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RESEARCH PAPER

A Resilient-Sustainable SCND Using Multiple Sourcing and Backup Facility Strategies in Iran's Broiler Network

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Abstract

Today's food supply chains are increasingly vulnerable to uncertainties in both supply and demand, as well as unexpected disruptions. Broiler supply chains, among the most vital globally, are no exception. To address this, the proposed model for this essential product, spanning five tiers and covering 31 states, incorporates resilience strategies such as backup facilities and multiple sourcing. The model utilizes bi-objective, multi-period, and multi-product mixed-integer linear programming to account for all three pillars of sustainability. The primary objectives are to maximize total supply chain profit while minimizing carbon dioxide (CO_2) emissions from transportation. Real-world deterministic data is imported into the model, which is solved using General Algebraic Modeling System (GAMS) software. The ε-constraint method is employed to generate Pareto-optimal solutions for the competing objectives. Additionally, validation and sensitivity analysis are conducted on key parameters within reasonable ranges. The results demonstrate an enhanced network that is both more profitable and less environmentally harmful.

Keywords:
Broiler Supply Chain; Integrated Supply Chain Network Design; Resiliency; Sustainability

Introduction

According to the research gap, supply chain (SC) networks are currently facing disruption risk, environmental change, and social legislation. As a result, they must find a way to deal with the world's uncertainties and changes, and the simultaneous implementation of sustainability regulations and resilience techniques is a quick and convenient way to navigate this perilous path. Recently, it has been discovered that sustainability is intertwined with resiliency and stakeholder interests to ensure long-term SC performance (Govindan et al. 2016)0. SC networks must develop resiliency plans to deal with disruptions, which are a type of risk with multiple triggers, such as changes in laws, sanctions, transportation disruptions, and so on. Sustainability is concerned with the long-term survival of the system (Katiar et al. 2018), whereas resilience increases the longevity of corporations by dealing with disruptions. Sustainability, from a

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managerial standpoint, seeks the optimal administration of human and environmental assistance, as well as financial considerations, whereas resilience is the ability to return to the initial state or reach even more promising circumstances following a disturbance (Christopher and Peck 2004). Another advantage of combining sustainability and resilience is the creation of value (Govindan et al. 2016).

Because every industry is vulnerable and constrained, the degree of trade-off between resiliency and sustainability may differ depending on the characteristics of each industry (Mehrjerdi and Shafiee 2020). Due to the high perishability and limited shelf life of fresh food and fruit products, food supply chain management is critical in managing increased food demand. Furthermore, unlike other products, product quality degrades continuously during downstream activities in the SC. As a result, dealing with food supply chain networks is complicated due to the variety of products used in these networks. One of the main goals of these supply chains (SCs) is to pay attention to the freshness and delivery of perishable products in the food supply and distribution chains. This problem has a direct impact on the responsiveness of the integrated network. Furthermore, because of their sensitivity to time, product value decreases over time. Choosing a good distribution network based on these facts is a critical factor for a logistics system manager. As a result, in the food supply chain, the emphasis is on the quality of the goods, and attention should be paid to minimizing shipping time or maximizing product quality during delivery time (Musavi and Bozorgi-Amiri 2017).

As a result, the integrated perishable supply chain of chicken meat has been chosen as the case study for the problem in this paper to investigate the relationships between resilience and sustainability. Meat chicken (broiler) contributes significantly to society's need for animal protein as an essential and nutritious protein material. Currently, despite the fact that numerous poultry farming units are being developed on a large scale, even above the required level, throughout the case’s network, the investments made in this field are not being fully and correctly utilized due to the existence of numerous issues and disruptions.

There are some questions to be presented. The following are the most important:

- How can the country's broiler supply chain network be improved, as well as the role of intermediaries and disruptive factors?
- How will a backup facility and multiple sourcing strategies affect the model's resilience?
- Is it possible, despite the network's many real-world limitations, to obtain an optimal value for both the objective function of profit and the amount of CO_2 emission?
- What effect will each model parameter have on the amount of objective functions?

