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Green Closed-Loop Supply Chain Networks' Response to Various Carbon Policies during COVID-19

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Abstract: As concerns about the environment continue to increase and restrictions become tougher, professionals in business and legislators are being compelled to investigate the environmental effects of the activities associated with their supply chains. The control of carbon emissions by governments all over the world has involved the adoption of a variety of strategies to lower such emissions. This research optimizes COVID-19 pandemic logistics management as well as a green closed-loop supply chain design (GCLSCD) by basing it on carbon regulatory rules. This research looks at three of the most common types of normal CO_2 restrictions. In the models that have been proposed, both costs and emissions are optimized. When it comes to supply chain (SC) activities, there is a delicate balance to strike between location selection, the many shipment alternatives, and the fees and releases. The models illustrate these tensions between competing priorities. Based on the numerical experiment, we illustrate the impact that a variety of policies have on costs in addition to the efficiency with which they reduce emissions. By analyzing the results of the models, managers can make predictions concerning how regulatory changes may affect overall emissions from SC operations.

Keywords: CO_2 policies; green supply chain; closed-loop; COVID-19 pandemic; Mixed integer linear programming

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1. Introduction

Forward and reverse flows are combined to create a closed-loop supply chain (CLSC) [1]. Considering their customers, their social duties, the environment, state and federal legislation, and waste management are the main reasons manufacturers pursue CLSC [2]. Formerly, CLSCs were an unwanted limitation, but they are now a desirable requirement and will be the only form of redress going forward. A green supply chain is an economic and environmental perspective-based supply chain (GSC). A green closed-loop supply chain (GCLSC) combines the forwarding and reverse supply chains [3]. The GSC aids in the reduction of environmental consequences and the production of eco-friendly goods. In addition to the economic benefits of product recovery, the law has elevated GCLSC's significance. CO_2, ozone, methane, and other greenhouse gases are emitted as a result of supply chain operations [4].

As greenhouse gas (GHG) emissions continue to increase, governments throughout the world are under increasing pressure to enact legislation restricting emissions and implement environmental measures, such as the Kyoto Protocol [5] and the European Union Emission Trading System [6]. As part of the 1997 United Nations Framework Convention on Climate Change, countries from all over the world negotiated the Kyoto Protocol. As of May 2008 [7], approximately 181 nationalities had confirmed, adhered to, or endorsed the protocol. COVID-19 can be transferred from one individual to another in a matter of minutes. A pandemic can create chaos in Supply Chains (SCs) [8]. To deal with environmental destruction and resource scarcity, closed-loop supply chains (CLSCs) are an alternative logistics method. Material control, emissions reduction, and cost-effective production are all characteristics of CLSC. By storing material in a CLSC, the SC activities can have a lower environmental impact. With growing concern over the environment, a Green Closed-Loop Supply Chain Network (GCLSCN) has been identified as a critical issue [9].

In addition to its continuing outbreak, COVID-19 impacts emissions fundamentally. With the development of environmental protection legislation, client awareness, and carbon policies, Supply Chain Design (SCD) has become a primary objective for reducing CO_2 emissions. According to China, CO_2 emissions were reduced during the COVID-19 outbreak [10].

According to Figure 1, countries have committed to achieving net zero emissions and have classified their climate change policies accordingly.

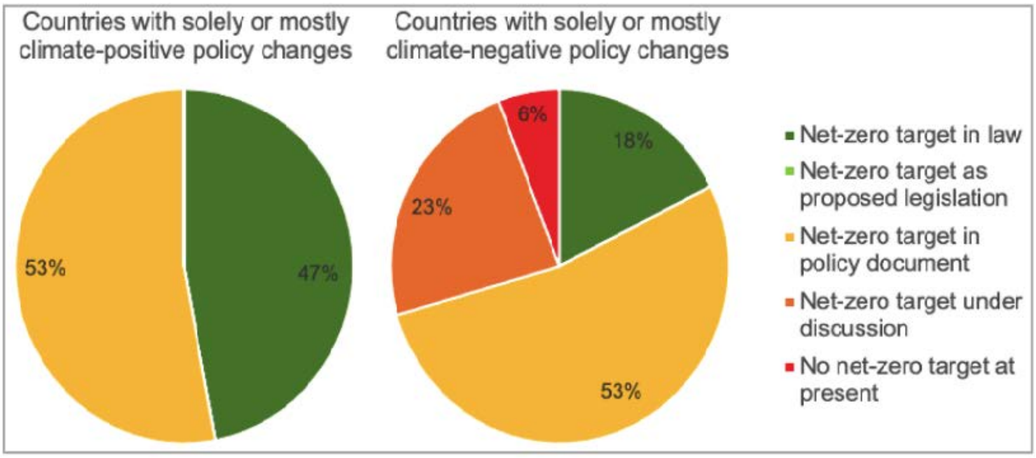

Figure 1. Country commitments to net-zero emissions and their climate change policy categories [11,12].

1.1. Brief Description of the Problem

The GSC considers sustainability from both an economic and an environmental perspective. In addition to saving costs and improving economic efficiency, recycling is an environmentally friendly procedure. During the COVID-19 epidemic, the Distribution Center (DC) was merged with the Collection Center (CC) to reduce building costs, reduce greenhouse gas emissions, reduce environmental pollution, and prevent physical contact with customers. This mathematical model has been designed to increase SC efficiency during the pandemic through economic and environmental performance indicators.

A GSC is also created by considering all the monetary expenditures in a specific SC design and the environmental and social efficiency indexes used in mathematical modeling. A study of this kind provides valuable information to decision makers (DMs), which can be used to create more sustainable decisions during the pandemic, including helping to inform judgments and providing helpful information to DMs.

In this paper, we present several models for a GCLSC design problem: (i) designing a logistics network during the COVID-19 outbreak should take into account both economic and environmental factors; (ii) making decisions related to the location of production, production technology, and transportation modes during an outbreak; and (iii) as part of this project, SC operations will be evaluated in light of three commonly used carbon policy guidelines: carbon caps, carbon taxes, and carbon cap-and-trade.

1.2. Research Gap and Contributions

In light of the novelty of the COVID-19 pandemic, many research gaps still exist. In conclusion, the proposed paper addresses some literature gaps and categorizes innovations as follows:

- Designed the SC by all hygiene guidelines.
- Designed a GSC that considers COVID-19 from two pillars.

- Measured the effect of the three carbon rules on GCLSCN in the outbreak.
- Provided a Multi-Objective Mixed-Integer Programming (MOMIP) model for analyzing COVID-19 pandemic issues within the CLSC.
- Analyzed the mathematical model's managerial implications.

This investigation tries to fill these gaps. The rest of the paper is organized as follows. Section 2 presents the literature review and the position of the present investigation compared with the previous research. Section 3 defines the problem statement, assumptions, and formulation. Section 4 shows the computational results and the case study Section 5 illustrates the sensitivity analysis of the problem. Section 6 states the managerial implications and practical insights Finally, Section 7 explains the conclusion and remarkable outcomes, limitations, and future works.

2. Literature Review

This literature review is divided into three parts. The research on the carbon tax is presented in the first section, the research on carbon caps in the second section, and cap-and-trade research in the last section.

2.1. Carbon Tax

In the research of Paksoy et al., altering the severity of emissions may result in a 100–400 percent increase in emissions [13]. According to Fahimnia et al. [14], for a significant shift to occur, a high tax rate must be accompanied by fluctuating fuel costs. According to the analysis by Zakeri et al., it no longer reduces emissions compared with the 5-speed pricing [15]. If the tax rate surpasses 50 AUD/ton, it is necessary to set the correct tax rate despite the likelihood of an increase. Only by converting the SC from a high-emitting to a low-emitting technology can a carbon tax be implemented. To choose pipelines, you must pay $5.50 per kg [16] By comparing the total cost to the carbon tax rate, Peng et al. [17] observe a relationship between the two variables.

Carbon taxes impact pricing decisions and social welfare in a SC with multiple competing retailers [18]. A study on human-driven edge computing for intelligent decision-making about low-carbon SCs based on carbon tax constraints [19]. Developing a competitive SC for low-carbon products following the implementation of carbon taxes [20]. Assessment of the effects of the carbon tax on manufacturing in a CLSC [21]. Carbon tax regulation for climate change mitigation under energy performance contracting with financially asymmetric manufacturers [22]. An analysis of a manufacturer's decisions under repurchase strategies of carbon emission permit capital constraints [23]. As a general rule, a carbon tax will lead to higher costs associated with burning fossil fuels, which will affect the cost of producing goods and services reliant on them. The impact of a carbon tax policy on SCM [24]. In the context of a carbon tax regulatory scheme, optimizing inventory choices for CLSC is important [25].

2.2. Carbon CAP

Carbon cap policies typically presume that carbon emissions are restricted and that this limitation must be maintained. In numerous GSCND studies, typical carbon cap strategies have been considered. Numerous authors have attempted to reduce CO_2 emissions from shipping by limiting manufacturing [26,27], warehousing [26,28], and transportation [26,28–32].

Among the numerous CO_2 emissions mentioned by Mart et al. [33] are those resulting from raw materials, production, storage, and transportation. Moreover, refs. [34–38] considered a serial or universal carbon cap for the GSCND. Zhang et al. [36] suggest that a worldwide carbon cap would be more advantageous. It is also feasible to employ varying emission limitations based on the policy in place. Several studies, including Tao et al. [38], have been conducted regarding this idea. In situations with a high emission limit, a global cap is preferable. Consequently, periodic caps have become prevalent. Benjaafar et al. [35] use different models for single and multiple enterprises in their research.

The impact of carbon limits on the environmental performance of SSCs [39]. Carbon-capped SCs are connected with issues [40]. A two-tier SC with two retailers and one supplier must make pricing decisions based on the carbon cap rule [41]. The various power structures in a SC with government carbon cap restrictions and attempts to decrease carbon emissions from manufacturers [42].

There is a comparison between various allocation rules for online and offline retail SCs and cap-and-trade regulations [43], including a carbon tax and the reduction in carbon emissions from a cement production facility in operation [44], which considered carbon cap-and-trade regulations, carbon market modeling, and chilled logistics services [45]. When choosing which channel will be used for the collection of carbon cap-and-trade rules, a reverse SC is recommended [46].

Combining vendor-managed inventory partnerships and carbon cap-and-trade policies to implement a low-carbon SC model [47]. Cap-and-trade methods reduce CO_2 emissions while considering price policies and reciprocal preferences [48]. Through cap-and-trade regulations, carbon emissions are reduced, and goods are collected in CLSCs [49]. Green technology was re-examined in a two-tiered SC with stringent carbon-cap rules [50]. Dual-channel stochastic SC combines the preferences of clients for low-carbon consumption and cap-and-trade regulations [51]. A dual-channel SC utilizes cap-and-trade legislation to decrease carbon emissions [52]. CLSC emissions should be traded through a cap-and-trade mechanism [53]. The SC regulates waste and CO_2 emissions through an eco-friendly cap-and-trade system [54].

Impact analysis of cap-and-trade regulations on SCs Regulatory authorities set a carbon cap for businesses. Maintaining a high penalty and paying for overages is an effective way to accomplish carbon emission goals. As a means of preventing growth in the economy from being impeded, implementing a carbon tax should be the main barrier. Despite appearing in scholarly journals, the strategy is rarely followed in practice [55].

According to refs. Marufuzzaman et al. and Choudhary et al. [16,30] offered that the policy is compared with others frequently. A carbon cap cannot be simply chosen due to the uncertainty of the future, although it is most likely based on existing or past emissions. The US Clean Air Act of 1970 established state and federal carbon limitations [56]. Every other study discusses at least one more source of emissions. According to Palak et al. [57], inventory levels, weights, and traveled distances are included when calculating purchasing and transportation costs. Rarely is the carbon cap determined using actual data.

The US Environmental Protection Agency (2013) [58], was acknowledged by Peng et al. as the source of pollutant indicators [17]. Xu et al. [59] studied a cap-and-trade rule for hybrid and specialized CLSCs. SCs containing two distinct polymeric products have a limit between 15,000 and 19,500. The utilization of sewage sludge biomass SCs was considered [60].

According to Rezaee et al., the stochastic model of an Australian furniture industry that has extended to five states is also employed [61]. In a policy-free SCN, a presumptive automotive products corporation's emissions will be capped at 95, 90, 80, 70, 60, and 50% [30]. In a global cap, the global cap is divided equitably among the facilities. Mart et al. [33] utilized clothing industry data. They explored a carbon footprint cap for the whole SC as well as a cap on the number of units sold. Each fabric manufacturer is granted a different emission cap for each period, ranging from 2200 to 2350 and 2090 to 2430 t CO_2 [62].

Choudhary et al. [30] designates 600 t CO_2 and 700 t CO_2 as distinct limitations for the forward and reverse sections of the SC, respectively. Warehousing emissions were calculated using emissions intensity, demand function mean value, reorder point, order quantity, and total lead time [20]. According to Kannegiesser and Günther [63], emission limits should be based on a percentage of the level of emissions at the outset. It is not unusual for firms to place internal limits on SCs. The complexity of a single SC necessitates the use of a limit. Centralized enforcement is still possible, for instance by a parent corporation or government body. Transport, assembly, and supplier emissions for an international computer company's facility were capped to reduce carbon-based transit, assembly, and supplier emissions [27].

Carbon footprints are used to quantify emissions per unit. In their analysis, Baud-Lavigne et al. also included the emissions associated with component selection, production, and transportation [64]. In reverse SCs, recycling, disposal, and collection are also covered. In addition, the corporation might implement a carbon cap to address the situation. Several studies, including Choudhary et al. and Mohammed et al. [30,65], have demonstrated that product recovery, collection, and disposal facilities reduce greenhouse gas emissions. According to Fareeduddin et al., recycling activities contribute to greenhouse gas emissions.

As anticipated, stricter carbon limitations have negative consequences for the SC [31]. According to Choudhary et al. [30], a stringent carbon cap results in lower emissions and higher prices than carbon taxes or cap-and-trade. Several other scholars have made comparable observations.

The cost curve gets concave and falls as the cap is lifted [29,41,61,63,65]. By [16,41], report a step-function relationship between cost and emissions. The conversion to low-emissions technology and greener transport techniques resulted in a low-cost increase due to the SC's redesigned efficiency. A stringent cap can alter the structure of a SC, regardless of whether it is forward or reverse.

This observation was validated by Xu et al. While carbon cap programs significantly cut emissions, their effects may not benefit all participants equally. It is crucial to impose a carbon cap at the highest level in a fair and equitable manner for all parties. In a global economy, a SC with diverse geographical criteria could drive countries to cut emissions [34,66]. To support light-emission technologies, Zhou et al. recommend reducing China's cap to 76.2% of its basic level and Taiwan's cap to 68.5% [27,57].

