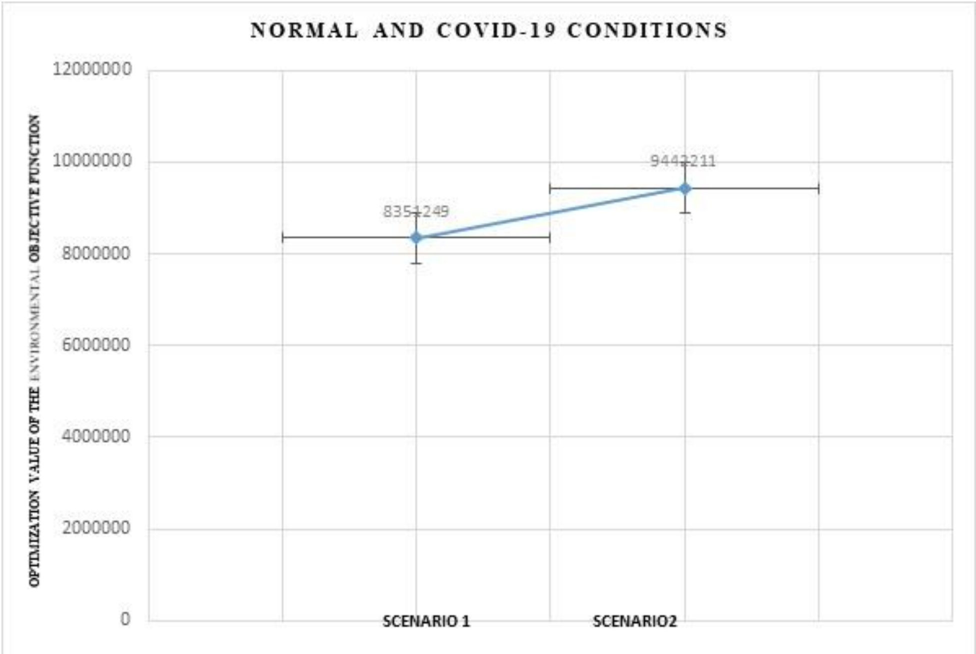

FIGURE 12
SENSITIVITY ANALYSIS OF ENVIRONMENTAL ASPECTS

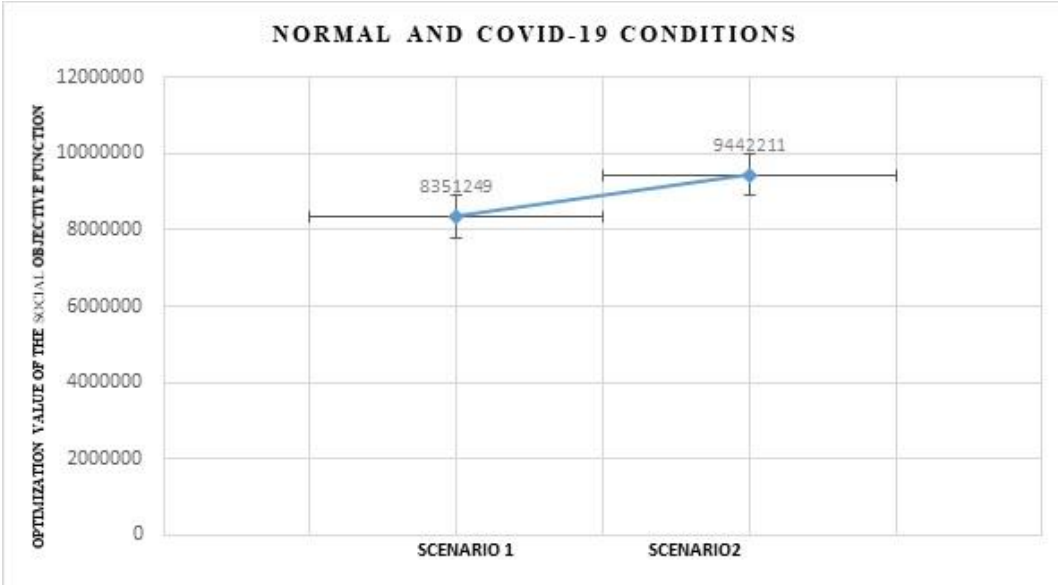

FIGURE 13
SENSITIVITY ANALYSIS OF SOCIAL ASPECTS

8. Conclusion, Results, And Outlook

In this investigation, first, the previous related works were reviewed. Subsequently, inspired by the latest research items, a sustainable closed-loop supply chain (SCLSC) was developed. The model consists of Suppliers, Factories, Collection/ Distribution centers, Recycling/ Landfill / Incineration centers, and Customer. We proposed a MOMIP problem model for SCLSCN during COVID-19 and lockdown periods. Considering the multidimensional aspects of sustainability, minimizing costs, minimizing environmental effects according to the carbon emission index, and minimizing bad social effects according to the criteria of the number of job opportunities created and the number of lost days, are formulated in the suggested mathematical model. The validation and performance of the model were demonstrated by the numerical example and case study. For the scalarization approach, we use WSM method. To optimize the process, Lingo software has been used. In the next step, the validation of the presented model has been illustrated by a case study and numerical example. This model is sensitive to the cost structure, and the cost included two parts, normal cost without considering coronavirus pandemic and the cost with considering coronavirus. The social aspects of this model include a variety of job opportunities in normal and COVID-19 conditions and the average number of lost days caused by normal and COVID-19 damages. Lockdowns during COVID-19 can have direct positive effects on emissions and air quality. The optimization value with different weights performances is calculated, and the sensitivity analysis of W_i (weights) is also measured. This model is solved with LINGO 19.0 software. The total cost of 25.14 % was increased. The average number of lost days caused by damages increased by 51.64%. From 19 February 2020 to 26 June 2021, our data were collected from the case study company and analyzed for CO_2 emissions. In Iranian cities, CO_2 was decreased by17.42 %. This paper presents the model of a SCLSCN during the pandemic and the great lockdowns. Our findings of this paper in summary such as following:

i) Suggested an application model of SSC to show better the trade-offs between three aspects of sustainability in the COVID-19 pandemic and lockdown periods, ii) Designing the hygienic and safe SC for the employees and employers, iii) developing the social and economic indicators during the COVID-19 and lockdown periods. iv) We have found the negative and positive impacts of COVID-19 and lockdowns on SC. It shows COVID-19 has benefic effects on the SC. In the c section, the results show that the individual optimization of each objective does not lead to the ideal level of other objectives, so the result is that economic, environmental, and social goals conflict with each other.

9. Limitations And Future Research Remarks

There are some limitations in our work, that can be addressed in future research:

i. We collected data from just one real company.
ii. The model is for a single product network design.
iii. The model is a single-period network design.

iv.In large dimensions, to get more accurate answers, we must use metaheuristics methods.

There are several recommendations for future work as follows:

a. The investigation can be extended to the multi-greenhouse gas emissions.

b. The impact of environmental aspects could be more explored by considering noise pollution, plastic pollution, and energy consumption.

c. Considering the agility concepts (Speed, Flexibility, Responsibility, Total Quality Management) in SC.

d. Considering model with multi-product and multi-period and solving with other methods, for example, heuristic or new meta-heuristics approaches (Gray Wolf Algorithm, Dragon Fly Algorithm, Grasshopper Algorithm, etc)

e. Improve the model by considering the uncertainties of demand or returned production.

f. Added other indicators for completing the social aspect (The satisfaction of anybody who is involved in the SC (Workers, Managers, Drivers, etc.) during COVID-19.

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TABLE 1
HYGIENIC RULES (ISOLATION, QUARANTINE, DISINFECTION, SOCIAL DISTANCING, LOCKDOWN, ETC) DURING THE LOGISTICS AND ACTIVITIES.