As a result, the primary motivations and objectives of this research are in using two important resilient strategies (i.e. multiple sourcing and backup facility) for a broiler supply chain network model considering perishability and sustainability conditions. The major contributions of this study that make a clear difference with the similar articles are brought as follows:

- Integrating the chicken meat supply chain, allocate resources, by implementing the resilience strategies, and balancing between sustainable development and resilience strategies.
- Making the network resilience to disruptions, price fluctuations, intervention of intermediaries and brokers, and lack of resources on the one hand, and high perishability of the products on the other by implementing backup facility strategies and multiple sourcing.
- Optimizing the number of broiler farms, production, and breeding industries, as well as calculating the amount of CO_2 emissions caused by product transportation using goal programming(GP).
- Considering perishability and defining the associated costs based on the added value at each plant.
- Application of the proposed model in a real case study of broiler industry.

The remainder of this research is as follows. In Section 2, the literature is reviewed on sustainable and resilient SCs under two titles. The definition of the problem is presented in section 3 and the mathematical model is given in Section 4. The solution approach is described in section 5. Sections 6 and 7 present the case study and validation, respectively. Section 8 is devoted to sensitivity analysis. Finally, the conclusion of this research and future research suggestions are proposed in Section 9.

Literature review

This section reviews relevant articles that can assist in determining the overall framework of this paper. The literature review was conducted in two sub-branches of sustainability and resiliency-sustainability, according to the purpose of this research:

Sustainability

Because of the growing concern of communities in the environmental and social fields, most researchers' attention in SC and distribution networks has been focused on the issue of sustainability in recent years. Researchers have made valuable studies in the field of sustainability and its integration with SC mathematical models in this manner. Bortolini et al. (2018) addressed the issue of designing a SC network, including the best package size, node location, and flow allocation. Because of the presence of disposable and reusable packaging containers in these chains, the dual-objective planning model focuses on the fresh vegetable and fruit distribution chains. This study's goal is to help industry managers, experts, and policymakers reduce costs and environmental impacts. The efficacy of the results is evaluated using a real-world example from Italy. The findings emphasize the importance of achieving an overall optimum that reduces greenhouse gas emissions while increasing costs by combining single-use and reusable packaging containers. 0Jozdani and Govindan (2020) developed a multi-objective mathematical model for the SC of perishable materials that takes into account all three aspects of sustainability in addition to minimizing network costs. In addition, the uncertainty of product lifetime and perishability rate is separately modeled as Weibull random variables. Furthermore, a multi-product model is being considered, as well as various modes of transportation. According to the findings of this study on perishable food SCs, emphasizing the economic aspect increases the environmental impact of the chain by 120% for very busy road networks, while increasing the social impact by 51%. However, a 15% economic compromise can improve supply chain network design sustainability by 150%. Environmental concerns were also taken into account in the study of Mohebalizadehgeshti et al. (2020), who developed a mathematical model for designing and arranging a multi-period, multi-product, and multi-stage green SC network. A multi-objective mixed-integer linear programming model has been proposed to simultaneously optimize three objectives: total cost, total CO_2 emissions from transportation, and facility capacity utilization. Tirkolaee et al. (2022) recently created a new sustainable mathematical model for designing a closed-loop mask supply chain network during the COVID-19 pandemic. The multi-objective, multi-period, and multi-product mixed-integer linear programming model proposed to address the problem takes into account locational, supply, production, distribution, collection, quarantine, recycling, reuse, and disposal decisions. Furthermore, sustainability practices are associated with total human risk, in addition to minimizing total cost and total pollution.