2.3. Cap-and-Trade

Important in a cap-and-trade system is mode selection [67]. Other carbon policies do not take income or offsets into consideration as explicitly as cap-and-trade rules. Shipping and production emissions are regulated and quantifiable. Each research paper on cap-and-trade comprises information on transportation [61,68–70]; extraction of raw materials [68,69,71,72], production [61,69,70], and distribution [69].

The consideration of emissions related to the supplier's material and transportation, power consumption at plants, and power consumption at distribution centers [72]. Chaabane et al. & Rezaee et al. proposed a linear programming approach [61,70] by connecting CO_2 emissions from items with their volumes. In a study conducted by He et al., a low-carbon product was designed for the life cycle of the product [73]. Kannan et al. develop a reverse logistics network design model [68] to decrease CO_2 emissions from open facilities and transportation.

Cap-and-trade systems and carbon taxes can reduce emissions more efficiently. The carbon cap-and-trade model created by Wu et al. accounts for product inventory and routing considerations. The model can reduce carbon dioxide emissions and operational costs [74].

In addition to refs. [31,34,75,76], a number of other authors examine emissions using unit emission intensity. Cap-and-trade could be used to synchronize the SC with green technology [66]. The dual-channel SC requires coordination and determination in light of the cap-and-trade rule [77]. Emissions-based SCs have an impact on planning and policymaking in cap-and-trade systems [78].

The blockchain and SC operations are looked at in the context of cap-and-trade [79]. By regulating carbon emissions and collecting products in a CLSC, it is possible to achieve cap-and-trade reductions [49]. Cap-and-trade is used to analyze the influence of government subsidies to coordinate green marketing and green technology investment [80]. A SC with emission-dependent emissions is evaluated under a cap-and-trade framework [81].

Cap-and-trade rules can achieve two degrees of cooperation [1]. Different financing mechanisms and power structures have an effect on SCs under cap-and-trade regulations [48,55]. Carbon emission pricing and reduction in a dynamic SC utilizing cap-and-trade systems were researched [60]. Cap and trade regulate pricing and coordination techniques in dual-channel SCs [82].

Emissions were reduced in a cap-and-trade system by coordinating a system based on orders during SC [83]. In addition to impacting strategic decisions and collaborations, cap-and-trade policies have an impact on contract decisions and collaborations [84]. The make-to-order SC and cap-and-trade regulations [59] cause issues with production and price. Examine caps, trade mechanisms, and customer preferences for retailer-led SCs. SC members make differential game decisions to limit GHG emissions through cap-and-trade legislation [85].

According to Golpîra et al. [86], this will lead to a 15% reduction in emissions by the year 2020. If Ontario joins the Western Climate Initiative alongside California and Quebec [87], it can acquire additional credits if necessary while maintaining the collective cap. There is a linear link between emissions from manufacturing and transportation and production volume [13,61,88]. According to Abdullah et al. [71], the limit applies to the cost of raw materials, the delivery of products, and the consumption of electricity at plants and distribution hubs.

A two-echelon SSC coordination system under cap-and-trade regulation was designed by Xu et al. [89]. Choudhary et al. and Shaw et al. [30,90] have also analyzed the stationary emissions induced by open facilities. If releases are specified as flow functions, the carbon footprint may be estimated more readily.

Based on refs. [31,34,75,91], the emission severity per unit is computed. Furthermore, Abdallah et al. demonstrate how a single cap may result in variable credit prices [71]. [69,90] Using hypothetical parameters, Shaw et al. and Diabat et al. investigated the effects of SCN.

Giarola et al. [92] state that a cap-and-trade system maximizes profitability by limiting carbon emissions. Abdallah et al. [93] assert that carbon taxes greatly reduce emissions. These savings were accomplished by decentralizing and outsourcing the SC. According to Giarola et al. [92], the application of cap-and-trade in the maritime industry may cut emissions in a cost-effective manner. Similar to carbon caps, cap-and-trade pricing increases decrease SC costs.

According to Chaabane et al. [70], when the emission cap increases, the model favors cheaper alternatives with higher emissions. Thus, low-cost technologies with high emissions can be utilized, and fewer credits are required. Several studies [30,34,61,88] have demonstrated that carbon credit prices have a higher impact on SC configuration than the cap. As demonstrated by Chaabane et al. [88], a rise in the price of credit reduces recycling and credit purchases.

According to Diabat et al. [69], remanufacturing is an attractive option for carbon-intensive procurement activities. A model of biofuel SC under a carbon trading mechanism was suggested by Memari et al. [94].

As some businesses may choose not to invest in reverse logistics (RLs), authorities should provide a recovery credit to boost the incentive to create in the face of high carbon prices [28].

In the final part of this section, we give a brief description of the items mentioned in the SC. Abbasi et al. [95] have prioritized the development of sustainable recovery networks for COVID-19 outbreaks in recent years. During the pandemic, Abbasi et al. [96] recommended a SC to coordinate and make decisions regarding CO_2 emissions. Abbasi et al. designed the GCLSCN during the COVID-19 focus on CO_2 emissions [97].

In recent years, Wang, et al. [98] considered the formation of a low-carbon SC by dominant retailers and small and medium-sized manufacturers. Research on how production decisions are made, as well as how to repurchase carbon emission permits, is conducted when capital is limited [99].

In COVID-19, Abbasi et al. measured the performance of the SSC [100]. In 2023, Abbasi et al. developed the tri-Objective, SCLSC in COVID-19 [101]. They analyzed the decision-making process of manufacturers based on the repurchase strategy of carbon emission permits and capital constraints [102].

The position of the present research in relation to the previous research is shown in Table 1. The research papers in Table 1 have no carbon tax, carbon cap, cap-and-trade, and COVID-19 pandemic occurring simultaneously in the GCLSC.

Hammami et al. [37], modeled production inventories with lead time constraints to estimate carbon emissions. In their paper, Liu et al. [103] suggest that China's special economic zones will come back a third time. A review of studies on COVID-19 epidemic estimation in Iran was presented by Pourmalek et al. [104].

Predicting COVID-19 incidence based on Google trends data in Iran: A data mining and deep learning study by Ayyoubzadeh et al. [105]. Technology-based policies for clean air were implemented by Gerard and his colleagues [106].

In a green supply chain under uncertainty, Entezaminia et al. [76], discussed robust aggregate production planning. As described by Xiao et al. [107], sewage sludge-derived biochar for resource recovery has been studied before, modified, and applied. An optimized inventory management system under controllable carbon emissions by Mishra et al. [108].

The early COVID-19 epidemic in Iran provides lessons for preparedness and causes for concern, according to Ghafari et al. [109]. A Cohort Study on the Clinical Profile, Risk Factors, and Outcomes of COVID-19 in Iran by Hatamabadi et al. [110].

Table 1. The position of the present research about the previous research.

Author(s)	References	Year	Focused Carbon Tax	Focused Carbon Cap	Focused Cap-and-Trade	Focused COVID-19
Waltho et al.	[111]	(2019)	*	*	*	
Zhang et al.	[42]	(2019)		*		
Cadavid-Giraldo et al.	[44]	(2020)	*	*		
Kuiti et al.	[84]	(2020)			*	
Cao et al.	[20]	(2020)	*			
Babagolzadeh et al.	[112]	(2020)	*			
Bai et al.	[113]	(2020)	*			
Zou et al.	[114]	(2020)	*		*	
Kushwaha et al.	[46]	(2020)			*	
Ghosh et al.	[50]	(2020,a)			*	
Ghosh et al.	[51]	(2020,b)			*	
Mishra et al.	[54]	(2020)			*	
Tang & Yang	[55]	(2020)			*	
Yang et al.	[67]	(2020)			*	
Tong et al.	[85]	(2019)			*	
Taleizadeh et al.	[82]	(2021)			*	
Xu & Choi	[79]	(2021)			*	
Li et al.	[80]	(2021)			*	
Yang et al.	[53]	(2021)			*	
Wang & Wu	[49]	(2021)			*	
Lang et al.	[115]	(2021)	*			
Liu et al.	[116]	(2021)	*			
Zhang et al.	[117]	(2021)	*			
Guo & Xi	[118]	(2022)	*			
Meng et al.	[119]	(2022)	*		*	
Zhu et al.	[120]	(2022)	*			
Hu & Wang	[121]	(2022)	*			
Zhang, Y. & Zhang, T.	[122]	(2022)	*			
Paul et al.	[123]	(2022)	*			
Shi & Liu	[124]	(2022)	*			
Shen et al.	[125]	(2022)	*		*	
Wu et al.	[74]	(2022)	*			
Yu et al.	[126]	(2022)	*			

Table 1. *Cont.*

Author(s)	References	Year	Focused Carbon Tax	Focused Carbon Cap	Focused Cap-and-Trade	Focused COVID-19
Lyu et al.	[127]	(2022)	*			
Cheng et al.	[21]	(2022)	*		*	
Luo et al.	[102]	(2022)	*			
Xu et al.	[22]	(2022)	*			
Astanti et al.	[47]	(2022)			*	
Wang et al.	[88]	(2022)			*	
Chen et al.	[128]	(2022)	*			
Wei & Huang	[129]	(2022)	*			
Luo et al.	[130]	(2022)	*			
Yi et al.	[131]	(2022)	*			
This investigation			*	*	*	*

3. Problem Statement, Assumptions, and Formulation

3.1. Problem Description

In this mathematical model, economic performance indicators and environmental performance indicators contribute to SC efficiency in times of pandemic. By using the environmental and social efficiency indexes in mathematical modeling, a GSC can also be created by including all the monetary expenditures in a specific SC design. We will evaluate SC's operations based on three commonly used carbon policies: carbon caps, carbon taxes, and carbon trading.

Five types of facilities are considered in the mathematical model described above:

- Suppliers (S);
- Hybrid centers type one (M): (Manufacturing, Remanufacturing, Refurbishing, Recovering);
- Hybrid centers type two (J): (Collection, Distribution);
- Customers (C);
- Hybrid centers type three (D): (Recycling, Disposing);

During the forward flow, raw materials are extracted from suppliers and shipped to factories for processing. A forward supply chain is used to transfer products to customers. Products returned by customers are collected by the reverse flow and sent to the hybrid centers in type two. The problem schematic is shown in Figure 2.

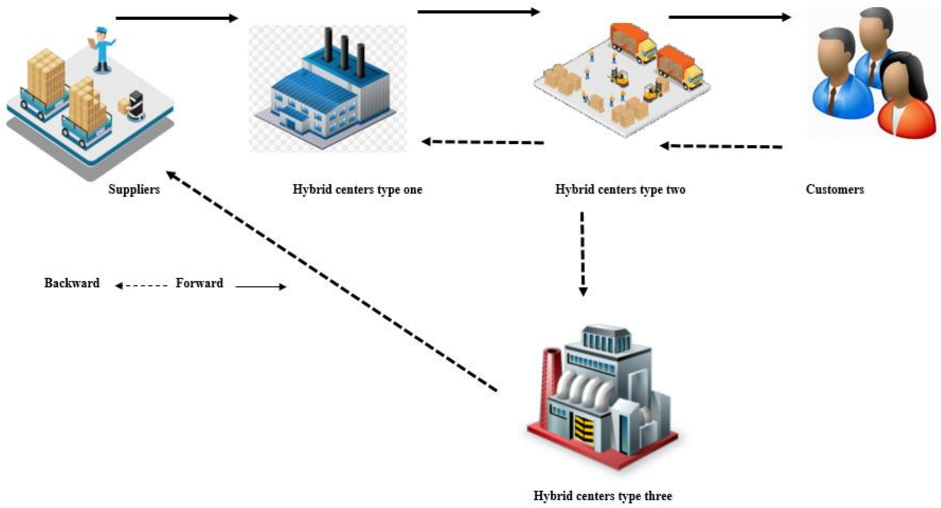

Figure 2. A closed-loop logistic network during COVID-19.

3.2. Model Assumptions

In configuring the network, the following assumptions will be made:

- As part of social distancing during the COVID-19 pandemic, the manufacturing, remanufacturing, refurbishing, and recovering center has been merged, making hybrid centers type one. The collection and distribution centers have been connected, making hybrid centers type two. The recycling and disposal centers have been merged, making hybrid centers type three.
- A normal and hygiene cost is included in the model.
- Despite the COVID-19 pandemic and lockdowns, all customer demands were always met.
- Each returned product that enters the hybrid center's type three disposal area is handled according to the COVID-19 hygiene protocol.
- There is certainty regarding customer demand and product returns.
- Potential locations include hybrid centers type one, two, and three
- The areas of suppliers and customers are known.
- For each node, there are various options for shipping.
- There is no limit to the capacity of any shipping alternative.
- Network nodes should be located at a feasible distance from each other.
- Supply chain networks are closed-loop systems.
- CO_2 release for processing and transporting is determined and depends on the type of facilities and transportation mode used in the network.

3.3. Formulation Process of the Problems

Mathematical models are formulated using Objective Functions (OFs) and Constraints. Various objectives are included in this mathematical model, such as minimizing the total cost (economic aspect) and minimizing environmental impacts (environmental aspect).