Number	***Descriptions***
1)	Daily assessment of COVID-19 symptoms of employees, administrators, carriers, and distributors, who are the portion of the SC.
2)	In case of symptoms, it should not be allowed in any case to continue the activities by the relevant person.
3)	If the person has symptoms during work or after work, that person should be quarantined in a separate area of the company until suitable actions are taken by the health care services.
4)	In any suspicious case, the responsible person for health and safety, and the manager instantly notify the relevant structures.
5)	Measuring the temperature of the employees, laborers, managers, drivers, or the other person at the entry and exit with a thermometer and keeping, daily, the related book with notes for temperatures higher than 37.5 C° (99.5 °F) or the appearance of other symptoms.
6)	The person in charge of health at the work manages the medical data according to the law for the protection of personal data, especially with the regulations of protecting sensitive personal data, and should maintain confidentiality.
7)	Equip continuously anyone involved in the recovery chain, especially personnel who engage in high-risk activities by assigned appropriate gloves, masks, face shields, goggles, and gowns.
8)	All cleaning servants must be trained and provided the PPE (Personal protective equipment) that is suitable for the task.
9)	Provide constantly any time, soap, hand sanitizers with over 60% alcohol, cleaning paper, disinfectants for surfaces, and closed garbage bins for any person and any place (especially at the entrance and exit)
10)	Disposing of the face masks and disposable tissues with hygiene ways in the closed bins.
11)	Clean and disinfect the items and surfaces you are dealing with in the SC. (factory floor, transportation machines, etc)
12)	Avoid direct touch of money and replace the credit payment with a cash payment during the SC process.
13)	Observe social distancing between the employed employers (keep 2 m apart from others). The SC entities reorganize their working with shifts according to an individual program to respect the above requirement.
14)	Publishing and illustrating, the posters, brochures, and checklists of COVID-19 symptoms, hygiene rules, and related activities based on the verified checklist. (The mentioned items are displayed at the entrance of the entity and also invisible places inside the enterprise.)
15)	Employees are obliged to declare to the administrator and the person responsible for health at the workplace if there has been contacted with persons who result or have tested positive for COVID-19.
16)	If they notice clinical signs while staying at home, they ought to not show up for work and will immediately inform the manager and the person in charge of health at the workplace.
1)	Proper collection, transport, storage, and handling of infectious and non-infectious waste during the SC.
17)	We considering special vehicles for transporting COVID-19 waste, (sealed load area capable of being locked, disinfected, and separate from the driver's cabin) during the SC.
18)	Follow routine disinfection and cleaning protocols for waste bins in collection centers, remanufacturing and refurbishing centers, and recovery/repair centers.
19)	Don't share your personal belongings with others and don't use the tools or workplace of colleagues while working.
20)	If you need coughing or sneezing, use a disposable tissue, and instantly dispose of it in a closed container.
21)	In all cases of indoor space of recovery network chain, provide natural aeration at least 5 times a day. The SC entities must take proper action against intervening in ventilation systems where to switch to natural air mode or through the addition of windows.
22)	When resting at work and during a meal break, avoid gatherings of people in a public or private place. (kitchens, Dining rooms, etc.)
23)	If it is possible set up the shower equipment in each facility of the recovery network chain.
24)	Disinfection your hands after touching a keyboard, mouse, printers, tables, and any other common office equipment, such as staplers, hole punches, pencils, etc.
25)	If your hands are not contaminated with dirt or dust, you can also use a gel or a hand sanitizer when you are not near the bath.
26)	Avoid unnecessary displacements and travel along the recovery chain.
27)	Avoiding physical meetings and holding online meetings.
28)	Reduce working hours as much as possible.
29)	Let employees work from home and reduce the number of employees working from offices. (if it is possible).

References: [4], [32]

TABLE 2
SURVEY ON RELATED WORK

Reference	*Network Structure*	*Objectives function*	*Focused economic issues*	*Focused environmental issues*	*Focused social issues*	*Focused hygienic issues*	*Focused COVID-19*
[9]	OL	SO	Yes	No	No	No	No
[28]	OL	SO	Yes	No	No	No	No
[84]	CL	MO	Yes	Yes	No	No	No
[90]	OL	SO	Yes	No	No	No	No
[87]	OL	MO	Yes	Yes	Yes	No	No
[85]	OL	SO	Yes	Yes	No	No	No
[95]	OL	MO	Yes	Yes	No	No	No
[86]	OL	MO	Yes	Yes	No	No	No
[88]	OL	MO	Yes	Yes	No	No	No
[91]	CL	MO	Yes	No	No	No	No
[89]	OL	SO	Yes	No	No	No	No
[92]	CL	MO	Yes	Yes	Yes	No	No
[94]	OL	SO	Yes	No	No	No	No
[93]	OL	MO	Yes	Yes	No	No	No
[100]	CL	MO	Yes	Yes	Yes	No	No
[96]	OL	MO	Yes	No	No	No	No
[97]	OL	MO	Yes	Yes	No	No	No

Note: **CL**: Closed-loop; **OL**: Open-loop; **SO**: Single objective; **MO**: Multi-objective

TABLE 3
SURVEY ON RELATED WORK

Reference	*Network Structure*	*Objectives function*	*Focused economic issues*	*Focused environmental issues*	*Focused social issues*	*Focused hygienic issues*	*Focused COVID-19*
[99]	OL	SO	Yes	No	No	No	No
[105]	CL	MO	Yes	Yes	Yes	No	No
[98]	OL	MO	Yes	Yes	No	No	No
[101]	CL	MO	Yes	Yes	No	No	No
[102]	CL	MO	Yes	Yes	No	No	No
[54]	OL	MO	Yes	No	No	No	No
[34]	CL	MO	Yes	Yes	No	No	No
[103]	OL	MO	Yes	Yes	No	No	Yes
[106]	OL	MO	Yes	Yes	No	No	No
[104]	CL	MO	Yes	Yes	No	No	No
[108]	CL	MO	Yes	Yes	No	No	No
[107]	CL	MO	Yes	Yes	Yes	No	No
[109]	CL	MO	Yes	Yes	Yes	No	No
This research	**CL**	**MO**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