Resiliency and sustainability

According to Christopher and Peck (2004), it is critical to pay attention to both resilient and sustainable approaches when expanding the SC's sustainability and stability. The sustainability procedure focuses on environmental factors and reducing their negative effects, but it ignores the effects of SC disruptions. While the resilience procedure focuses on the SC's ability to regain the desired state following a disruption, it ignores the effects on the environment and sustainable development. According to Fixel (2006), creating sustainability and resilience in the SC provides many business opportunities through green technologies, reducing raw material and energy consumption, and discovering creative ways to recover and reuse waste instead of clean resources. In a similar study, Jiang et al. (2009) proposed a tool for managers and decision-makers to use to create resilient meat and food supply chain networks against disruption. Bender’s decomposition algorithm was used to solve this mixed integer model. Finally, a case study of the meat and food network was presented to demonstrate the significance and efficiency of the developed model. In addition, a new method of measuring resilience was developed to compare the flexibility of various supply chain network structures. Rosic et al. (2009) assessed procurement trends such as outsourcing and centralization in terms of cost, risk, and environmental impact. They discovered that in order to improve the SC's overall performance, both resilience and sustainability approaches should be incorporated into supply chain management. The findings of Kaur and Singh's (2016) study provided compelling motivation for combining sustainability and resilience aspects. For example, designing the aforementioned SC with carbon emission constraints reduces procurement costs. Zahiri et al. (2017) presented a stable and resilient mixed integer linear programming supply chain network design model for the pharmaceutical industry under uncertain parameters for this purpose. The industry's high susceptibility to internal or external tragedies, which ultimately leads to a halt in production or a failure to respond to demand, combined with an awareness of environmental issues, leads to regard this chain as a sustainable and resilient integrated chain. By doing so, new resilience and sustainability criteria have been presented, developed, and applied to this pharmaceutical model. Jabarzadeh et al. (2018) presented a hybrid method for supply chain network design that included two phases: sustainability estimation and resilience enhancement. They used the fuzzy clustering method to assess each supplier's global sustainability performance and created a two-objective stochastic optimization model. Finally, they investigated the mutual effects of cost stability performance and resilience strategies under different disruption scenarios. Furthermore, according to a case study in the plastic pipe manufacturing industry, the proposed combined approach has significantly reduced costs in various aspects of sustainability. Because one of the primary goals of SC design is to reduce SC threats, costs, and market share, Sabouhi et al. (2018) used a hybrid approach for designing a resilient SC that relied on data envelopment analysis and mathematical programming methods. The efficiency of potential suppliers was first evaluated in the fuzzy model, and then a two-stage stochastic probabilistic programming model was developed to select suppliers using the obtained efficiency. The integrated supply chain design was evaluated for disruption and operational risks, which included partial and total disruptions as well as a procurement discount. Furthermore, in a case study of a pharmaceutical company, several resiliency strategies such as fortification and predetermining the emergency inventory position in established suppliers and multiple sourcing were used to mitigate the adverse effects of disruption risks. The findings demonstrate how changing important parameters, such as supplier capacity and emergency inventory holding costs, can affect overall costs and which resilience strategies are effective in various situations. An integrated hybrid approach was used to investigate the impact of considering efficiency and resilience simultaneously for SC design. Ivanov (2018) investigated the effects of resilience factors on the sustainability of SCs and discovered that facility protection improved sustainability. Similarly, a recent study concluded that sustainability improves the state of resilience in SC network design (Miller and Engemann, 2019). Yavari and Geraeli (2019) used a heuristic approach to design and solve a mixed integer linear programming model. The results demonstrated the impact on objective functions caused by the perishable product life cycle and the rates of demand uncertainty. Bottani et al. (2019) also presented a mixed integer linear programming model for designing the problem of a food resilient SC, with the goal of maximizing and minimizing total profit in one year and production time along the SC, respectively. It was solved using the ant colony optimization algorithm. The model developed is also appropriate for a multi-product resilient food supply chain that employs a multi-sourcing strategy to deal with unexpected market demand fluctuations and raw material supply disruptions. Mehrjardi and Shafiei (2020) also used strategies that allow information to be shared along the SC and provide the capability of multiplying sources to make the SC more resilient. Finally, using linguistic variables, the evaluation expressed the effects of strategies on resilience measures. The final results show that information sharing and multiple sourcing strategies have the greatest impact on tier industry resilience measures. Vali-Siar and Roghanian (2022) believe that considering SC resilience and greenness aspects at the same time is important. As a result, a resilient and green open and closed-loop supply chain network has been designed with operational and disruption risks in mind. To address disruption risks and improve SC resilience, a two-objective mixed-integer linear programming model with some resilience strategies was developed. A new meta-heuristic algorithm dubbed multi-objective hybrid Ant-colony optimization and teaching and learning-based optimization (ACO-TLBO) has been offered and compared through several test problems with both hybrid metaheuristics and the augmented -constraint methods to devastate the complexity of the models and solve it with data of medium and large sizes. Finally, the results of an analysis of a real case study in the tire industry have demonstrated the increased importance of resilience strategies and the need for collaborative resilience and greenness deliberation in SC design. The COVID-19 outbreak has exposed vulnerabilities in food supply chains, highlighting their susceptibility to disruptions due to food perishable nature. Kazancoglu et al. (2024) examined the need for resilience in food supply chains during the pandemic. The study identifies key enablers of resilience and then employs the graph theory matrix approach to analyze the interrelationships and importance. The findings offer valuable insights for policymakers and managers to enhance the resilience of the food supply chains. Hobbs and Hadachek (2024) reviewed various perspectives on food supply chain resilience. Additionally, they investigated methodologies employed in studying resilience to help economists delving into this topic and then offered a comprehensive overview and forward-looking insights to help in the understanding and improvement of food supply chain resilience. Also, Su et al. (2024) reviewed the literature on food supply chain resilience, focusing on digital technologies and sustainability integration to cope with for future uncertainties. They systematically analyzed academic journal articles from 2010 to 2020 to identify research gaps and provide guidances for enhancing food supply chain resilience against various disruptions. Emphasizing on the role of digital technologies and sustainability, their findings offer strategies for supply chain practitioners and highlight ways to achieve a more resilient and sustainable food supply chain through digital innovations.