Index:

s: Fixed suppliers ($s = 1, 2, \ldots, |S|$),

m: Potential hybrid centers type one ($m = 1, 2, \ldots, |M|$),

j: Potential hybrid centers type two ($j = 1, 2, \ldots, |J|$),

d: Potential hybrid centers type three ($d = 1, 2, \ldots, |D|$),

c: Fixed customers ($c = 1, 2, \ldots, |C|$),

ts: Various modes of transportation from suppliers ($ts = 1, 2, \ldots, |TS|$),

tm: Various modes of transportation from hybrid centers type one ($tm = 1, 2, \ldots, |TM|$),

tj: Various modes of transportation from hybrid centers type two ($tj = 1, 2, \ldots, |TJ|$),

tc: Various modes of transportation from customers ($tc = 1, 2, \ldots, |TC|$),

td: Various modes of transportation from hybrid centers type three ($td = 1, 2, \ldots, |TD|$),

Technical parameters:

(Demand)

θ_i: customers' demand,

(Maximum Capacity)

ε_i: Maximum capacity of suppliers,

ε_m: Maximum capacity of hybrid centers type one,

ε_j: Maximum capacity of hybrid centers type two,

ε_d: Maximum capacity of hybrid centers type three,

(Limits on returned products)

MR: Minimum percentage of the returned product to be remanufactured, refurbished, recovered,

MP: Minimum percentage of the returned product to be recycled and disposed of,

(Shipping Rates)

γ_{sm}^{ts}: Shipping rate from the supplier s to hybrid center type one m with various modes of transportation ts,

γ_{mj}^{tm}: Shipping rate from hybrid center type one m to potential hybrid centers type two j with various modes of transportation tm,

γ_{jm}^{tj}: Shipping rate from hybrid centers type two j to hybrid center type one m with various modes of transportation tj,

γ_{jc}^{tj}: Shipping rate from hybrid centers type two j to customer c with various modes of transportation tj,

γ_{cj}^{tc}: Shipping rate from customer c to hybrid centers type two j with various modes of transportation tc,

γ_{jd}^{tj}: Shipping rate from hybrid centers type two j to hybrid centers type three d with various modes of transportation tj,

γ_{ds}^{td}: Shipping rate from hybrid centers type three d to supplier s with various modes of transportation td,

(Distances)

$\varnothing_{sm}$: Distance between supplier s and hybrid center type one m,

$\varnothing_{mj}$: Distance between hybrid center type one m and hybrid center type two j,

$\varnothing j_{m}$: Distance between hybrid center type two j and hybrid center type one m,

$\varnothing_{jc}$: Distance between hybrid center type two j and customer c,

$\varnothing_{cj}$: Distance between customer c and hybrid center type two j,

$\varnothing_{jd}$: Distance between hybrid center type two j and hybrid centers type three d

$\varnothing_{ds}$: Distance between hybrid centers type three d and supplier s,

Economic parameters:

(Fixed costs)

F_m: Fixed cost for establishing hybrid center type one m,

F_j: Fixed cost for establishing hybrid center type two j,

F_d: Fixed cost for establishing hybrid centers type three d,

(Variable costs)

V_s: Variable costs for extracting a unit of raw material from the supplier s,

V_m: Variable costs for producing a unit of product in the hybrid center type one m,

V_j: Variable costs for distribution a unit of product in the hybrid center type two j,

V_{rj}: Variable cost for collecting, inspecting, consolidating, and sorting a unit of the returned product in the hybrid center type two j,

V_d: Variable costs for recycling and landfilling a unit of the returned product in hybrid center type three d,

V_{rm}: Variable costs for remanufacturing and refurbishing a unit of the returned product in the hybrid center type one m,

(Transportation costs)

β_{sm}^{ts}: Transportation cost of a unit of raw material from the supplier s to hybrid center type one m with various modes of transportation ts,

β_{mj}^{tm}: Transportation cost of a unit product from hybrid center type one m to hybrid center type two j with various modes of transportation tm,

β_{jc}^{tj}: Transportation cost of a unit of product from hybrid center type two j to customer c with various modes of transportation tj,

β_{cj}^{tc}: Transportation cost of a unit of the returned product is collected from customer c to hybrid center type two j with various modes of transportation tc,

β_{jm}^{tj}: Transportation cost of a unit of the returned product is available for remanufacturing and refurbishing from hybrid center type two j to hybrid center type one m with various modes of transportation tj,

β_{jd}^{tj}: Transportation cost of a unit of returned product that is unsuitable for remanufacturing, refurbishing, and recovering from hybrid center type two j to hybrid center type three d with various modes of transportation tj,

β_{ds}^{td}: Transportation cost of a unit of recycled product from hybrid center type three d to supplier s with various modes of transportation td,

(Hygiene costs)

H_s: Hygiene costs while extracting a unit of raw material from the supplier s,

H_m: Hygiene costs while manufacturing a unit of product in the hybrid center type one m,

H_j: Hygiene costs while distributing a unit of product from the hybrid center type two j,

H_{rj}: Hygiene costs while collecting and inspecting a unit of the returned product in the hybrid center type two j,

H_d: Hygiene costs while recycling and disposing of a unit of the returned product in the hybrid center type three d,

Hr_m: Hygiene costs while remanufacturing, refurbishing, and recovering a unit of the returned product in the hybrid center type one m,

$H\beta_{sj}^{ts}$: Hygiene costs while transporting of a unit of raw material from the supplier s to hybrid center type two j with various modes of transportation ts,

$H\beta_{mj}^{tm}$: Hygiene costs while transporting of a unit of product from hybrid center type one m to hybrid center type two j with various modes of transportation tm,

$H\beta_{jc}^{tj}$: Hygiene costs while transporting of a unit of product from hybrid center type two j to customer c with various modes of transportation tj,

$H\beta_{cj}^{tc}$: Hygiene costs while transporting of a unit of returned product from customer c to hybrid center type two j with various modes of transportation tc,

$H\beta_{jm}^{tj}$: Hygiene costs while the transporting of a unit of the returned product is available for remanufacturing and refurbishing from hybrid center type two j to hybrid center type one m with various modes of transportation tj,

$H\beta_{jd}^{tj}$: Hygiene cost while transporting a unit of returned product that is unsuitable for remanufacturing and refurbishing from hybrid center type two j to hybrid center type three d with various modes of transportation tj,

$H\beta_{ds}^{td}$: Hygiene costs while transporting a unit of recycled product from hybrid center type three d to supplier s with various modes of transportation td,

Environmental parameters:

(CO_2 emissions caused by activities)

E_s: Rate of CO_2 emissions to extract a unit of raw material in supplier s,

E_m: Rate of released CO_2 to produce one unit of product in hybrid center type one m,

E_j: Rate of CO_2 emissions to handle and distribute one unit of product in the hybrid center type two j,

Er_j: Rate of CO_2 emissions to collect, inspect consolidate and sort one unit of the returned product in the hybrid center type two j,

Er_m: Rate of CO_2 emissions to remanufacture one unit of the returned product in the hybrid center type one j,

Er_d : Rate of CO_2 emissions to recycle and landfill one unit of the returned product in hybrid center type three d,

(CO_2 emissions caused by transporting)

$E\beta_{sm}^{ts}$: CO_2 emissions by transporting alternative ts to send a unit of raw material from supplier s to center type one m for a unit distance,

$E\beta_{mj}^{tm}$: CO_2 emissions by transporting tm to send a unit of product from hybrid center type one m to hybrid center type two j for a unit distance,

$E\beta_{jc}^{tj}$: CO_2 emissions by transporting tj to send a unit of product from hybrid center type two j to customer c for a unit distance,

$E\beta_{cj}^{tc}$: CO_2 emissions by transporting tc to collect a unit of returned production from customer c to hybrid center type two j for a unit distance,

$E\beta_{jm}^{tj}$: CO_2 emissions by transporting tj to send a unit of the returned product to be remanufactured from hybrid center type two j to hybrid center type one m for a unit distance,

$E\beta_{jd}^{tj}$: CO_2 emissions by transporting tj to send a unit of returned production from hybrid center type two j to hybrid center type three d for a unit distance,

$E\beta_{ds}^{td}$: CO_2 emissions by transporting td to send a unit of returned production from hybrid center type three d to supplier s for a unit distance,

C^{cap}: Fixed carbon cap on emission over the entire planning horizon (kg),

δ: The carbon tax rate per unit (Amount of tax paid per unit emitted),

P^{+}: The carbon selling price per unit (kg) in the carbon market,

P^{-}: The carbon buying price per unit (kg) in the carbon market,

Decision Variables

Binary Variables:

x_m: If hybrid center type one m is established, equal 1; otherwise 0,

x_j: If hybrid center type two j is established, equal 1; otherwise 0,

x_d: If hybrid center type three d is established, equal 1; otherwise 0,

Continuous variables:

Y_{sm}^{ts}: Quantity of units of raw material sent from supplier s to hybrid center m with various modes of transportation ts,

Y_{mj}^{tm}: Quantity of units of product sent from hybrid center m to hybrid center j with various modes of transportation tm,

Y_{jc}^{tj}: Quantity of units of product sent from hybrid center type two j to customer c with various modes of transportation tj,

Y_{cj}^{tc}: Quantity of units of returned product collected from customer c to hybrid center j with various modes of transportation tc,

Y_{jm}^{tj}: Quantity of units of returned product available for remanufacturing, refurbishing, and recovering sent from hybrid center j to hybrid center m with various modes of transportation tj,

Y_{jd}^{tj}: Quantity of units of returned product available for refurbishing and disposal sent from hybrid center j to hybrid center d with various modes of transportation tj,

Y_{ds}^{td}: Quantity of units of recycled product sent from hybrid center type three d to supplier s with various modes of transportation td,

e^{+}: The amount of carbon credit purchased,

e^{-}: The amount of carbon credit sold,

3.3.1. Designing the CLSC Network without Taking into Consideration Carbon Emissions

Cost-only models are based solely on economic performance for strategic and operational decisions. CLSC's total expected cost will be minimized by using a cost-only model.

Cost-Only Model during the COVID-19 Pandemic (M_1)

Total Cost = Fixed costs (TFC) + Transportations costs (TTC)+ Variable costs (TVC) {Extracting costs+ Production cost + Collection, inspection and distribution cost + Recycling costs+ Disposal costs} +Hygiene costs (THC) {Disinfection costs + PPE costs+ COVID-19 education costs+ COVID-19 medicines, vaccine and vaccination costs}.

$$MinZ_1 = TFC + TTC + TVC + THK \tag{1}$$

$$TFC = \sum_{m=1}^{M} F_m X_m + \sum_{j=1}^{J} F_j X_J + \sum_{d=1}^{D} F_d X_d \tag{2}$$

$$\begin{aligned} TTC = \sum_{s=1}^{S} V_s \quad & \sum_{m=1}^{M} \sum_{ts=1}^{TS} Y_{sm}^{ts} \\ & + \sum_{m=1}^{M} V_m \sum_{J=1}^{J} \sum_{tm=1}^{TM} Y_{mj}^{tm} \\ & + \sum_{\imath=1}^{I} V_j \sum_{c=1}^{C} \sum_{ti=1}^{TI} Y_{ic}^{ti} + \sum_{j=1}^{J} Vr_j \sum_{c=1}^{C} \sum_{tc=1}^{TC} Y_{cj}^{tj} + \sum_{m=1}^{M} Vr_m \sum_{j=1}^{J} \sum_{tj=1}^{TJ} Y_{jf}^{tj} \\ & + \sum_{d=1}^{D} V_d \sum_{j=1}^{J} \sum_{tj=1}^{TJ} Y_{jd}^{tj} \end{aligned} \tag{3}$$

$$TVC = \sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{ts=1}^{TS}\beta_{sm}^{ts}Y_{sm}^{ts} + \sum_{m=1}^{M}\sum_{J=1}^{J}\sum_{tm=1}^{TM}\beta_{mj}^{tm}Y_{mj}^{tm} + \sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{ti=1}^{TI}\beta_{ic}^{tl}Y_{ic}^{tl} + \sum_{c=1}^{C}\sum_{i=1}^{I}\sum_{tc=1}^{TC}\beta_{cj}^{cj}Y_{cj}^{tc} + \sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{tj=1}^{TJ}\beta_{jm}^{tj}Y_{jm}^{tj} + \sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{tj=1}^{TJ}\beta_{jd}^{tj}Y_{jd}^{tj} + \sum_{d=1}^{D}\sum_{s=1}^{S}\sum_{td=1}^{TD}\beta_{ds}^{td}Y_{ds}^{td} \tag{4}$$

$$THC = \sum_{s=1}^{S}H_s\sum_{m=1}^{M}\sum_{ts=1}^{TS}Y_{sf}^{ts} + \sum_{m=1}^{M}H_m\sum_{J=1}^{J}\sum_{tm=1}^{TM}Y_{mj}^{tm} + \sum_{j=1}^{I}H_J\sum_{c=1}^{C}\sum_{tj=1}^{TI}Y_{jc}^{tj} + \sum_{j=1}^{J}Hr_j\sum_{c=1}^{C}\sum_{tc=1}^{TC}Y_{cj}^{tc} + \sum_{m=1}^{m}Hr_m\sum_{j=1}^{J}\sum_{tj=1}^{TJ}Y_{jm}^{tj} + \sum_{d=1}^{D}H_d\sum_{j=1}^{J}\sum_{tj=1}^{TJ}Y_{jd}^{tj} + \sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{ts=1}^{TS}H\beta_{sm}^{ts}Y_{sm}^{ts} + \sum_{m=1}^{M}\sum_{j=1}^{I}\sum_{tm=1}^{TM}H\beta_{mj}^{tm}Y_{mj}^{tm} + \sum_{j=1}^{J}\sum_{c=1}^{C}\sum_{tj=1}^{TJ}H\beta_{jc}^{tj}Y_{jc}^{tc} + \sum_{c=1}^{C}\sum_{j=1}^{J}\sum_{tc=1}^{TC}H\beta_{cj}^{tc}Y_{cj}^{tc} + \sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{tj=1}^{TJ}H\beta_{jd}^{tj}Y_{jd}^{tj} + \sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{tb=1}^{TB}H\beta_{bs}^{tb}Y_{bs}^{tb} \tag{5}$$

Subject to:

$$\sum_{s\in S}\sum_{ts\in TS}Y_{sm}^{ts} \le \varepsilon_m x_m \tag{6}$$

$$\sum_{f\in F}\sum_{tf\in TF}Y_{jm}^{tf} \le \varepsilon_j x_j \quad \forall j\in J \tag{7}$$

$$\sum_{j\in J}\sum_{tj\in TJ}Y_{jd}^{tj} \le \varepsilon_d x_d \quad \forall d\in D \tag{8}$$

$$\sum_{j\in J}\sum_{tj\in TJ}Y_{jm}^{tj} \le \varepsilon_m x_m \quad \forall m\in M \tag{9}$$

$$\sum_{c\in C}\sum_{tc\in TC}Y_{cj}^{tc} \le \varepsilon_j x_j \quad \forall j\in J \tag{10}$$

$$\sum_{s\in S}\sum_{ts\in TS}Y_{sm}^{ts} \le \varepsilon_m x_m \quad \forall m\in M \tag{11}$$

$$\sum_{c\in C}\sum_{tj\in TJ}Y_{jc}^{tj} \le \sum_{j\in J}\sum_{tm\in TM}Y_{mj}^{tm} \quad \forall j\in J \tag{12}$$

$$\sum_{d\in D}\sum_{tj\in TJ}Y_{jd}^{tj} \le \sum_{j\in J}\sum_{tm\in TM}Y_{mj}^{tm} \quad \forall j\in J \tag{13}$$

$$\sum_{m\in M}\sum_{tj\in TJ}Y_{jm}^{tj} \le \sum_{j\in J}\sum_{tm\in TM}Y_{jm}^{tm} \quad \forall j\in J\ \forall m\in M \tag{14}$$

$$\sum_{c\in C}\sum_{tj\in TJ}Y_{jc}^{tj} \le \sum_{j\in J}\sum_{tc\in TC}Y_{jc}^{tc} \quad \forall j\in J\ \forall c\in C \tag{15}$$

$$\theta_c \le \sum_{J=1}^{J}\sum_{tj=1}^{TJ}Y_{jc}^{tj} \quad \forall \mathrm{c}\in \mathrm{C} \tag{16}$$

$$\sum_{c=1}^{C}\sum_{tc=1}^{TC}Y_{cj}^{tc} \le \theta_c \quad \forall \mathrm{c}\in \mathrm{C} \tag{17}$$

$$MP\theta_c \le \sum_{J=1}^{J}\sum_{tc=1}^{TC}Y_{cj}^{tc} \quad \forall \mathrm{c}\in \mathrm{C} \tag{18}$$

$$\sum_{m=M}\sum_{tj=TJ}Y_{jm}^{tj} \ge MR\sum_{c=C}\sum_{tj=TJ}Y_{cj}^{tj} \quad \forall \mathrm{j}\in \mathrm{J} \tag{19}$$

$$Y_{sm,}^{ts} Y_{mj}^{tm}, Y_{jc}^{tj}, Y_{cj}^{tc}, Y_{jm,}^{tj} Y_{jd}^{tj}, Y_{ds}^{td} \geq 0$$

$$\forall s \in s\ \forall c \in C\ \forall m \in M\ \forall j \in J\ \forall d \in D\ \forall ts \in TS\ \forall tm \in TM\ \forall tj \in TJ\ \forall td \in TD\ \ \forall tc \in TC \quad (20)$$

$$X_m, X_j, X_d \in \{0,1\}\ \forall m \in M\ \forall j \in J\ \forall d \in D \quad (21)$$

In addition to the objective functions, there are also constraints.