TABLE 4
DATA OF ECHELONS

Number	Type of echelons	The locations of echelons	Average fixed cost during COVID-19 pandemic (*Rail*)	Average variable costs before COVID-19 (*Rail*) [100,000 units]	Average variable costs + hygienic costs during COVID-19 (*Rail*) [100,000 units]	Specific net CO_2 emissions due to the activities before COVID-19 (kg CO_2 per tonne of material)	Specific net CO_2 emissions due to the activities during COVID-19 (kg CO_2 per tonne of material)	The average number of lost days caused by normal damages before COVI-19 (in a month)	The average number of lost days caused by normal damages + The average number of lost days caused by COVID-19 damages (in a month)	The number of created job opportunities during COVID-19 (in a month)	Capacity
1	Supplier	Ahvaz	-------	12,033,000,022	13,000,000,985	555,2	444,1	4.1	4.9	150	445.000
2	Supplier	Tabriz	-------	14,010,880,077	15,500,274,022	254,1	231,2	2	2.7	310	290.000
3	Supplier	Mashhad	-------	20,000,440,001	22,200,094,056	354,8	341,9	3	3.3	290	670.000
4	Factory	Karaj	180,440,000,000	13,021,022,000	15,000,88,000	588,0	570,0	3.2	4.1	96	855.000
5	Factory	Tehran	400,000,000,000	15,066,470,077	16,000,000,088	470,2	460,1	3.5	4	201	400.000
6	Factory	Rasht	580,000,000,000	19,055,022,090	19,900,210,314	680,1	669,1	4	6.4	400	1200.000
7	RLI	Islamshahr	29,000,000,000	12,099,123,001	13, 900,020,000	877,1	858,9	4.2	48	110	250.000
8	RLI	Robat Karim	17,000,000,000	7,220,000,660	9,500,000,113	690,0	570,1	6	7.1	113	180.000
9	RLI	Kashan	32,000,000,000	11,077,060,089	11, 400,800,009	500,0	460,0	1.9	4.1	295	320.000
10	CD	Gorgan	42,000,000,000	9,0123,099,090	10,444,000,765	290,2	101,8	2.7	3.8	45	611.000
11	CD	Qazvin	83,000,000,000	21,010,213,985	23,000,770,000	210,0	190,2	3.9	5	73	490.000
12	CD	Sanandaj	63,000,000,000	8,022,000,127	10,000,432,011	378,0	260,0	7.3	9	80	280.000
13	CD	Zanjan	75,000,000,000	10,044,000,000	11,985,000,054	311,9	190,0	2.0	2.4	65	255.000
14	CD	Lahijan	82,000,000,000	9,022,011,032	10,050,019,009	270,0	274,0	1.8	1.7	32	247.000
15	CD	Fardis	99,000,000,000	2,000,248,985	3,804,022,006	390,2	380,3	1.5	4.1	40	470.000
16	CD	Borujerd	49,000,000,000	1,578,765,000	5,500,011,018	770,1	750,1	2.4	2.2	20	690.000

TABLE 5
DISTANCE BETWEEN ECHELONS

Km	**Ahvaz**	**Tabriz**	**Mashhad**	**Karaj**	**Tehran**	**Rasht**	**Islamshahr**	**Robat Karim**	**Kashan**	**Gorgan**	**Qazvin**	**Sanandaj**	**Zanjan**	**Lahijan**	**Fardis**	**Borujerd**
Ahvaz	--------	1153	1603	787	781	954	760	744	743	1158	795	644	864	983	772	419
Tabriz	1153	--------	1513	568	612	472	621	623	773	994	469	444	295	516	584	734
Mashhad	1603	1153	--------	949	904	1061	916	931	1054	565	1050	1368	1227	1019	948	1212
Karaj	787	586	949	--------	44	282	52	47	256	425	104	488	281	311	17	397
Tehran	781	612	904	44	--------	327	26	41	245	381	148	485	325	301	44	389
Rasht	954	472	1061	282	327	--------	333	٣٣٦	535	495	175	570	200	43	296	537
Islamshahr	760	621	916	52	26	333	--------	17	230	409	156	464	333	313	42	372
Robat Karim	744	623	931	47	41	336	17	--------	222	423	160	448	310	325	33	355
Kashan	743	773	1054	265	245	535	230	222	--------	423	358	553	710	566	255	352
Gorgan	1158	994	565	425	381	495	409	423	623	--------	533	872	710	454	431	769
Qazvin	795	469	1050	104	148	175	156	160	358	533	--------	409	181	204	118	376
Sanandaj	644	444	1368	488	485	570	464	448	553	872	409	--------	301	596	473	312
Zanjan	864	295	1227	281	325	200	333	310	477	710	181	301	--------	228	259	446
Lahijan	983	516	1019	311	301	43	313	325	566	454	204	596	228	--------	323	565
Fardis	722	584	948	17	44	296	42	33	255	431	118	473	295	323	--------	385
Borujerd	419	734	1212	397	389	537	372	335	352	769	376	312	446	565	385	--------
Customer 1 (Shiraz)	--------	--------	--------	--------	--------	--------	--------	--------	--------	1288	941	1120	1079	1140	920	809
Customer 2 (Tehran)	--------	--------	--------	--------	--------	--------	--------	--------	--------	381	148	489	325	301	44	389
Customer 3 (Ardebil)	--------	--------	--------	--------	--------	--------	--------	--------	--------	753	423	540	271	301	544	786
Customer 4 (Semnan)	--------	--------	--------	--------	--------	--------	--------	--------	--------	339	367	686	554	477	265	530
Customer 5 (Qom)	--------	--------	--------	--------	--------	--------	--------	--------	--------	522	230	444	368	430	154	246