As a result, articles in the field of SC optimization models have been reviewed in the category of sustainability-resilience integration. This section describes the findings of some of the reviewed studies. A summary based on the criteria considered is also provided in a comparative Table 1. Given the importance of sustainability and resilience criteria in perishable product SC networks, incorporating these three criteria into the modeling space will make it more practical and realistic. According to the literature review, previous studies have not taken into account the issue of resilient and sustainable network design for perishable items from all three environmental, economic, and social perspectives. Furthermore, none of the articles on the design of the perishable goods network, specifically the broiler chain and the unique conditions of its supply, production, and distribution, have been examined. Furthermore, the results show that the social dimension of sustainability has received far less attention than other dimensions, particularly in food SCs. As one of the research gaps in this field is defining the problem of designing a sustainable and resilient network for perishable items, studying sustainability and resilience criteria for these basic and perishable product chains is critical.

Table 1 Comparison of the scope of earlier studies with the current study

Author/Year	Performance measures											Model Type*	Time Period		Objective Function		Case Study/ Application
		Sustainability			Risk												
	Cost/Profit	Economic	Environmental	Social	Disruption	Operational	Demand	Shortage	Transportation	Resiliency	Perishability		Single Period	Multi Period	Single Objective	Multi Objective	
(Ekici et al. 2014)	✓				✓							MILP		✓	✓		Pandemic / Food Industry
0 (Al-Harrasi et al. 2017)	✓											MILP	✓		✓		Poultry Industry of Muscat(Oman)
0(Gholamian and Taghanzadeh 2017)	✓								✓			MILP		✓	✓		Agricultural(Wheat)
0 (Khadem et al. 2017)	✓								✓			LP	✓		✓		Poultry SC
0 (Musavi and Bozorgi-Amiri 2017)	✓	✓	✓						✓			MILP	✓			✓	Food Industry
0 (Zahiri et al. 2017)	✓	✓	✓	✓	✓	✓			✓	✓		MILP		✓		✓	Pharmaceutical
(Bortolini et al. 2018)	✓	✓	✓									MILP		✓		✓	Food Industry
(Fahimnia et al. 2018)	✓	✓	✓						✓	✓		MINLP	✓		✓		Apparel Industry
0 (Jabbarzadeh et al. 2018)	✓				✓	✓				✓		MIP		✓	✓		Hamadan Glass Company (HGC)
0(Jabbarzadeh et al. 2018)	✓				✓			✓	✓	✓		MILP	✓			✓	Plastic Industry
0 (Sabouhi et al. 2018)	✓			✓	✓					✓		TSPSP	✓		✓		Pharmaceutical
0 (Bottani et al. 2019)	✓				✓		✓		✓	✓		MIP		✓		✓	Food Industry
0(Yavari & Garaeli 2019)	✓	✓	✓			✓	✓		✓		✓	MILP		✓		✓	Dairy Industry
0(Yavari & Zaker 2020)	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	MILP		✓		✓	Dairy Industry
0 (Jouzdani&Govindan 2020)	✓	✓	✓	✓					✓		✓	MINLP		✓		✓	Dairy Products
0 (Mohebalizadeh et al. 2020)	✓	✓	✓						✓			MILP		✓		✓	Meat SC
0 (Mehrjerdi & Shafiee 2020)	✓	✓	✓	✓	✓				✓	✓		MIP	✓			✓	Tier Industry
0 (Gholami-Zanjani et al. 2021)	✓				✓		✓		✓	✓	✓	MIP		✓	✓		Food SC - Pandemic
0(Gholami-Zanjani et al.2021)	✓	✓	✓		✓				✓	✓		MILP		✓		✓	Meat SC
0(Vali-Siar and Roghanian 2022)	✓	✓	✓		✓	✓	✓	✓	✓			MILP		✓		✓	Tier Industry
0 (Wang et al. 2022)	✓	✓	✓		✓	✓	✓					MINLP	✓			✓	-
This research	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	MILP		✓		✓	Broiler SC