The objective functions are expressed quantitatively in Equations (1)–(5). The overall expense equals the sum of the fixed, variable, transportation, and hygiene expenses. The limitations are given by Equations (6)–(21).

The total number of raw material units entering a type one hybrid center from any supplier via any shipping option must not exceed the hybrid center's maximum capacity, as shown by Constraint (6).

Constraint (7) states that the number of product units entering a type two hybrid center from a type one hybrid center via any transport method must be less than or equal to the type two hybrid center's maximum capacity.

As stated in Constraint (8), the total quantity of returned products to be recycled or discarded at the type three hybrid facility cannot exceed its maximum capacity.

By Constraint (9), all returned product units carried from a type two hybrid center to a type one hybrid center must not exceed the type two hybrid center's maximum capacity.

Based on Constraint (10) the total quantity of returned items transported by any method to a type two hybrid center must be less than or equal to the maximum capacity of the hybrid center.

Constraint (11) demonstrates that the total number of product units transported from a type one hybrid center to any type two hybrid center via any transportation method must be less than or equal to the total number of raw material units transported from a supplier to any type two hybrid center.

Under Constraint (12), the total number of products delivered from type two hybrid centers to customers by any mode of transport must be fewer than or equal to the total number of products moved from type one hybrid centers to type two hybrid centers.

According to Constraint (13), the total number of product units delivered from a type two hybrid center to any other center by any mode of transportation must be less than or equal to the total number of product units shipped from a type one hybrid center to another hybrid center type.

Constraint (14) shows the total number of product units conveyed from a type two hybrid center to a type one hybrid center must be less than or equal to the total number of product units transported from a type two hybrid center to a type one hybrid center.

Constraint (15) specifies the total number of returned product units shipped from a customer to a type two hybrid center via any mode of transport must be less than or equal to the total number of product units supplied from the type two hybrid center to any customers.

As stated in Constraint (16), the total number of product units delivered by any type two hybrid center to satisfy a customer's demand must be greater than or equal to the customer's demand.

As demonstrated in Constraint (17), a type two hybrid distribution center should receive less returned products than it would otherwise via transportation methods.

Constraint (18) specifies that the total number of product units to be recycled or discarded by a customer via any transportation method must exceed the minimum percentage of return from the total number of customer demands.

Under Constraint (19), the total number of units of product that must be remanufactured, refurbished, and recovered must be greater than or equal to the minimum percentage of units of product that will be remanufactured, refurbished, and recovered out of the total number of returned units.

The Constraint (20) specifies that the flow of raw materials, goods, and returned products through the network via transportation alternatives must be higher than or equal to zero.

The location of possible facilities is described by a binary integer in Constraint (21).

3.3.2. Model Carbon Cap Policy (M_2) Formulation

This policy limits the number of carbon allowances a firm may use, known as the carbon cap, and indicated by C''' (in kg). As a result of Constraint (23), Model M_1 becomes Model M_2. Constraint (23) equals or is less than the amount of the carbon cap imposed, including emissions contained within facilities and those resulting from logistical activities.

$$Minimize\ Z_2 = Z_1 \tag{22}$$

Subject to:
Constraints (6)–(21) and

$$\begin{aligned}
&\sum_{s=1}^{S} E_s \sum_{m=1}^{M} \sum_{ts=1}^{TS} Y_{sf}^{ts} \\
&+ \sum_{m=1}^{M} E_m \sum_{J=1}^{J} \sum_{tm=1}^{TM} Y_{mj}^{tm} \\
&+ \sum_{j=1}^{I} E_i \sum_{c=1}^{C} \sum_{tj=1}^{TJ} Y_{jc}^{tj} + \sum_{j=1}^{J} Er_j \sum_{c=1}^{C} \sum_{tc=1}^{TC} Y_{cj}^{tc} + \sum_{m=1}^{m} Er_m \sum_{j=1}^{J} \sum_{tj=1}^{TJ} Y_{jm}^{tj} \\
&+ \sum_{d=1}^{D} Er_d \sum_{d=1}^{J} \sum_{tj=1}^{TJ} Y_{jd}^{tj} \\
&+ \sum_{s=1}^{S} \sum_{m=1}^{M} \sum_{ts=1}^{TS} E\beta_{sm}^{ts} Y_{sm}^{ts} \varphi_{sm} \gamma_{sm}^{ts} \\
&+ \sum_{m=1}^{M} \sum_{j=1}^{J} \sum_{tm=1}^{TM} E\beta_{mj}^{tm} Y_{fi}^{tf} \delta_{fj} \gamma_{mj}^{tm} \\
&+ \sum_{j=1}^{J} \sum_{c=1}^{C} \sum_{ti=1}^{TI} E\beta_{jc}^{tj} Y_{jc}^{tc} \delta_{jc} \gamma_{jc}^{tj} + \sum_{c=1}^{C} \sum_{j=1}^{J} \sum_{tc=1}^{TC} E\beta R_{cj}^{tc} Y_{cj}^{tc} \varphi_{cj} \gamma_{cj}^{tc} \\
&+ \sum_{i=1}^{I} \sum_{m=1}^{M} \sum_{ti=1}^{TJ} E\beta R_{jm}^{tj} Y_{jm}^{tj} \varphi_{jm} \gamma_{jm}^{tj} + \sum_{j=1}^{J} \sum_{d=1}^{D} \sum_{tj=1}^{TJ} E\beta_{jd}^{tj} Y_{jd}^{tj} \varphi_{jd} \gamma_{jd}^{tj} \\
&+ \sum_{d=1}^{D} \sum_{s=1}^{S} \sum_{td=1}^{TD} E\beta R_{ds}^{td} Y_{ds}^{td} \varphi_{ds} \gamma_{ds}^{td} \leq C^{cap}
\end{aligned} \tag{23}$$

3.3.3. Model Formulation of Carbon Tax Policy (M_3)

This rule offers alternatives to restrictive carbon caps. There is no emission restriction under this policy, nor are there any limits on emissions, as in carbon cap policies. Still, emissions are penalized through a carbon tax. The tax is a financial penalty (δ) in which emissions are correlated with carbon taxes.

$$Minimize\ Z_3 = Z_1 + \delta\ (Z_{31} + Z_{32}) \tag{24}$$

Subject to: Constraints (6)–(21)

$$\begin{aligned}
Z_{31} = &\sum_{s=1}^{S} E_s \sum_{m=1}^{M} \sum_{ts=1}^{TS} Y_{sf}^{ts} + \sum_{m=1}^{M} E_m \sum_{J=1}^{J} \sum_{tm=1}^{TM} Y_{mj}^{tm} + \sum_{j=1}^{I} E_i \sum_{c=1}^{C} \sum_{tj=1}^{TJ} Y_{jc}^{tj} \sum_{j=1}^{J} Er_j \sum_{c=1}^{C} \sum_{tc=1}^{TC} Y_{cj}^{tc} + \sum_{m=1}^{m} Er_m \sum_{j=1}^{J} \sum_{tj=1}^{TJ} Y_{jm}^{tj} \\
&+ \sum_{d=1}^{D} Er_d \sum_{d=1}^{J} \sum_{tj=1}^{TJ} Y_{jd}^{tj}
\end{aligned} \tag{25}$$

$$Z_{31} = \sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{ts=1}^{TS} E\beta_{sm}^{ts} Y_{sm}^{ts} \varphi_{sm} \gamma_{sm}^{ts} + \sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{tm=1}^{TM} E\beta_{mj}^{tm} Y_{fi}^{tf} \delta_{fj} \gamma_{mj}^{tm} + \sum_{j=1}^{J}\sum_{c=1}^{C}\sum_{ti=1}^{TI} E\beta_{jc}^{tj} Y_{jc}^{tc} \delta_{jc} \gamma_{jc}^{tj} + \sum_{c=1}^{C}\sum_{j=1}^{J}\sum_{tc=1}^{TC} E\beta R_{cj}^{tc} Y_{cj}^{tc} \varphi_{cj} \gamma_{cj}^{tc} + \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{ti=1}^{TJ} E\beta R_{jm}^{tj} Y_{jm}^{tj} \varphi_{jm} \gamma_{jm}^{tj} + \sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{tj=1}^{TJ} E\beta_{jd}^{tj} Y_{jd}^{tj} \varphi_{jd} \gamma_{jd}^{tj} + \sum_{d=1}^{D}\sum_{s=1}^{S}\sum_{td=1}^{TD} E\beta R_{ds}^{td} Y_{ds}^{td} \varphi_{ds} \gamma_{ds}^{td} \quad (26)$$

3.3.4. Model Formulation of Carbon Cap-and-Trade Policy (M_4)

It is an alternative to either a carbon tax or a hard carbon cap. Taking advantage of this policy, companies are permitted to trade carbon incentives, i.e., they can sell new carbon emissions if they emit less than the recommended carbon cap. Firms can buy extra carbon emissions if they use more than their carbon cap to retain their supply chain processes.

The new variables e^+ and e^- represent this model's amount of selling and buying carbon in kg.

$$Minimize\ Z_4 = Z_1 - p^+ e^+ + p^- e^- \quad (27)$$

Subject to:

$$\sum_{s=1}^{S} E_s \sum_{m=1}^{M}\sum_{ts=1}^{TS} Y_{sf}^{ts} + \sum_{m=1}^{M} E_m \sum_{J=1}^{J}\sum_{tm=1}^{TM} Y_{mj}^{tm} + \sum_{j=1}^{I} E_i \sum_{c=1}^{C}\sum_{tj=1}^{TJ} Y_{jc}^{tj} + \sum_{j=1}^{J} Er_j \sum_{c=1}^{C}\sum_{tc=1}^{TC} Y_{cj}^{tc} + \sum_{m=1}^{m} Er_m \sum_{j=1}^{J}\sum_{tj=1}^{TJ} Y_{jm}^{tj} + \sum_{d=1}^{D} Er_d \sum_{d=1}^{J}\sum_{tj=1}^{TJ} Y_{jd}^{tj} + \sum_{s=1}^{S}\sum_{m=1}^{M}\sum_{ts=1}^{TS} E\beta_{sm}^{ts} Y_{sm}^{ts} \varphi_{sm} \gamma_{sm}^{ts} + \sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{tm=1}^{TM} E\beta_{mj}^{tm} Y_{fi}^{tf} \delta_{fj} \gamma_{mj}^{tm} + \sum_{j=1}^{J}\sum_{c=1}^{C}\sum_{ti=1}^{TI} E\beta_{jc}^{tj} Y_{jc}^{tc} \delta_{jc} \gamma_{jc}^{tj} + \sum_{c=1}^{C}\sum_{j=1}^{J}\sum_{tc=1}^{TC} E\beta R_{cj}^{tc} Y_{cj}^{tc} \varphi_{cj} \gamma_{cj}^{tc} + \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{ti=1}^{TJ} E\beta R_{jm}^{tj} Y_{jm}^{tj} \varphi_{jm} \gamma_{jm}^{tj} + \sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{tj=1}^{TJ} E\beta_{jd}^{tj} Y_{jd}^{tj} \varphi_{jd} \gamma_{jd}^{tj} + \sum_{d=1}^{D}\sum_{s=1}^{S}\sum_{td=1}^{TD} E\beta R_{ds}^{td} Y_{ds}^{td} \varphi_{ds} \gamma_{ds}^{td} + e^- \leq C^{cap} + e^+$$

Constraints (6)–(21) & $e^+, e^- \geq 0$

4. Computational Results and Case Study

4.1. Numerical Example

The applicability of the proposed models is tested through a numerical example in this section. Consider three fixed suppliers (|S| = 3), two potential factories (|F| = 2), four potential CDCs (|I| = 4), three potential RLCs (|B| = 3), and ten fixed customers (|C| = 10), with one transporting option from suppliers (|TS| = 1), two transporting options from factories (|TF| = 2), five transporting options from CDCs (|TI| = 5), two transporting options from customers (|TC| = 2), and three transporting options from RLCs (|TB| = 3). In general, it is recognized that different facilities and transportation methods have considerable differences in CO_2 emissions. The rule parameters are elected as C^{cap} (carbon cap) = 20,000 kg, δ (carbon tax) = 0.5 \$/kg, p^+ (sell) = 0.2 \$/kg, and p^- (buy) = 0.6 \$/kg which is \$0.1 lower than p^+ to demonstrate various among the selling and purchasing prices in a market after regarding transaction costs. The other parameters presented in all four models are solved using LINGO19 on a notebook with an Intel core i7 2.40 GHz processor and 8 GB of RAM. There is a range of computational times between

3 s and 19 s; carrying out intensive numerical examples is acceptable. A table showing the parameters of the model can be found in Table 2. According to different carbon policies, Table 3 shows the optimal value solution for objective functions before and during COVID-19.

Table 2. Parameter values for the model.