TABLE 6

Unit Transportations costs (Before COVID-19)

Km	**Ahvaz**	**Tabriz**	**Mashhad**	**Karaj**	**Tehran**	**Rasht**	**Islamshahr**	**Robat Karim**	**Kashan**	**Gorgan**	**Qazvin**	**Sanandaj**	**Zanjan**	**Lahijan**	**Fardis**	**Borujerd**
Ahvaz	--------	1,234,510	15,22,000	810,920	811,021	999,141	805,111	700,112	750,420	1,131,533	690.111	715,310	814,140	1,000,000	815,061	500,001
Tabriz	1,034,170	--------	1,634,888	334,510	734,881	434,900	554,110	634,141	730,310	1,234,911	455,000	400,100	334,911	531,931	588,900	700,900
Mashhad	16,21,099	15,24,004	--------	9,22,011	9,00,991	10,24,011	11,23,876	10,14,999	10,24,333	7,22,999	10,11,322	12,24,300	11,24,222	11,02,513	10,11,322	13,11,344
Karaj	634,686	530,850	934,000	--------	434,001	230,812	130,822	122,800	234,804	434,001	73,881	534,800	234,899	334,855	34,881	534,800
Tehran	834,800	634,800	934,001	434,800	--------	334,700	234,022	34,021	214,022	333,022	134,020	411,922	334,077	334,010	50,021	334,099
Rasht	934,044	444,022	1,234,555	218,022	334,999	--------	334,882	334,011	534,444	554,021	134,088	534,099	200,022	30,092	300,091	550,091
Islamshahr	770,091	660,090	900,011	50,091	20,000	400,091	--------	40,888	220,090	440,090	190,091	440,022	330,011	688,090	77,000	330,050
Robat Karim	630,050	770,000	990,020	99,033	550,011	330,000	150,008	--------	220,000	440,000	170,022	440,000	330,000	440,000	70,000	440,000
Kashan	770,099	780,011	1,999,555	280,055	220,099	550,011	230,010	220,011	--------	660,011	330,011	550,011	440,011	550,011	200,055	300,000
Gorgan	1,229,500	999,444	559,004	400,000	660,022	550,011	404,011	488,011	660,000	--------	550,801	880,440	720,099	401,001	430,099	770,088
Qazvin	880,000	405,022	1,459,510	205,011	310,028	205,000	155,020	205,021	335,020	555,021	--------	445,021	105,020	205,821	105,021	405,020
Sanandaj	605,020	405,020	1,589,510	1,050,510	405,066	500,011	500,099	600,022	466,000	900,004	528,000	--------	300,022	496,000	550,000	300,066
Zanjan	800,012	210,000	1,339,510	589,333	489,599	489,511	389,991	430,511	480,500	779,511	179,511	389,500	--------	122,511	400,511	489,333
Lahijan	889,511	589,571	1,239,522	339,577	439,510	59,510	439,510	339,914	560,000	540,000	220,000	550,000	220,001	--------	330,000	655,000
Fardis	779,192	559,000	909,522	9,510	77,500	229,510	89,510	89,500	200,711	480,512	101,811	400,510	289,599	339,510	--------	589,510
Borujerd	440,000	770,000	1,438,500	239,500	439,900	555,800	439,811	539,300	339,955	779,512	339,519	400,911	500,555	666,210	300,510	--------
Customer1 (Shiraz)	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,000,500	929,500	1,555,522	1,333,544	1,889,511	829,400	729,501
Customer2 (Tehran)	--------	--------	--------	--------	--------	--------	--------	--------	--------	330,022	140,000	440,004	330,000	220,001	66,022	330,001
Customer3 (Ardebil)	--------	--------	--------	--------	--------	--------	--------	--------	--------	760,022	550,044	600,033	270,001	330,000	550,022	677,000
Customer4 (Semnan)	--------	--------	--------	--------	--------	--------	--------	--------	--------	440,000	550,000	670,099	550,000	440,000	210,000	650,077
Customer5 (Qom)	--------	--------	--------	--------	--------	--------	--------	--------	--------	450,033	300,033	330,033	400,037	550,031	150,032	220,031