*The abbreviation of model types is defined as follows. S: Simulation, MILP: Mixed Integer Linear Programming, MINLP: Mixed Integer Non-Linear Programming, MIP: Mixed Integer Programming, TSPSP: Two-Stage Possibilistic-Stochasting Programming

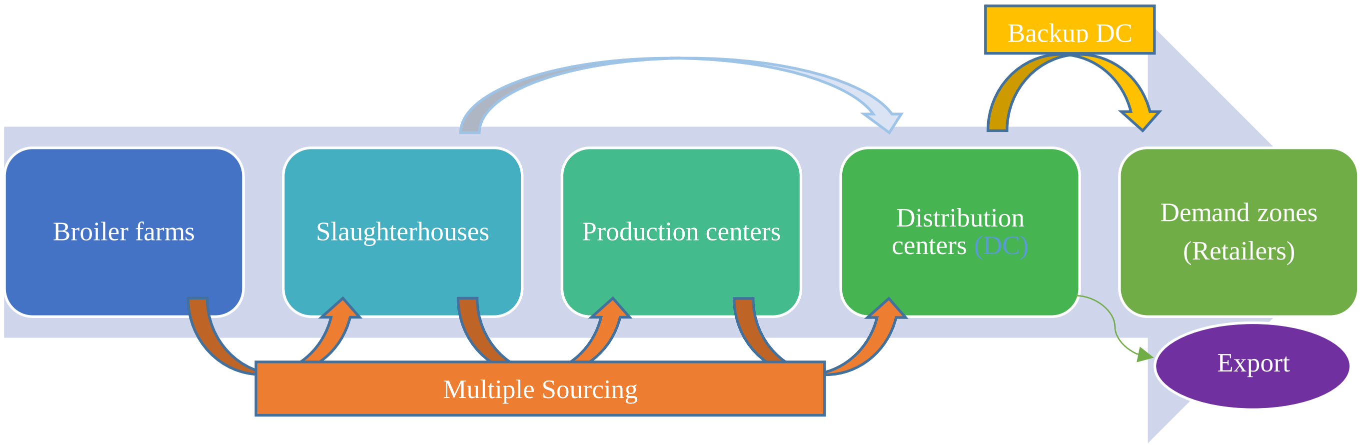

Fig. 1 The schematic of broiler supply chain network model

Problem statement

As a basic commodity, chicken meat in this network, as shown in Fig. *1*, faces issues such as price fluctuation, supply shortages, disruption in supply and demand estimation, and the presence of dealers at various levels of the supply chain. As a result, this chain must be integrated in order to meet the enormous demand of its domestic market. The integrated chicken meat supply chain consists of broiler farms, chicken slaughterhouses, packing centers, chicken meat product production centers, distribution centers, and, finally, retailers. By removing the intervention of intermediaries and brokers, this chain provides a correct estimate of demand, which well meets the entire needs of customers, and becomes resilient by using strategies integrated with the model against unpredictable disturbances such as a facility's loss of capacity or the presence of intermediaries that disrupt the price. Multiple sourcing is the most common approach to risk reduction (Peng et al., 2011), which refers to the practice of obtaining goods, services or resources from more than one supplier or source to enhance the resilience of a supply chain or business operation by reducing the risk of dependency to a single supplier. This strategy has been implemented at three levels of this supply chain as constraints: the poultry farm, the slaughterhouse, and the manufacturing plant. It gives each plant the ability to reduce the risk of not meeting the demand of the next level. On the other hand, it is essential to minimize downtime and ensure that all operations can continue during unexpected disruptions. So backup facilities are crucial for ensuring business continuity and resilience in disruptions. These facilities can be physical locations, systems, or processes that protect operations when the primary systems or facilities fail (Snyder and Daskin, 2005). Here it is considered as a backup distribution center in our model. This strategy has been activated in the event of a disruption in any of the distribution centers to mitigate the damage caused by the disorder and allow the supply and distribution chain to function properly. In addition, by considering the amount of CO_2 gas emitted by product transportation, the quality of the primary product, and the level of desirability of the fulfilled demand, all three dimensions of sustainability have been entered into the model.