Parameter	Values
θ_c	Uniform (5000; 6500)
ε_s	Uniform (25,000; 30,000)
ε_m	Uniform (45,000; 50,000)
ε_j	Uniform (30,000; 35,000)
ε_d	Uniform (15,000; 20,000)
MR	Uniform (0.1; 0.5)
MP	Uniform (0.1; 0.4)
Y_{sm}^{ts}	Uniform (18; 60)
Y_{mj}^{tm}	Uniform (18; 60)
Y_{jm}^{tj}	Uniform (18; 60)
Y_{jc}^{tj}	Uniform (18; 60)
Y_{cj}^{tc}	Uniform (18; 60)
Y_{jd}^{tj}	Uniform (18; 60)
Y_{ds}^{td}	Uniform (18; 60)
Φ_{sm}	Uniform (10; 1000)
Φ_{mj}	Uniform (10; 1000)
Φ_{jm}	Uniform (10; 1000)
Φ_{jc}	Uniform (10; 1000)
Φ_{ci}	Uniform (10; 1000)
Φ_{jd}	Uniform (10; 1000)
Φ_{ds}	Uniform (10; 1000)
F_m	Uniform (2,000,000,000; 9,000,000,000)
F_j	Uniform (1,000,000,000; 7,000,000,000)
F_d	Uniform (1,500,000,000; 6,500,000,000)
V_s	Uniform (50,000; 150,000)
V_m	Uniform (60,000; 200,000)
V_j	Uniform (40,000; 130,000)
Vr_j	Uniform (35,000; 120,000)
V_d	Uniform (40,000; 90,000)
Vr_m	Uniform (20,000; 100,000)
$ß_{sf}^{ts}$	Uniform (75,000; 95,000)
$ß_{fi}^{tf}$	Uniform (80,000; 100,000)
$ß_{ic}^{ti}$	Uniform (50,000; 90,000)
$ß_{ci}^{tc}$	Uniform (40,000; 120,000)

Table 2. *Cont.*

Parameter	Values
$ß_{jm}^{ti}$	Uniform (60,000; 110,000)
$ß_{jd}^{ti}$	Uniform (70,000; 130,000)
$ß_{ds}^{td}$	Uniform (85,000; 140,000)
H_s	Uniform (20,000; 120,000)
H_m	Uniform (15,000; 110,000)
H_j	Uniform (10,000; 135,000)
Hr_j	Uniform (12,000; 85,000)
H_d	Uniform (17,000; 90,000)
Hr_m	Uniform (20,000; 100,000)
$Hß_{sj}^{ts}$	Uniform (89,000; 110,000)
$Hß_{mj}^{tm}$	Uniform (110,000; 150,000)
$Hß_{jc}^{tj}$	Uniform (88,000; 140,000)
$Hß_{cj}^{tc}$	Uniform (77,000; 120,000)
$Hß_{jm}^{tj}$	Uniform (55,000; 110,000)
$Hß_{jd}^{tj}$	Uniform (66,000; 100,000)
$Hß_{ds}^{td}$	Uniform (30,000; 90,000)
E_s	Uniform (10; 5000)
E_m	Uniform (10; 6000)
E_j	Uniform (10; 5500)
Er_j	Uniform (10; 7500)
Er_m	Uniform (10; 4500)
Er_d	Uniform (10; 3500)
$Eß_{sm}^{ts}$	Uniform (10; 2500)
$Eß_{mj}^{tm}$	Uniform (10; 350)
$Eß_{jc}^{tj}$	Uniform (10; 200)
$EßR_{cj}^{tc}$	Uniform (10; 100)
$EßR_{jm}^{tj}$	Uniform (10; 300)
$EßR_{jd}^{tj}$	Uniform (10; 100)
$EßR_{ds}^{td}$	Uniform (10; 550)

Table 3. Optimal value solution of objective functions Pre–during the COVID-19 under different carbon policies.

	No Carbon Policy (M_1)	**Carbon Cap Policy (M_2)**	**Carbon Tax Policy (M_3)**	**Cap-and Trade Policy (M_4)**
Optimization value of objective function pre-COVID-19.	4,560,141	2,380,049	2,586,517	2,780,070
Optimization value of objective function during the COVID-19.	5,844,481	1,807,612	1,986,001	1,782,229

According to Table 3, the carbon tax policy (M_3) leads to higher costs for the GCLSC during COVID-19, while the other rules result in a lower economic burden. The fixed carbon cap policy (M_2) and cap-and-trade policy (M_4) can decrease CO_2 emissions without raising the cost of GCLSC during the COVID-19 outbreak. A comparison of optimization values before and after COVID-19 is illustrated in Figure 3.

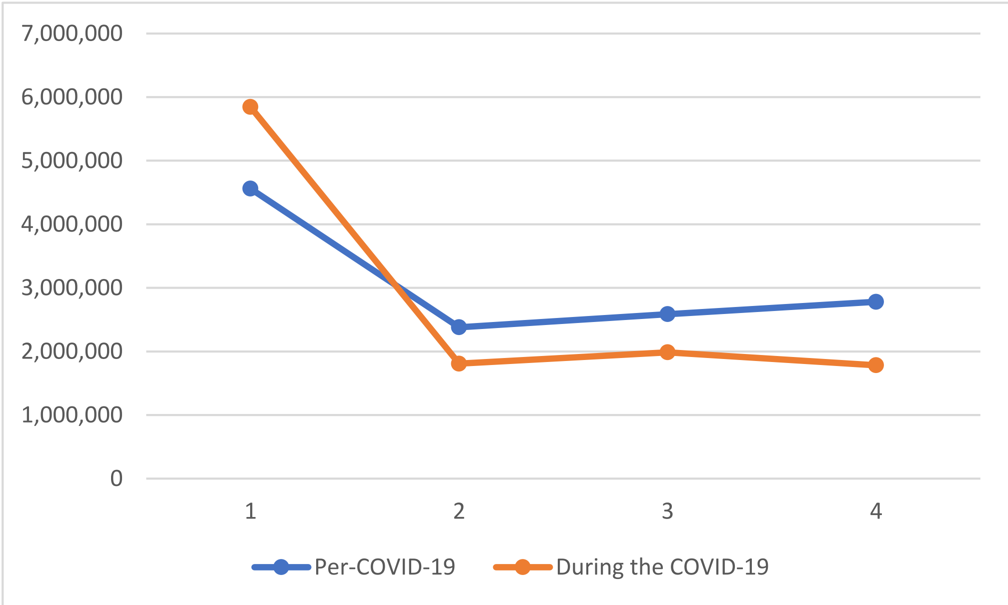

Figure 3. Illustrates the comparison optimization value between pre-COVID-19 and during COVID-19.

4.2. Case Study

Iran confirmed its first COVID-19 cases on February 19, 2020. The data for the considered case study is used to assess the model's validity and the functionality of the solution methods [78,114,117]. An evaluation of the model's outcomes has been conducted in a real-life case study context. Based on the data for the case study, the model's accuracy and functionality are evaluated. Lastly, the proposed model should be referred to as closed-loop, reliable, and responsive.

According to this study, the closed-loop network includes: fixed suppliers (∣S∣ = 2), potential hybrid centers type one (∣M∣ = 1), potential hybrid centers type two (∣J∣ = 3), potential hybrid centers type three (∣D∣ = 1), fixed customers (∣C∣ = 5), various modes of transportation from suppliers (∣TS∣ = 1), various modes of transportation from hybrid centers type one (∣TM∣ = 1), various modes of transportation from hybrid centers type two (∣TJ∣ = 3), various modes of transportation from customers (∣TC∣ = 2), various modes of transportation from hybrid centers type three (∣TD∣ = 2). The exact data from the case study are available on request from the corresponding author.

Figures 4 and 5 show the percentage of COVID-19 cases in Iran that are either increasing or decreasing. A comparison of optimization values, as shown in Figure 6 for the case study before and after COVID-19.

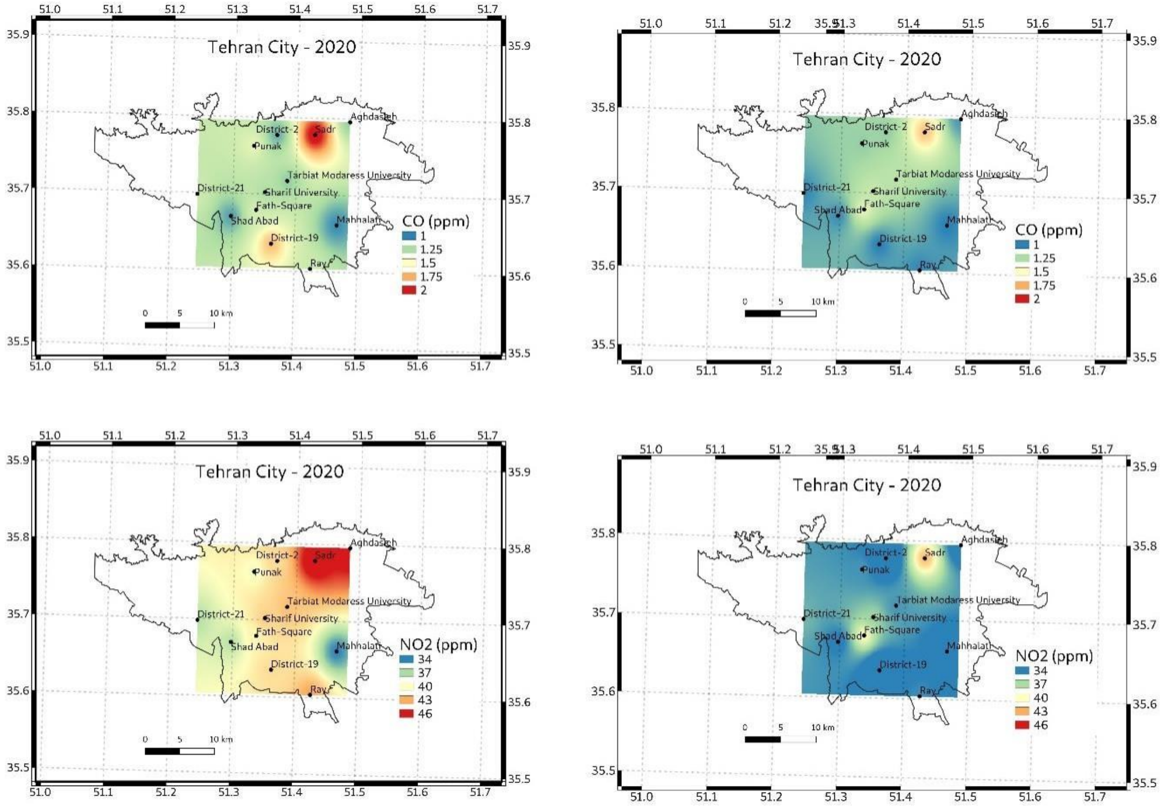

Figure 4. During the period of 21 March to 21 April 2019 and 2020, the average CO (ppm) and NO_2 (ppb) concentrations in Tehran megacity, Iran, were measured at the study stations [132].

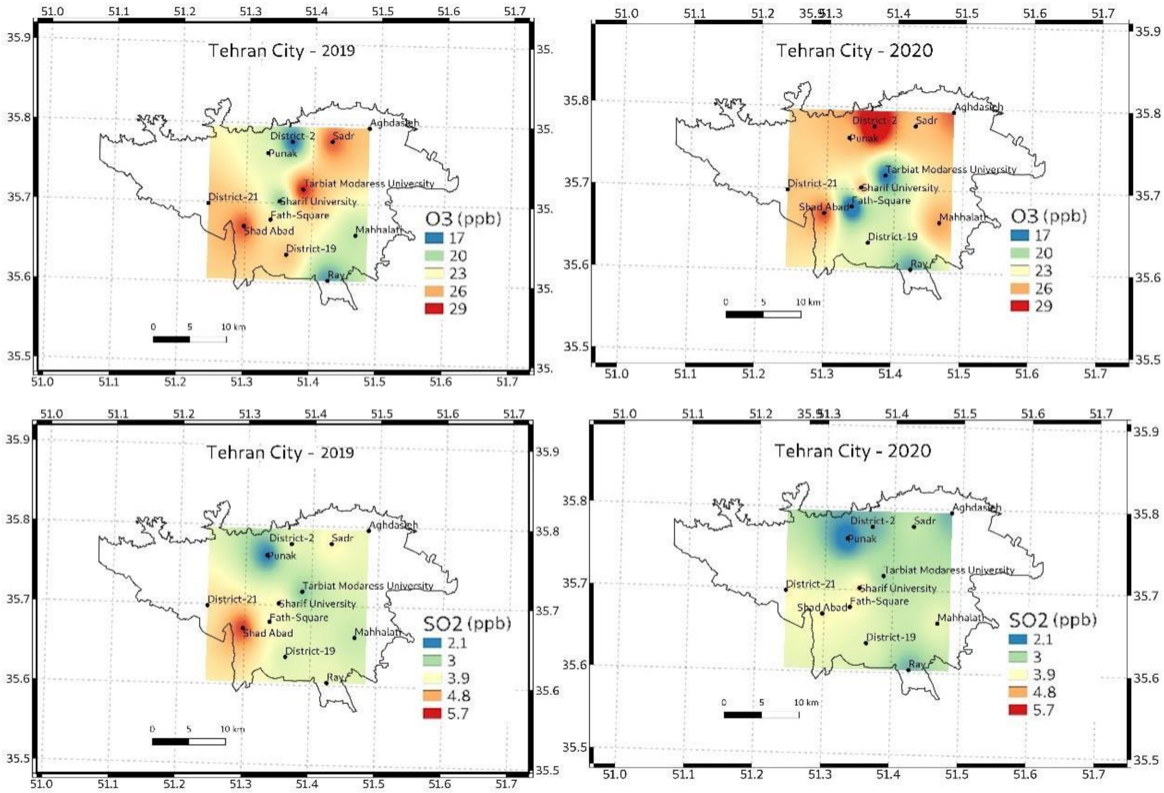

Figure 5. For the period of 21 March to 21 April in 2019 and 2020, the average concentrations of SO_2 (ppb) and O_3 (ppb) at studied stations of the Tehran megacity, Iran, were calculated [132].

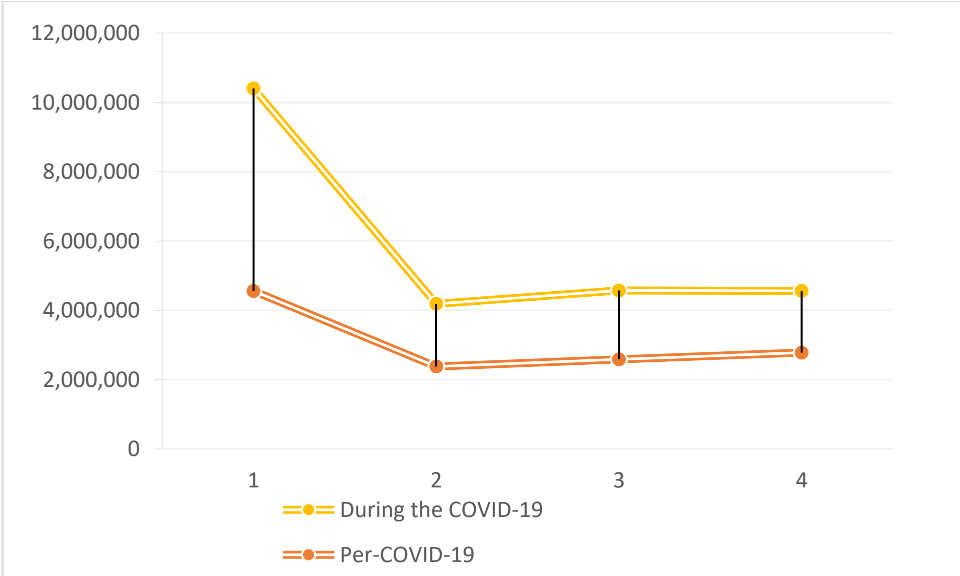

Figure 6. Illustrates the comparison optimization value between pre-COVID-19 and during COVID-19 for the case study.