TABLE 7

UNIT TRANSPORTATIONS COSTS (DURING COVID-19)

Rail	**Ahvaz**	**Tabriz**	**Mashhad**	**Karaj**	**Tehran**	**Rasht**	**Islamshahr**	**Robat Karim**	**Kashan**	**Gorgan**	**Qazvin**	**Sanandaj**	**Zanjan**	**Lahijan**	**Fardis**	**Borujerd**
Ahvaz	--------	1,334,999	16,22,033	910,620	821,011	909,141	905,122	750,122	850,429	1,231,443	755.111	815,310	914,140	1,200,033	915,069	600,001
Tabriz	1,224,150	--------	1,734,877	374,510	834,877	454,600	664,110	639,141	830,110	1,534,990	677,000	500,140	334,911	551,930	620,900	800,901
Mashhad	18,21,444	17,24,224	--------	8,22,021	9,40,990	11,23,011	13,23,000	12,14,449	11,24,399	8,22,990	12,11,322	14,24,400	11,99,222	12,02,555	11,11,000	13,11,322
Karaj	722,612	630,110	844,011	--------	422,001	250,819	145,888	112,809	277,811	477,001	84,881	554,890	289,899	454,855	37,881	599,800
Tehran	900,100	644,877	899,000	454,877	--------	399,800	257,000	39,011	299,022	344,021	164,020	499,900	388,077	454,018	55,021	338,099
Rasht	894,099	554,111	1,334,500	319,022	321,990	--------	399,899	344,011	588,440	594,021	144,081	599,099	200,022	50,090	320,090	566,999
Islamshahr	800,011	599,080	910,099	48,000	22,033	409,099	--------	45,888	277,011	520,090	200,091	478,022	330,045	678,088	78,000	344,059
Robat Karim	770,012	790,044	998,770	100,020	544,011	344,000	190,011	--------	222,099	480,022	185,020	445,099	389,000	450,001	79,001	490,000
Kashan	790,044	880,022	1,900,313	380,011	247,090	588,010	266,099	280,021	--------	670,099	410,022	550,099	540,011	550,011	250,051	300,088
Gorgan	1,339,555	1,237,500	544,011	400,000	680,099	599,010	466,011	499,010	677,000	--------	580,833	899,440	720,099	401,099	444,099	780,088
Qazvin	900,000	505,011	1,700,522	205,011	355,000	233,011	230,044	288,021	340,020	599,021	--------	435,091	225,020	299,821	110,020	495,020
Sanandaj	700,011	485,011	1,449,533	1,440,599	415,099	544,012	590,088	690,022	490,022	908,022	570,001	--------	450,022	496,990	588,002	300,099
Zanjan	887,010	310,055	1,439,577	609,323	499,600	499,500	390,991	455,510	490,500	801,511	192,511	329,520	--------	199,511	422,511	509,333
Lahijan	800,411	620,111	1,439,444	329,587	449,590	60,810	459,010	344,914	590,011	560,000	250,000	510,000	350,081	--------	344,002	680,099
Fardis	799,188	659,044	889,500	9,990	78,522	240,510	99,120	93,100	220,711	520,512	121,811	444,511	288,599	339,599	--------	619,510
Borujerd	455,000	790,022	1,931,560	299,100	499,000	570,200	455,111	540,220	344,955	811,512	369,519	401,911	600,555	699,210	370,990	--------
Customer1 (Shiraz)	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,200,000	989,500	1,445,520	1,233,599	1,889,997	889,455	700,501
Customer2 (Tehran)	--------	--------	--------	--------	--------	--------	--------	--------	--------	350,021	139,000	340,000	350,088	250,022	77,021	311,001
Customer3 (Ardebil)	--------	--------	--------	--------	--------	--------	--------	--------	--------	770,042	580,044	620,033	280,044	320,005	590,022	611,000
Customer4 (Semnan)	--------	--------	--------	--------	--------	--------	--------	--------	--------	450,000	555,000	670,091	590,044	470,000	220,011	650,099
Customer5 (Qom)	--------	--------	--------	--------	--------	--------	--------	--------	--------	490,031	317,000	370,030	488,037	590,031	160,031	220,333