Overall, the study objectives are as follows:

- Determining the location of broiler farms, slaughterhouses, production centers, and distribution centers;
- Integrating network levels to minimize CO_2 emissions and maximize profit;
- Applying multiple sourcing and backup facility strategies to make the network resilient
- Considering sustainability factors all along the model

Assumptions

- The amount of hatching, production, and capacities in the facilities are clearly defined and deterministic.
- All costs are considered the same in different periods.
- Shipping costs are linearly proportional to the distance factor.
- All the deterioration, production ,and distribution costs are regarded the same for all nodes.
- The capacity of facilities is considered limited.
- There is no lateral transshipment between facilities.

- The utilized notations in the broiler supply chain mathematical model are presented below.

Indices

i	index of candidate location for broiler farms i = {1,…,I}
j	index of candidate location for slaughterhouses j = {1,…,J}
p	index of candidate location for production centers p = {1,…,P}
f	index of candidate location for distribution centers f = {1,…,F}
b	index of candidate location for backup facilities b = {1,…,B}
r	index of demand nodes r = {1,…,R}
k	index of export demand nodes k = {1,…,K}
t	index of time periods t = {1,…,T}
m	index of transportation modes m = {1,…,M}
n	index of product types n = {1,…,N}

Parameters

Ra_i	price of buying chicken from broiler farm i
Rb^n	price of exporting product n
Rc^n	price of selling product n
$F1_i$	the fixed installation cost of aviculture in the prospect location i
$F2_j$	the fixed installation cost of a slaughterhouse in the prospect location j
$F3_p$	the fixed installation cost of a production center in the prospect location p
$F4_f$	the fixed installation cost of a distribution center in the prospect location f
$F5_b$	the fixed installation cost of a backup facility in the prospect location b
$C1_{ijm}$	transportation cost between aviculture i and slaughterhouse j using carrier mode m per unit
$C2_{jpm}$	transportation cost between slaughterhouse j and production center p using carrier mode m per unit
$C3_{pfm}$	transportation cost between production center p and distribution center f using carrier mode m per unit
$C4_{frm}$	transportation cost between distribution center f and demand node r using carrier mode m per unit
$C5_{fkm}$	transportation cost between distribution center f and export demand node k using carrier mode m per unit
$C6_{jfm}$	transportation cost between slaughterhouse j and distribution center f using carrier mode m per unit
$C7_{brm}$	transportation cost between backup center b and demand node r using carrier mode m per unit
O_n	production cost of product type n in manufacturing centers per unit
Cu_i	highest capacity level of aviculture i
Cap_j	highest capacity level of slaughterhouse j
Cap_p	highest capacity level of production center p
Cap_f	highest capacity level of distribution center f
Cap_b	highest capacity level of backup facility b
U_p	lowest amount of chicken meat entering to production center p
Din_r	demand of demand zone r
Dex_k	demand of country k
Qu^n	chicken meat percentage of product type n
$Det1_p$	deterioration cost in production center p
$Det2_f$	deterioration cost in distribution center f
$Dec1_{it}$	percent of decayed chicken in broiler farm i at the end of time period t
$Dec2_{jt}$	percent of decayed chicken in broiler farm i at the end of time period t
R_t	Disruption rate in time period t
CE1	the CO_2 pollution emitted by the transportation per product transporting from i to j

CE2	the CO_2 pollution emitted by the transportation per product transporting from j to p
CE3	the CO_2 pollution emitted by the transportation per product transporting from p to f
CE4	the CO_2 pollution emitted by the transportation per product transporting from f to r
CE5	the CO_2 pollution emitted by the transportation per product transporting from f to k
CE6	the CO_2 pollution emitted by the transportation per product transporting from j to f
CE7	the CO_2 pollution emitted by the transportation per product transporting from b to r
ψ	Penalty for the lack of utility that is created in poultry farm
α	the number of poultry farms that can be assigned to a slaughterhouse
β	the number of slaughterhouses that can be assigned to a production center
γ	the number of production centers that can be assigned to a distribution center