5. Sensitivity Analysis

5.1. Sensitivity Analysis of the Second Model

In this part, by changing the parameter C^{cap} (carbon cap), we examine how objective function two changed during the outbreak. A base value is considered the same as the existing value (C^{cap} = 20,000 kg) and then increased incrementally. The optimization value of the second objective function is shown in Table 4 by increasing the change in the C^{cap}.

Table 4. The optimization value of the second objective function by increasing change in C^{cap}.

The Optimization Value of the Second Objective Function	Increased Change in C^{cap} %
1,904,412	5%
1,994,500	7%
2,195,650	10%
2,388,600	15%
2,489,900	20%
2,782,180	25%
3,082,990	30%
3,584,410	40%
4,088,811	50%

As shown in Figure 7, different carbon cap policies have different sensitivity analyses based on the second objective value. With the increase in the carbon cap, the costs of the objective value of the second objective value were increased.

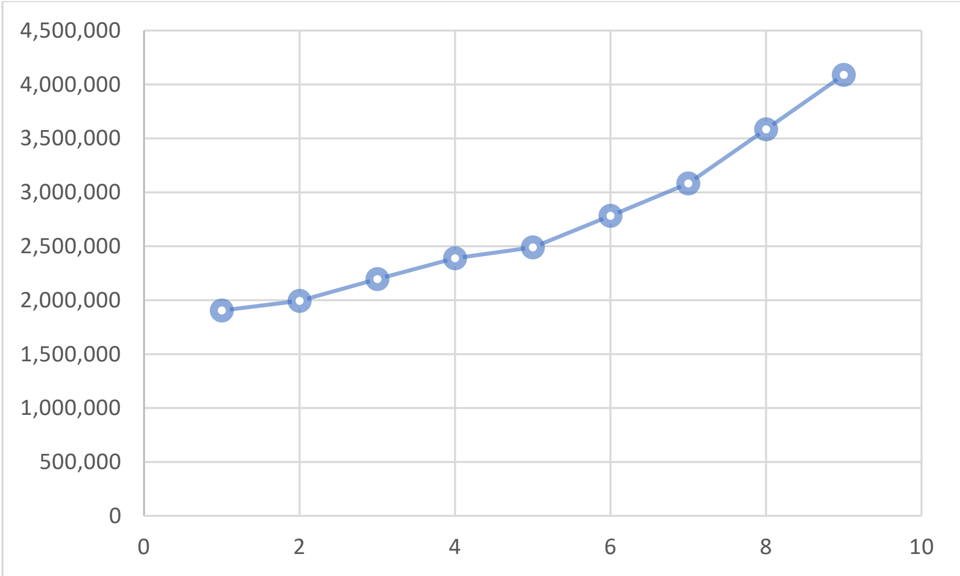

Figure 7. Sensitivity analysis for different carbon cap policies on second objective value.

5.2. Sensitivity Analysis of the Third Model

In this part, by changing the parameter carbon tax, we examine how objective function two changed during the outbreak. A base value is considered the same as the already existing value and then increased step by step. According to Table 5, the third objective function can be optimized by increasing the carbon tax.

Table 5. The optimization value of the third objective function by increasing change in carbon tax.

The Optimization Value of the Third Objective Function	Increased Change in Carbon Tax %
1,994,120	5%
2,091,220	7%
2,193,330	10%
2,495,890	15%
2,692,290	20%
2,701,190	25%
2,988,190	30%
3,284,000	40%
3,799,810	50%

As you can see, with the increase in the carbon tax, supply chain costs will increase. In Figure 8, we show sensitivity analyses for different policies for taxing carbon.

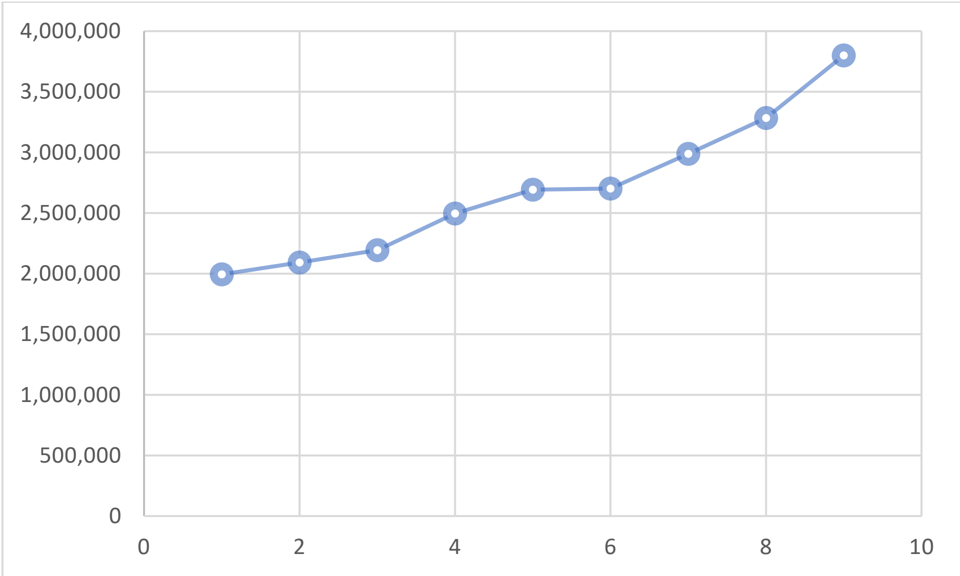

Figure 8. Sensitivity analysis for different carbon tax policies on third objective value.

5.3. Sensitivity Analysis of the Fourth Model

In this part, by changing the parameter cap-and-trade, we examine how objective function two changed during the outbreak. A base value is considered the same as the existing value and then increases slowly.

Based on increasing changes in cap-and-trade, Table 6 shows the optimization value of the third objective function. In Figure 9, sensitivity analysis is shown for different cap-and-trade policies. By increasing cap-and-trade, the optimization value of the third objective function was increased.

Table 6. The optimization value of the third objective function by increasing change in cap-and-trade.

The Optimization Value of the Third Objective Function	Increased Change in Cap-and-Trade %
1,820,220	5%
2,095,550	7%
2,391,240	10%
2,594,400	15%
2,788,890	20%
2,922,190	25%
2,987,177	30%
3,185,050	40%
3,344,899	50%

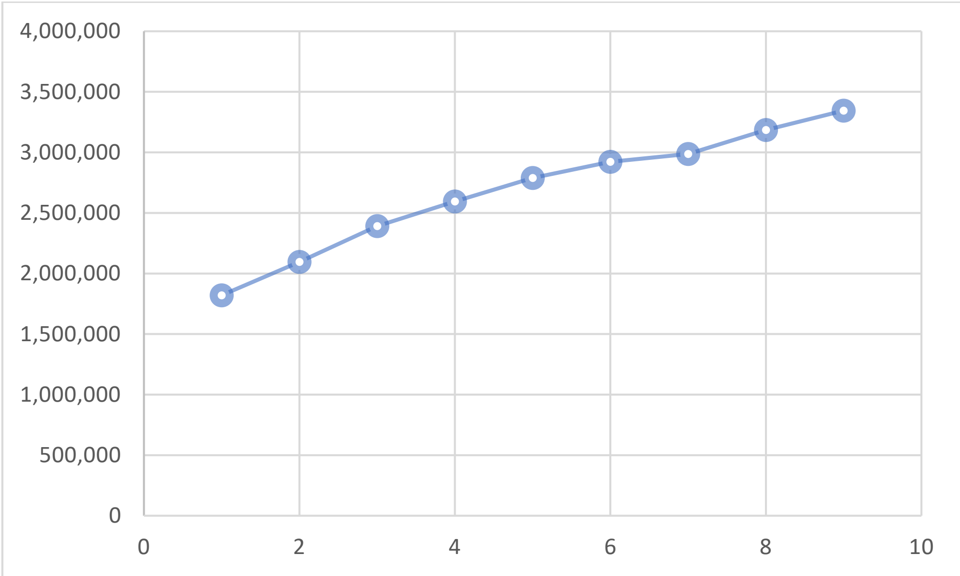

Figure 9. Sensitivity analysis for different cap-and-trade policies on fourth objective value.

6. Practical Ideas and Managerial Consequences

This section illustrates how to obtain valuable insights using the models presented in the previous quarter. Our study offers managerial implications in the following ways:

The results show that with the increase in the carbon tax, the supply chain costs will increase and the number of carbon emissions will decrease. Therefore, managers should look for ways to reduce costs. All the methods mentioned help reduce carbon dioxide emissions. Managers can use the right tools and techniques to maintain the SC's greening. To improve process performance and get accurate estimates, SC managers should identify and address hygiene issues within their organizations during COVID-19. Managers can better understand the reality by comparing the model with several carbon policies during COVID-19.

In order to improve the economic performance of the SC during COVID-19, managers should consider hygienic costs. This study contributes to the performance of managing SC during the COVID-19 and lockdown periods by allowing managers to make informed choices and determine the trade-off between costs and emissions. Workers' health should be considered when collecting hazardous waste.

7. Conclusions and Remarkable Outcomes, Limitations, and Future Works

7.1. Conclusion and Remarkable Outcomes

CLSC models were proposed in order to measure the impact of SC strategic and functional actions on the optimization process. The three most popular carbon policies are examined: carbon tax, carbon cap-and-trade, and strict carbon caps. The model is tested statistically, and the impact of alternative regulations on the supply chain's total cost and CO_2 emissions is examined. As a result, carbon cap regulations impose stringent restrictions on supply chain emissions. The carbon market price and cap allocation have a substantial impact on the cap-and-trade system. Carbon tax regimes provide greater freedom but place enormous financial pressure on firms to meet carbon reduction targets. In order to reach the defined emission limitations, companies and politicians must restore their SCs with respect to operational and strategic decisions.

A GCLSC design problem is presented in this paper. Summary of the paper's findings:

i. Keeping all hygiene guidelines in mind when designing a SC.

ii. Logistics networks should take both economic and environmental factors into account during the COVID-19 outbreak.

iii. An integrated GSC that addresses COVID-19 from two pillars.

iv. A study was conducted to measure the effect of the three carbon rules on GCLSCN during the outbreak.
v. We analyzed COVID-19 pandemic issues within the CLSC using a Multi-Objective Mixed-Integer Programming (MOMIP) model.
vi. A study of the managerial implications of the mathematical model was conducted.
vii. When an outbreak occurs, making decisions about production locations, production technology, and transportation modes is crucial.
viii. A carbon cap, carbon tax, and carbon cap-and-trade policy framework will be used to evaluate SC operations as part of this project.

7.2. Limitations

Due to the lack of database access, articles from other primary sources were impossible to process. There may be insufficient breadth in the utilized keywords. By including the names of developing countries and emerging markets in the search, a thorough analysis of the topic can be accomplished.

7.3. Insights into Future Research Directions

The presented model is capable of being solved by a variety of approaches. The model is open to including other environmental considerations. By incorporating components of social interaction, the original model can be modified to become more robust.

The model needs to include social aspects. A sustainable supply chain can be achieved through it. The stochastic parameters can be added to the model to improve it. A shock to the SC can be attributed to the effects of mortality and the reduction in manpower, as well as COVID-19, on the labor force's productivity and output. In future studies, these factors should be explored with a closer focus on employment than the effects of shocks.

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References

1. Poursoltan, L.; Seyed-Hosseini, S.M.; Jabbarzadeh, A. Green closed-loop supply chain network under the COVID-19 pandemic. *Sustainability* **2021**, *13*, 9407. [CrossRef]
2. Zand, F.; Yaghoubi, S.; Sadjadi, S.J. Impacts of government direct limitation on pricing, greening activities and recycling management in an online to offline closed loop supply chain. *J. Clean. Prod.* **2019**, *215*, 1327–1340. [CrossRef]
3. Su, J.; Li, C.; Zeng, Q.; Yang, J.; Zhang, J. A green closed-loop supply chain coordination mechanism based on third-party recycling. *Sustainability* **2019**, *11*, 5335. [CrossRef]
4. Herrmann, F.F.; Barbosa-Povoa, A.P.; Butturi, M.A.; Marinelli, S.; Sellitto, M.A. Green supply chain management: Conceptual framework and models for analysis. *Sustainability* **2021**, *13*, 8127. [CrossRef]
5. UNFCCC. Kyoto Protocol. 1997. Available online: http://unfccc.int/kyoto_protocol/items/2830.php/ (accessed on 20 December 2022).
6. EU ETS. Emissions Trading System. 2009. Available online: http://ec.europa.eu/clima/policies/ets/index_en.htm (accessed on 18 December 2022).
7. The Kyoto Protocol-Status of Ratification. Available online: http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php (accessed on 12 December 2022).
8. Farooq, M.U.; Hussain, A.; Masood, T.; Habib, M.S. Supply chain operations management in pandemics: A state-of-the-art review inspired by COVID-19. *Sustainability* **2021**, *13*, 2504. [CrossRef]