TABLE 8
MINIMUM PERCENTAGE OF UNITS OF THE RETURNED PRODUCT AND WEIGHTING FACTOR

$\mathbf{N}_{\mathbf{dismantled}} = 0.3$	$\mathbf{N}_{\mathbf{disposed-recycled}} = 0.2$	$W_{n_{ld}} = W_{COVI-19_{ld}} = W_{jo} = W_{COVID-19_{jo}} = 0.25$

TABLE 9
DEMAND OF CUSTOMERS

Average demand of customers (millions) (19 February 2020- 16 June 2021)
2.8

TABLE 10
RATE OF CO_2 EMISSIONS FOR EACH TRANSPORTATION OPTION (EMISSION FACTOR)

Transportations types	**Estimate the range of emission factor (gCO_2 / tonne-km)**
Normal Road	(55-65)
Rail	(20-22)
Barge	(30-32)
Short sea	(15-17)
Intermodal road	(20-35)
Sea transports	(5-8)
Air transports	(590-605)

***Notation*:** CO_2 emissions = Average distance × Rate of CO_2 emissions (Emission factor)
[Tonnes = km ×g CO_2 per tonne-km / 1.000.000]

TABLE 11
WEIGHED SUM METHOD OUTPUT (OBJECTIVE VALUE)

Objective	**Weights (wi)** $\Sigma wi = 1$	**Weights (wi)** $\Sigma wi = 1$	**Weights (wi)** $\Sigma wi = 1$
Economic performance	0.5396	0.2970	0.1634
Environmental performance	0.2970	0.1634	0.5396
Social performance	0.1634	0.5396	0.2970
Objective Value	$Z^*_{1=}$ 0.5839783E+14	$Z^*_{2=}$0.3214262E+14	$Z^*_{3=}$0.1768723E+14

TABLE 12
DATA SOURCES FOR NUMERICAL EXAMPLE

Data	**Sources**
(Demand of customers, Fixed costs, Variable costs, Capacity data, and Transportations costs)	[110], [111]
(Distance)	[112]
(CO_2 information)	[113], [114]
(The number of created normal job opportunities, The averages number of normal lost days)	[115], [114]
(Hygienic costs, The number of created COVID-19 job opportunities, The average number of COVID-19 of lost days)	This study

TABLE 13
THE RESULTS OF SOLVING THE SSC MODEL WITH LINGO AND DIFFERENT OBJECTIVE WEIGHTS
(W_i is generated randomly or determined by the DM)

Objective	**Weights (wi)** $\Sigma wi = 1$	**Weights (wi)** $\Sigma wi = 1$	**Weights (wi)** $\Sigma wi = 1$
Economic performance	0.5396	0.2970	0.1634
Environmental performance	0.2970	0.1634	0.5396
Social performance	0.1634	0.5396	0.2970
Objective value	$Z^*_{1=}$ 4006821	$Z^*_{2=}$2205365	$Z^*_{3=}$6939799

TABLE 14
Performances Weights

No.	Economical Performance Weight	Environmental Performance Weight	Social Performance Weight	Optimization Value
1	0.1	0.2	0.7	2589772
2	0.2	0.1	0.7	1357989
3	0.2	0.7	0.1	8997161
4	0.1	0.7	0.2	8955749
5	0.7	0.1	0.2	1565052
6	0.7	0.2	0.1	2838247
7	0.3	0.2	0.5	2672597
8	0.2	0.3	0.5	3904380
9	0.3	0.5	0.2	6492183
10	0.2	0.5	0.3	6450771
11	0.5	0.3	0.2	4028617
12	0.5	0.2	0.3	2755422
13	0.6	0.2	0.2	2796835
14	0.2	0.6	0.2	7723966
15	0.2	0.2	0.6	2631184
16	0.8	0.2	0	2879660
17	0.8	0	0.2	333268.8
18	0.2	0	0.8	84793.20
19	0	0.2	0.8	2548359
20	0.2	0.8	0	0.1027036E+08
21	0	0.8	0.2	0.1018753E+08
22	0.1	0	0.9	43380.60
23	0	0.1	0.9	1275163
24	0.9	0	0.1	374681.4
25	0.9	0.1	0	1647877
26	0	0.9	0.1	0.1146073E+08
27	0.1	0.9	0	0.1150214E+08
28	0.3	0	0.7	126205.8
29	0	0.3	0.7	3821554
30	0	0.7	0.3	8914336
31	0.7	0	0.3	291856.2
32	0.3	0.7	0	9038574
33	0.4	0	0.6	167618.4
34	0.6	0	0.4	250443.6
35	0	0.6	0.4	7641141
36	0	0.4	0.6	5094750
37	0.4	0.6	0	7806791
38	0.6	0.4	0	5343225
39	0.5	0	0.5	209031.0