Variables

$Y1_{ijtm}$	flow of broiler transferred from aviculture i to slaughterhouse j using carrier mode m in period t
$Y2_{jptm}$	flow of slaughtered broiler transferred from slaughterhouse j to production center p using carrier mode m in period t
$Y3^n_{pftm}$	flow of product type n transferred from production center p to distribution center f using carrier mode m in period t
$Y4^n_{frtm}$	flow of product type n transferred from distribution center f to demand node r using carrier mode m in period t
$Y5^n_{fktm}$	flow of product type n transferred from distribution center f to export demand node k using carrier mode m in period t
$Y6^s_{jftm}$	flow of product type s transferred from slaughterhouse j to distribution center f using carrier mode m in period t
$Y7^n_{brtm}$	flow of product type n transferred from backup distribution center b to demand node r using carrier mode m in period t
$X1_{it}$	the amount of hatching in the poultry farm i in period t
$X2^n_{pt}$	quantity of product type n produced in production center p in period t
$EX1^n_{pt}$	the amount of expired product n in production center p at the end of time period t
$EX2^n_{ft}$	the amount of expired product n in production center p at the end of time period t
$W1_i$	if poultry farm i is established, it is 1; otherwise 0.
$W2_j$	if slaughterhouse j is established, it is 1; otherwise 0.
$W3_p$	if production center p is established, it is 1; otherwise 0.
$W4_f$	if distribution center f is established, it is 1; otherwise 0.
$W5_b$	if backup facility b is established, it is 1; otherwise 0.
$A1_{ij}$	if poultry farm i is assigned to slaughterhouse j, it is 1; otherwise 0.
$A2_{jp}$	if slaughterhouse j is assigned to production center p, it is 1; otherwise 0.
$A3_{pf}$	if production center p is assigned to distribution center f, it is 1; otherwise 0.

Mathematical formulation

The first objective function (1) aims to maximize the total profit of the network by subtracting establishment costs (4), purchasing costs of the primary products (5), transportation costs (6), manufacturing costs (7), deterioration costs (8), and shortage penalty costs (9), respectively from exporting income (2) and the income of selling products (3).

$$Max \quad Z1 = TRN + TRD - TF - TRQ - TC - TX - TEX - TSAT \tag{1}$$

$$TRN = \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{k\epsilon K}\sum_{t\epsilon T}\sum_{m\epsilon M} Rb^n Y5^n_{fktm} \tag{2}$$

$$TRD = \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{r\epsilon R}\sum_{t\epsilon T}\sum_{m\epsilon M} Rc^n Y4^n_{frtm} \tag{3}$$

$$TF = \sum_{i\epsilon I} F1_i W1_i + \sum_{j\epsilon J} F2_j W2_j + \sum_{p\epsilon P} F3_p W3_p + \sum_{f\epsilon F} F4_f W4_f + \sum_{b\epsilon B} F5_b W5_b \tag{4}$$

$$TRQ = \sum_{i\epsilon I}\sum_{j\epsilon J}\sum_{t\epsilon T}\sum_{m\epsilon M} Ra_i Y1_{ijtm} \tag{5}$$

$$TC = \sum_{i\epsilon I}\sum_{j\epsilon J}\sum_{t\epsilon T}\sum_{m\epsilon M} C1_{ijm}Y1_{ijtm} + \sum_{j\epsilon J}\sum_{p\epsilon P}\sum_{t\epsilon T}\sum_{m\epsilon M} C2_{jpm}Y2_{jptm} + \sum_{f\epsilon F}\sum_{t\epsilon T}\sum_{m\epsilon M} C3_{pfm}Y3^{n}_{pftm} + \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{r\epsilon R}\sum_{t\epsilon T}\sum_{m\epsilon M} C4_{frm}Y4^{n}_{frtm} + \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{k\epsilon K}\sum_{t\epsilon T}\sum_{m\epsilon M} C5_{fkm}Y5^{n}_{fktm} + \sum_{s\epsilon N}\sum_{j\epsilon J}\sum_{f\epsilon F}\sum_{t\epsilon T}\sum_{m\epsilon M} C6_{jfm}Y6^{s}_{jftm} + \sum_{n\epsilon N}\sum_{b\epsilon B}\sum_{\rho\epsilon P}\sum_{t\epsilon T}\sum_{m\epsilon M} C7_{b\rho m}\, Y7^{n}_{b\rho tm} \quad (6)$$