9. Zhao, H.; Zhang, H.; Xu, Y.; Lu, J.; He, W. Relation between awe and environmentalism: The role of social dominance orientation. *Front. Psychol.* **2018**, *9*, 2367. [CrossRef]
10. Myllyvirta, L. Coronavirus Has Temporarily Reduced China's CO_2 Emissions by a Quarter. Carbon Brief. Retrieved (2020). Available online: https://www.carbonbrief.org/analysis-coronavirus-hastempo-rarily-reduced-chinas-CO2-emissions-by-a-quarter (accessed on 21 December 2022).
11. ECIU (2021), Net Zero Emissions Race-2021. Scorecard. Available online: https://eciu.net/netzerotracker (accessed on 19 August 2021).
12. Towards a Sustainable Recovery? Carbon Pricing Policy Changes during COVID-19. Available online: https://www.oecd.org/coronavirus/policy-responses/towards-a-sustainable-recovery-carbon-pricing-policy-changes-during-covid-19-92464d20/ (accessed on 21 December 2022).
13. Paksoy, T.; Bektaş, T.; Özceylan, E. Operational and environmental performance measures in a multi-product closed-loop supply chain. *Transp. Res. Part E Logist. Transp. Rev.* **2011**, *47*, 532–546. [CrossRef]
14. Fahimnia, B.; Sarkis, J.; Boland, J.; Reisi, M.; Goh, M. Policy insights from a green supply chain optimization model. *Int. J. Prod. Res.* **2015**, *53*, 6522–6533. [CrossRef]
15. Zakeri, A.; Dehghanian, F.; Fahimnia, B.; Sarkis, J. Carbon pricing versus emissions trading: A supply chain planning perspective. *Int. J. Prod. Econ.* **2015**, *164*, 197–205. [CrossRef]
16. Marufuzzaman, M.; Ekşioğlu, S.D.; Hernandez, R. Environmentally friendly supply chain planning and design for biodiesel production via wastewater sludge. *Transp. Sci.* **2014**, *48*, 555–574. [CrossRef]
17. Peng, Y.; Ablanedo-Rosas, J.H.; Fu, P. A multi-period supply chain network design considering carbon emissions. *Math. Probl. Eng.* **2016**, *2016*, 1581893. [CrossRef]
18. Liu, Z.; Hu, B.; Zhao, Y.; Lang, L.; Guo, H.; Florence, K.; Zhang, S. Research on an intelligent decision of low carbon supply chain based on carbon tax constraints in human-driven edge computing. *IEEE Access* **2020**, *8*, 48264–48273. [CrossRef]
19. Fahimnia, B.; Sarkis, J.; Choudhary, A.; Eshragh, A. Tactical supply chain planning under a carbon tax policy scheme: A case study. *Int. J. Prod. Econ.* **2015**, *164*, 206–215. [CrossRef]
20. Cao, K.; He, P.; Liu, Z. Production and pricing decisions in a dual-channel supply chain under remanufacturing subsidy policy and carbon tax policy. *J. Oper. Res. Soc.* **2020**, *71*, 1199–1215. [CrossRef]
21. Cheng, P.; Ji, G.; Zhang, G.; Shi, Y. A closed-loop supply chain network considering consumer's low carbon preference and carbon tax under the cap-and-trade regulation. *Sustain. Prod. Consum.* **2022**, *29*, 614–635. [CrossRef]
22. Xu, S.; Fang, L.; Govindan, K. Energy performance contracting in a supply chain with financially asymmetric manufacturers under carbon tax regulation for climate change mitigation. *Omega* **2022**, *106*, 102535. [CrossRef]
23. Zhou, Y.; Hu, F.; Zhou, Z. Pricing decisions and social welfare in a supply chain with multiple competing retailers and carbon tax policy. *J. Clean. Prod.* **2018**, *190*, 752–777. [CrossRef]
24. Wang, L.; Xu, T.; Qin, L. A Study on supply chain emission reduction level based on carbon tax and consumers' Low-carbon preferences under stochastic demand. *Math. Probl. Eng.* **2019**, *2019*, 1621395. [CrossRef]
25. Konstantaras, I.; Skouri, K.; Benkherouf, L. Optimizing inventory decisions for a closed–loop supply chain model under a carbon tax regulatory mechanism. *Int. J. Prod. Econ.* **2021**, *239*, 108185. [CrossRef]
26. Government Canada. *Turning the Corner: Regulatory Framework for Industrial Greenhouse Gas Emissions*; Monograph, Environment Canada: Ottawa, ON, Canada, 2008.
27. Zhou, Y.; Gong, D.C.; Huang, B.; Peters, B.A. The impacts of carbon tariff on green supply chain design. *IEEE Trans. Autom. Sci. Eng.* **2015**, *14*, 1542–1555. [CrossRef]
28. Alkahtani, M.; Ziout, A.; Salah, B.; Alatefi, M.; Abd Elgawad AE, E.; Badwelan, A.; Syarif, U. An insight into reverse logistics with a focus on collection systems. *Sustainability* **2021**, *13*, 548. [CrossRef]
29. Mirzapour Al-e-hashem, S.M.J.; Baboli, A.; Sazvar, Z. A stochastic aggregate production planning model in a green supply chain: Considering flexible lead times, nonlinear purchase and shortage cost functions. *Eur. J. Oper. Res.* **2013**, *230*, 26–41. [CrossRef]
30. Choudhary, A.; Sarkar, S.; Settur, S.; Tiwari, M.K. A carbon market sensitive optimization model for integrated forward—Reverse logistics. *Int. J. Prod. Econ.* **2015**, *164*, 433–444. [CrossRef]
31. Fareeduddin, M.; Hassan, A.; Syed, M.N.; Selim, S.Z. The impact of carbon policies on closed-loop supply chain network design. *Procedia CIRP* **2015**, *26*, 335–340. [CrossRef]
32. Soleimani, H.; Govindan, K.; Saghafi, H.; Jafari, H. Fuzzy multi-objective sustainable and green closed-loop supply chain network design. *Comput. Ind. Eng.* **2017**, *109*, 191–203. [CrossRef]
33. Martí, J.M.C.; Tancrez, J.S.; Seifert, R.W. Carbon footprint and responsiveness trade-offs in supply chain network design. *Int. J. Prod. Econ.* **2015**, *166*, 129–142. [CrossRef]
34. Xu, Z.; Pokharel, S.; Elomri, A.; Mutlu, F. Emission policies and their analysis for the design of hybrid and dedicated closed-loop supply chains. *J. Clean. Prod.* **2017**, *142*, 4152–4168. [CrossRef]
35. Benjaafar, S.; Li, Y.; Daskin, M. Carbon footprint and the management of supply chains: Insights from simple models. *IEEE Trans. Autom. Sci. Eng.* **2012**, *10*, 99–116. [CrossRef]
36. Zhang, G.; Sun, H.; Hu, J.; Dai, G. The closed-loop supply chain network equilibrium with products lifetime and carbon emission constraints in multiperiod planning horizon. *Discret. Dyn. Nat. Soc.* **2014**, *2014*, 784637. [CrossRef]

37. Hammami, R.; Nouira, I.; Frein, Y. Carbon emissions in a multi-echelon production-inventory model with lead time constraints. *Int. J. Prod. Econ.* **2015**, *164*, 292–307. [CrossRef]
38. Tao, Z.G.; Guang, Z.Y.; Hao, S.; Song, H.J. Multi-period closed-loop supply chain network equilibrium with carbon emission constraints. *Resour. Conserv. Recycl.* **2015**, *104*, 354–365. [CrossRef]
39. Ding, H.; Zhao, Q.; An, Z.; Tang, O. Collaborative mechanism of a sustainable supply chain with environmental constraints and carbon caps. *Int. J. Prod. Econ.* **2016**, *181*, 191–207. [CrossRef]
40. Diabat, A.; Simchi-Levi, D. A carbon-capped supply chain network problem. In Proceedings of the 2009 IEEE International Conference on Industrial Engineering and Engineering Management; Hong Kong, China, 2009; pp. 523–527.
41. Qi, Q.; Wang, J.; Bai, Q. Pricing decision of a two-echelon supply chain with one supplier and two retailers under a carbon cap regulation. *J. Clean. Prod.* **2017**, *151*, 286–302. [CrossRef]
42. Zhang, S.; Wang, C.; Yu, C.; Ren, Y. Governmental cap regulation and manufacturer's low carbon strategy in a supply chain with different power structures. *Comput. Ind. Eng.* **2019**, *134*, 27–36. [CrossRef]
43. Ji, J.; Zhang, Z.; Yang, L. Comparisons of initial carbon allowance allocation rules in an O2O retail supply chain with the cap-and-trade regulation. *Int. J. Prod. Econ.* **2017**, *187*, 68–84. [CrossRef]
44. Cadavid-Giraldo, N.; Velez-Gallego, M.C.; Restrepo-Boland, A. Carbon emissions reduction and financial effects of a cap and tax system on an operating supply chain in the cement sector. *J. Clean. Prod.* **2020**, *275*, 122583. [CrossRef]
45. Wang, M.; Zhao, L.; Herty, M. Modelling carbon trading and refrigerated logistics services within a fresh food supply chain under carbon cap-and-trade regulation. *Int. J. Prod. Res.* **2018**, *56*, 4207–4225. [CrossRef]
46. Kushwaha, S.; Ghosh, A.; Rao, A.K. Collection activity channels selection in a reverse supply chain under a carbon cap-and-trade regulation. *J. Clean. Prod.* **2020**, *260*, 121034. [CrossRef]
47. Astanti, R.D.; Daryanto, Y.; Dewa, P.K. Low-carbon supply chain model under a vendor-managed inventory partnership and carbon cap-and-trade policy. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 30. [CrossRef]
48. Xia, L.; Guo, T.; Qin, J.; Yue, X.; Zhu, N. Carbon emission reduction and pricing policies of a supply chain considering reciprocal preferences in cap-and-trade system. *Ann. Oper. Res.* **2018**, *268*, 149–175. [CrossRef]
49. Wang, Z.; Wu, Q. Carbon emission reduction and product collection decisions in the closed-loop supply chain with cap-and-trade regulation. *Int. J. Prod. Res.* **2021**, *59*, 4359–4383. [CrossRef]
50. Ghosh, A.; Sarmah, S.P.; Kanauzia, R.K. The effect of investment in green technology in a two echelon supply chain under strict carbon-cap policy. *Benchmarking Int. J.* **2020**, *27*, 1875–1891. [CrossRef]
51. Ghosh, S.K.; Seikh, M.R.; Chakrabortty, M. Analyzing a stochastic dual-channel supply chain under consumers' low carbon preferences and cap-and-trade regulation. *Comput. Ind. Eng.* **2020**, *149*, 106765. [CrossRef]
52. Wang, X.; Xue, M.; Xing, L. Analysis of carbon emission reduction in a dual-channel supply chain with cap-and-trade regulation and low-carbon preference. *Sustainability* **2018**, *10*, 580. [CrossRef]
53. Yang, Y.; Goodarzi, S.; Bozorgi, A.; Fahimnia, B. Carbon cap-and-trade schemes in closed-loop supply chains: Why firms do not comply? *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *156*, 102486. [CrossRef]
54. Mishra, M.; Hota, S.K.; Ghosh, S.K.; Sarkar, B. Controlling waste and carbon emission for a sustainable closed-loop supply chain management under a cap-and-trade strategy. *Mathematics* **2020**, *8*, 466. [CrossRef]
55. Tang, R.; Yang, L. Impacts of financing mechanism and power structure on supply chains under cap-and-trade regulation. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *139*, 101957. [CrossRef]
56. Office of Air Quality Planning and Standards, US Environmental Protection Agency. *The Plain English Guide to the Clean Air Act*; Publication No. EPA-456/K-07–001; Environmental Protection Agency: Washington, DC, USA, 2007.
57. Palak, G. *Optimization Models for Cost Efficient and Environmentally Friendly Supply Chain Management*; Mississippi State University: Starkvill, MI, USA, 2013.
58. US EPA. *U.S. Transportation Sector Greenhouse Gas Emissions: 1990–2011*; Office of Transportation and Air Quality: Washington, DC, USA, 2013.
59. Xu, X.; Zhang, W.; He, P.; Xu, X. Production and pricing problems in make-to-order supply chain with cap-and-trade regulation. *Omega* **2017**, *66*, 248–257. [CrossRef]
60. Wang, X.; Sethi, S.P.; Chang, S. Pollution abatement using cap-and-trade in a dynamic supply chain and its coordination. *Transp. Res. Part E Logist. Transp. Rev.* **2022**, *158*, 102592. [CrossRef]
61. Rezaee, A.; Dehghanian, F.; Fahimnia, B.; Beamon, B. Green supply chain network design with stochastic demand and carbon price. *Ann. Oper. Res.* **2017**, *250*, 463–485. [CrossRef]
62. Oh, J.; Jeong, B. Profit analysis and supply chain planning model for closed-loop supply chain in fashion industry. *Sustainability* **2014**, *6*, 9027–9056. [CrossRef]
63. Kannegiesser, M.; Günther, H.O.; Gylfason, Ó. Sustainable development of global supply chains—Part 2: Investigation of the European automotive industry. *Flex. Serv. Manuf. J.* **2014**, *26*, 48–68. [CrossRef]
64. Baud-Lavigne, B.; Agard, B.; Penz, B. Environmental constraints in joint product and supply chain design optimization. *Comput. Ind. Eng.* **2014**, *76*, 16–22. [CrossRef]
65. Mohammed, F.; Selim, S.Z.; Hassan, A.; Syed, M.N. Multi-period planning of closed-loop supply chain with carbon policies under uncertainty. *Transp. Res. Part D Transp. Environ.* **2017**, *51*, 146–172. [CrossRef]