40	0	0.5	0.5	6367945
41	0.5	0.5	0	6575008

TABLE 15

Aspects	Weights (wi) $\Sigma wi = 1$	Weights (wi) $\Sigma wi = 1$	Weights (wi) $\Sigma wi = 1$
Economic	1	0	0
Environment	0	1	0
Social	0	0	1
Optimization value	Z^*_{1}= 416094.0	Z^*_{2}=0.1273392E+08	Z^*_{3}=1968.000

TABLE 16
THE OPTIMIZATION VALUE OF THE ECONOMY OBJECTIVE FUNCTION UNDER DIFFERENT SCENARIOS

Number of instances	(Normal Condition) Considering model with hygienic costs	Number of instances	(COVID-19 Condition) Considering model without hygienic costs
Scenario 1	• Normal fixed costs. • Normal variable costs. • Transportation costs. • $Z^*_{\text{Normal Economy}}$ = **4522610**	**Scenario 2**	• Fixed costs in the disaster. • Variable costs in the disaster. • Transportation costs in the disaster. • Hygienic costs. • $Z^*_{\text{COVID-19 Economy}}$ =**5429900**

TABLE 17
THE OPTIMIZATION VALUE OF THE ENVIRONMENTAL OBJECTIVE FUNCTION UNDER DIFFERENT SCENARIOS

Number of instances	(Normal Condition) Total environmental impact without concerning COVID-19	Number of instances	(COVID-19 Condition) Total environmental impact concerning COVID-19
Scenario 1	• Normal CO_2 emissions of industrial activities • Normal CO_2 emissions of shipping activities • $Z^*_{\text{Normal environmental}}$ =**2901200**	**Scenario2**	• CO_2 emissions of industrial activities during the COVID-19 and lockdown periods. • CO_2 emissions of shipping activities during the COVID-19 and lockdown periods. • $Z^*_{\text{COVID-19 environmental}}$ =**2091273**

TABLE 18
RESULTS OF THE EXPERIMENTAL ANALYSIS OF SUSTAINABILITY INDICATORS IN OUR INVESTIGATION

Number of instances	**Normal condition model Total social impact without concerning COVID-19**	**Number of instances**	**COVID-19 condition model Total social impact concerning COVID-19**
Scenario 1	• The average number of lost days caused by normal damages (e.g. accidents, other hospitalizations…) • The number of created normal job opportunities. • $Z^*_{\text{Normal economic}}$ =8351249	**Scenario 2**	• The average number of lost days caused by normal damages (e.g. accidents, other hospitalizations…) • The number of created normal job opportunities. • The average number of lost days caused by COVID-19 damages (e.g. mental illness during the coronavirus, coronavirus hospitalization, etc). • The number of created new job opportunities related to COVID-19. • $Z^*_{\text{COVID-19 economic}}$ =9442211

TABLE 19
RESULTS OF THE EXPERIMENTAL ANALYSIS OF SUSTAINABILITY INDICATORS IN OUR INVESTIGATION

Number of indicators	***Descriptions***	***Analysis during the COVID-19***	***Effect on SC***
1.	Disinfection and sanitization costs during the SC.	Increasing in COVID-19 condition	Negative
		Increasing in COVID-19 condition	Negative
2.	Preparing the PPE (Shield-Mask-Gown-Gloves etc) costs for SC employees.	Increasing in COVID-19 condition	Negative
3.	The costs of COVID-19 tests for SC employees. (Normal - Fast)	Increasing in COVID-19 condition	Negative
4.	The costs of educating for healthcare for SC employees.	Increasing in COVID-19 condition	Negative
5.	Vaccine and vaccination costs of employees.	Increasing in COVID-19 condition	Negative
6.	Separating the infectious and non-infectious waste costs.	Reducing in COVID-19 condition	Positive
7.	CO_2 emissions and industrial activities.	Reducing in COVID-19 condition	Positive
8.	CO_2 emissions and shipping activities.	Increasing in COVID-19 condition	Positive
9.	A variety of job opportunities is provided (In connection with COVID).	Increasing in COVID-19 condition	Negative
10.	The average number of lost days caused.	Increasing in COVID-19 condition	Negative
11.	The number of employees' health damaged.		

References: [1-16-64-65-66-67-68-69-70-71-72-73]