66. Xu, X.; He, P.; Xu, H.; Zhang, Q. Supply chain coordination with green technology under cap-and-trade regulation. *Int. J. Prod. Econ.* **2017**, *183*, 433–442. [CrossRef]
67. Yang, L.; Hu, Y.; Huang, L. Collecting mode selection in a remanufacturing supply chain under cap-and-trade regulation. *Eur. J. Oper. Res.* **2020**, *287*, 480–496. [CrossRef]
68. Kannan, D.; Diabat, A.; Alrefaei, M.; Govindan, K.; Yong, G. A carbon footprint based reverse logistics network design model. *Resour. Conserv. Recycl.* **2012**, *67*, 75–79. [CrossRef]
69. Diabat, A.; Abdallah, T.; Al-Refaie, A.; Svetinovic, D.; Govindan, K. Strategic closed-loop facility location problem with carbon market trading. *IEEE Trans. Eng. Manag.* **2012**, *60*, 398–408. [CrossRef]
70. Chaabane, A.; Ramudhin, A.; Paquet, M. Designing supply chains with sustainability considerations. *Prod. Plan. Control* **2011**, *22*, 727–741. [CrossRef]
71. Abdallah, T.; Diabat, A.; Rigter, J. Investigating the option of installing small-scale PVs on facility rooftops in a green supply chain. *Int. J. Prod. Econ.* **2013**, *146*, 465–477. [CrossRef]
72. Lewczuk, K.; Kłodawski, M.; Gepner, P. Energy consumption in a distributional warehouse: A practical case study for different warehouse technologies. *Energies* **2021**, *14*, 2709. [CrossRef]
73. He, B.; Wang, J.; Huang, S.; Wang, Y. Low-carbon product design for product life cycle. *J. Eng. Des.* **2015**, *26*, 321–339. [CrossRef]
74. Wu, H.; Sun, Y.; Su, Y.; Chen, M.; Zhao, H.; Li, Q. Which Is the Best Supply Chain Policy: Carbon Tax, or a Low-Carbon Subsidy? *Sustainability* **2022**, *14*, 6312. [CrossRef]
75. Mintz-Woo, K.; Dennig, F.; Liu, H.; Schinko, T. Carbon pricing and COVID-19. *Clim. Policy* **2021**, *21*, 1272–1280. [CrossRef]
76. Entezaminia, A.; Heidari, M.; Rahmani, D. Robust aggregate production planning in a green supply chain under uncertainty considering reverse logistics: A case study. *Int. J. Adv. Manuf. Technol.* **2017**, *90*, 1507–1528. [CrossRef]
77. Xu, L.; Wang, C.; Zhao, J. Decision and coordination in the dual-channel supply chain considering cap-and-trade regulation. *J. Clean. Prod.* **2018**, *197*, 551–561. [CrossRef]
78. Du, S.; Zhu, L.; Liang, L.; Ma, F. Emission-dependent supply chain and environment-policy-making in the 'cap-and-trade system. *Energy Policy* **2013**, *57*, 61–67. [CrossRef]
79. Xu, X.; Choi, T.M. Supply chain operations with online platforms under the cap-and-trade regulation: Impacts of using blockchain technology. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *155*, 102491. [CrossRef]
80. Li, Z.; Pan, Y.; Yang, W.; Ma, J.; Zhou, M. Effects of government subsidies on green technology investment and green marketing coordination of supply chain under the cap-and-trade mechanism. *Energy Econ.* **2021**, *101*, 105426. [CrossRef]
81. Du, S.; Ma, F.; Fu, Z.; Zhu, L.; Zhang, J. Game-theoretic analysis for an emission-dependent supply chain in a 'cap-and-trade system. *Ann. Oper. Res.* **2015**, *228*, 135–149. [CrossRef]
82. Taleizadeh, A.A.; Shahriari, M.; Sana, S.S. Pricing and coordination strategies in a dual channel supply chain with green production under cap and trade regulation. *Sustainability* **2021**, *13*, 12232. [CrossRef]
83. Bai, Q.; Xu, J.; Zhang, Y. Emission reduction decision and coordination of a make-to-order supply chain with two products under cap-and-trade regulation. *Comput. Ind. Eng.* **2018**, *119*, 131–145. [CrossRef]
84. Kuiti, M.R.; Ghosh, D.; Basu, P.; Bisi, A. Do cap-and-trade policies drive environmental and social goals in supply chains: Strategic decisions, collaboration, and contract choices. *Int. J. Prod. Econ.* **2020**, *223*, 107537. [CrossRef]
85. Tong, W.; Mu, D.; Zhao, F.; Mendis, G.P.; Sutherland, J.W. The impact of cap-and-trade mechanism and consumers' environmental preferences on a retailer-led Supply Chain. *Resour. Conserv. Recycl.* **2019**, *142*, 88–100. [CrossRef]
86. Golpîra, H.; Zandieh, M.; Najafi, E.; Sadi-Nezhad, S. A multi-objective multi-echelon green supply chain network design problem with risk-averse retailers in an uncertain environment. *Sci. Iran.* **2017**, *24*, 413–423. [CrossRef]
87. Carmody, C. A guide to emissions trading under the Western Climate Initiative. *Can.-USLJ* **2019**, *43*, 148.
88. Chaabane, A.; Ramudhin, A.; Paquet, M. Design of sustainable supply chains under the emission trading scheme. *Int. J. Prod. Econ.* **2012**, *135*, 37–49. [CrossRef]
89. Xu, J.; Chen, Y.; Bai, Q. A two-echelon sustainable supply chain coordination under cap-and-trade regulation. *J. Clean. Prod.* **2016**, *135*, 42–56. [CrossRef]
90. Shaw, K.; Irfan, M.; Shankar, R.; Yadav, S.S. Low carbon chance constrained supply chain network design problem: A Benders decomposition-based approach. *Comput. Ind. Eng.* **2016**, *98*, 483–497. [CrossRef]
91. Arampantzi, C.; Minis, I. A new model for designing sustainable supply chain networks and its application to a global manufacturer. *J. Clean. Prod.* **2017**, *156*, 276–292. [CrossRef]
92. Giarola, S.; Shah, N.; Bezzo, F. A comprehensive approach to the design of ethanol supply chains including carbon trading effects. *Bioresour. Technol.* **2012**, *107*, 175–185. [CrossRef] [PubMed]
93. Abdallah, T.; Diabat, A.; Simchi-Levi, D. A carbon-sensitive supply chain network problem with green procurement. In Proceedings of the 40th International Conference on Computers & Industrial Engineering, Awaji, Japan, 25–28 July 2010; pp. 1–6.
94. Memari, Y.; Memari, A.; Ebrahimnejad, S.; Ahmad, R. A mathematical model for optimizing a biofuel supply chain with outsourcing decisions under the carbon trading mechanism. *Biomass Convers. Biorefinery* **2021**, *13*, 1047–1070. [CrossRef]
95. Abbasi, S.; Daneshmand-Mehr, M.; Ghane Kanafi, A. Designing Sustainable Recovery Network of End-of-Life Product during the COVID-19 Pandemic: A Real and Applied Case Study. *Discret. Dyn. Nat. Soc.* **2022**, *2022*, 6967088. [CrossRef]
96. Abbasi, S.; Daneshmand-Mehr, M.; Ghane Kanafi, A. The sustainable supply chain of CO_2 emissions during the coronavirus disease (COVID-19) pandemic. *J. Ind. Eng. Int.* **2021**, *17*, 83–108. [CrossRef]

97. Abbasi, S.; Daneshmand-Mehr, M.; Ghane Kanafi, A. Green Closed-Loop Supply Chain Network Design During the Coronavirus (COVID-19) Pandemic: A Case Study in the Iranian Automotive Industry. *Environ. Model Assess* **2023**, *28*, 69–103. [CrossRef]
98. Wang, Y.; Yu, Z.; Jin, M.; Mao, J. Decisions and coordination of retailer-led low-carbon supply chain under altruistic preference. *Eur. J. Oper. Res.* **2021**, *293*, 910–925. [CrossRef]
99. Wang, Y.; Lv, L.; Shen, L.; Tang, R. Manufacturer's decision-making model under carbon emission permits repurchase strategy and capital constraints. *Int. J. Prod. Res.* **2021**, 1–19. [CrossRef]
100. Abbasi, S.; Khalili, H.A.; Daneshmand-Mehr, M.; Hajiaghaei-Keshteli, M. Performance Measurement of the Sustainable Supply Chain During the COVID-19 Pandemic: A real-life case study. *Found. Comput. Decis. Sci.* **2022**, *47*, 327–358. [CrossRef]
101. Abbasi, S.; Daneshmand-Mehr, M.; Ghane, K. Designing a Tri-Objective, Sustainable, Closed-Loop, and Multi-Echelon Supply Chain During the COVID-19 and Lockdowns. *Found. Comput. Decis. Sci.* **2023**, *48*.
102. Luo, R.; Zhou, L.; Song, Y.; Fan, T. Evaluating the impact of carbon tax policy on manufacturing and remanufacturing decisions in a closed-loop supply chain. *Int. J. Prod. Econ.* **2022**, *245*, 108408. [CrossRef]
103. Liu, C.; Chen, X. The Third Coming of China's Special Economic Zones: The Rise and Regional Dimensions of Tianjin Binhai New Area. In *Rethinking Global Urbanism*; Routledge: London, UK, 2012; pp. 145–167.
104. Pourmalek, F.; Rezaei Hemami, M.; Janani, L.; Moradi-Lakeh, M. Rapid review of COVID-19 epidemic estimation studies for Iran. *BMC Public Health* **2021**, *21*, 257. [CrossRef]
105. Ayyoubzadeh, S.M.; Ayyoubzadeh, S.M.; Zahedi, H.; Ahmadi, M.; Kalhori, S.R.N. Predicting COVID-19 incidence through analysis of google trends data in Iran: Data mining and deep learning pilot study. *JMIR Public Health Surveill.* **2020**, *6*, e18828. [CrossRef]
106. Gerard, D.; Lave, L.B. Implementing technology-forcing policies: The 1970 Clean Air Act Amendments and the introduction of advanced automotive emissions controls in the United States. *Technol. Forecast. Soc. Chang.* **2005**, *72*, 761–778. [CrossRef]
107. Xiao, Y.; Raheem, A.; Ding, L.; Chen, W.H.; Chen, X.; Wang, F.; Lin, S.L. Pretreatment, modification and applications of sewage sludge-derived bio char for resource recovery-A review. *Chemosphere* **2022**, *287*, 131969. [CrossRef]
108. Mishra, U.; Wu, J.Z.; Sarkar, B. Optimum sustainable inventory management with backorder and deterioration under controllable carbon emissions. *J. Clean. Prod.* **2021**, *279*, 123699. [CrossRef]
109. Ghafari, M.; Hejazi, B.; Karshenas, A.; Dascalu, S.; Kadvidar, A.; Khosravi, M.A.; Katzourakis, A. Lessons for preparedness and reasons for concern from the early COVID-19 epidemic in Iran. *Epidemics* **2021**, *36*, 100472. [CrossRef]
110. Hatamabadi, H.; Sabaghian, T.; Sadeghi, A.; Heidari, K.; Safavi-Naini SA, A.; Looha, M.A.; Sahebkar, A. Epidemiology of COVID-19 in Tehran, Iran: A Cohort Study of Clinical Profile, Risk Factors, and Outcomes. *BioMed Res. Int.* **2022**, *2022*, 2350063. [CrossRef]
111. Waltho, C.; Elhedhli, S.; Gzara, F. Green supply chain network design: A review focused on policy adoption and emission quantification. *Int. J. Prod. Econ.* **2019**, *208*, 305–318. [CrossRef]
112. Babagolzadeh, M.; Shrestha, A.; Abbasi, B.; Zhang, Y.; Woodhead, A.; Zhang, A. Sustainable cold supply chain management under demand uncertainty and carbon tax regulation. *Transp. Res. Part D Transp. Environ.* **2020**, *80*, 102245. [CrossRef]
113. Bai, Q.; Xu, J.; Chauhan, S.S. Effects of sustainability investment and risk aversion on a two-stage supply chain coordination under a carbon tax policy. *Comput. Ind. Eng.* **2020**, *142*, 106324. [CrossRef]
114. Zou, F.; Zhou, Y.; Yuan, C. The impact of retailers' low-carbon investment on the supply chain under carbon tax and carbon trading policies. *Sustainability* **2020**, *12*, 3597. [CrossRef]
115. Lang, L.; Liu, Z.; Hu, B. Optimization decision of cooperative emission reduction of clothing supply chain based on the carbon tax. *J. Phys. Conf. Ser.* **2021**, *1790*, 012092. [CrossRef]
116. Liu, Z.; Lang, L.; Hu, B.; Shi, L.; Huang, B.; Zhao, Y. Emission reduction decision of agricultural supply chain considering carbon tax and investment cooperation. *J. Clean. Prod.* **2021**, *294*, 126305. [CrossRef]
117. Zhang, H.; Li, P.; Zheng, H.; Zhang, Y. Impact of a carbon tax on enterprise operation and production strategy for low-carbon products in a co-opetition supply chain. *J. Clean. Prod.* **2021**, *287*, 125058. [CrossRef]
118. Guo, J.; Xi, M. Greening, Pricing, and Marketing Coordination for a Complex Three-Level Supply Chain Under the Carbon Tax in China. *IEEE Access* **2022**, *10*, 76895–76905. [CrossRef]
119. Meng, C.; Zhang, R.; Liu, B. Energy Performance Contracting in a Supply Chain under Cap-and-Trade Regulation and Carbon Tax Policy. *Int. Trans. Elector. Energy Syst.* **2022**, *2022*, 1716380. [CrossRef]
120. Zhu, X.; Ding, L.; Guo, Y.; Zhu, H. Decisions and Coordination of Dual-Channel Supply Chain considering Retailers' Bidirectional Fairness Concerns under Carbon Tax Policy. *Math. Probl. Eng.* **2022**, *2022*, 4139224. [CrossRef]
121. Hu, Z.H.; Wang, S.W. An Evolutionary Game Model Between Governments and Manufacturers Considering Carbon Taxes, Subsidies, and Consumers' Low-Carbon Preference. *Dyn. Games Appl.* **2022**, *12*, 513–551. [CrossRef]
122. Zhang, Y.; Zhang, T. Dynamic analysis of a dual-channel closed-loop supply chain with fairness concerns under carbon tax regulation. *Environ. Sci. Pollut. Res.* **2022**, *29*, 57543–57565. [CrossRef]
123. Paul, A.; Pervin, M.; Roy, S.K.; Maculan, N.; Weber, G.W. A green inventory model with the effect of carbon taxation. *Ann. Oper. Res.* **2022**, *309*, 233–248. [CrossRef]
124. Shi, S.; Liu, G. Pricing and coordination decisions in a low-carbon supply chain with risk aversion under a carbon tax. *Math. Probl. Eng.* **2022**, *2022*, 7690136. [CrossRef]

125. Shen, L.; Lin, F.; Cheng, T.C.E. Low-Carbon Transition Models of High Carbon Supply Chains under the Mixed Carbon Cap-and-Trade and Carbon Tax Policy in the Carbon Neutrality Era. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11150. [CrossRef]
126. Yu, W.; Wang, Y.; Feng, W.; Bao, L.; Han, R. Low carbon strategy analysis with two competing supply chain considering carbon taxation. *Comput. Ind. Eng.* **2022**, *169*, 108203. [CrossRef]
127. Lyu, S.; Chen, Y.; Wang, L. Optimal Decisions in a Multi-Party Closed-Loop Supply Chain Considering Green Marketing and Carbon Tax Policy. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9244. [CrossRef]
128. Chen, L.; Zhao, J.; Zhao, J.; Li, F.; Yang, Y. A Supply Chain Model Based on Data-Driven Demand Uncertainty under the Influence of Carbon Tax Policy. *Mob. Inf. Syst.* **2022**, *2022*, 5960949. [CrossRef]
129. Wei, Z.; Huang, Y. Supply Chain Coordination under Carbon Emission Tax Regulation Considering Greening Technology Investment. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9232. [CrossRef]
130. Luo, R.; Chang, H.; Zhang, D. Carbon Emission Reduction and Pricing Decisions of Dual-Channel Closed-Loop Supply Chain with Fairness Concern Under Carbon Tax Policy. *Int. J. Econ. Financ. Manag. Sci.* **2022**, *10*, 102. [CrossRef]
131. Yi, Y.; Wang, Y.; Fu, C.; Li, Y. Taxes or subsidies to promote investment in green technologies for a supply chain considering consumer preferences for green products. *Comput. Ind. Eng.* **2022**, *171*, 108371. [CrossRef]
132. Broomandi, P.; Karaca, F.; Nikfal, A.; Jahanbakhshi, A.; Tamjidi, M.; Kim, J.R. Impact of COVID-19 event on the air quality in Iran. *Aerosol Air Qual. Res.* **2020**, *20*, 1793–1804. [CrossRef]