$$TX = \sum_{n\epsilon N}\sum_{p\epsilon P}\sum_{t\epsilon T} O^{n}\, X2^{n}_{pt} \quad (7)$$

$$TEX = \sum_{n\epsilon N}\sum_{p\epsilon P}\sum_{t\epsilon T} Det1_{p}\, EX1^{n}_{pt} + \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{t\epsilon T} Det2_{f}\, EX2^{n}_{ft} \quad (8)$$

$$TSAT = \sum_{i\epsilon I}\sum_{j\epsilon J}\sum_{t\epsilon T}\sum_{m\epsilon M} \psi \max\{0, (X1_{it} - Y1_{ijtm})\} \quad (9)$$

The second objective function (10) is concerned with the environmental impact of network transportation. As a result, the amount of CO_2 emitted per transported product is taken into account in each period between the plants. The final section of the equation is related to the amount of product transported from a backup distribution center to the retailer. Because the valency of backup distribution centers is significantly lower than that of primary distribution centers, transportation produces significantly more CO_2 per product in this case. To maintain this state, the related expression is multiplied by a higher parameter ($CE7$).

$$Min\ \ Z2 = \sum_{i\epsilon I}\sum_{j\epsilon J}\sum_{t\epsilon T}\sum_{m\epsilon M} Y1_{ijtm}\, CE1 + \sum_{j\epsilon J}\sum_{p\epsilon P}\sum_{t\epsilon T}\sum_{m\epsilon M} Y2_{jptm}\, CE2 + \sum_{n\epsilon N}\sum_{p\epsilon P}\sum_{f\epsilon F}\sum_{t\epsilon T}\sum_{m\epsilon M} Y3^{n}_{pftm}\ CE3 + \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{r\epsilon R}\sum_{t\epsilon T}\sum_{m\epsilon M} Y4^{n}_{frtm}\, CE4 + \sum_{n\epsilon N}\sum_{f\epsilon F}\sum_{k\epsilon K}\sum_{t\epsilon T}\sum_{m\epsilon M} Y5^{n}_{fktm}\, CE5 + \sum_{s\epsilon N}\sum_{j\epsilon J}\sum_{f\epsilon F}\sum_{t\epsilon T}\sum_{m\epsilon M} Y6^{s}_{jftm}\, CE6 + \sum_{n\epsilon N}\sum_{b\epsilon B}\sum_{r\epsilon R}\sum_{t\epsilon T}\sum_{m\epsilon M} Y7^{n}_{brtm}\, CE7 \quad (10)$$

Constraint (11) limits the amount of hatching, taking into account the number of losses until transfer to the next stage.

$$X1_{it}(1 - Dec1_{it}) = \sum_{j\in J}\sum_{m\in M} Y1_{ijtm} \qquad \forall i \in I, t \in T \quad (11)$$

Constraints (12)-(16) are capacity constraints for poultry farm, slaughterhouse, production center, and distribution center (both primary and backup), respectively, and ensure that the total product outflow in each node and period will not exceed the defined maximum capacity.

$$\sum_{m\in M}\sum_{j\in J} Y1_{ijtm} \le Cu_{i}\, W1_{i} \qquad \forall i \in I, t \in T \quad (12)$$

$$\sum_{m\in M}\sum_{j\in J} Y1_{ijtm} \le Capj_{j}\, W2_{j} \qquad \forall j \in J, t \in T \quad (13)$$

$$X2^{n}_{pt} \le Capp_{p}\, W3_{p} \qquad \forall p \in P, t \in T, n \in N \quad (14)$$

$$\sum_{n\in N} EX2^{n}_{ft} + \sum_{r\in R}\sum_{n\in N}\sum_{m\in M} Y4^{n}_{frtm} + \sum_{k\in K}\sum_{n\in N}\sum_{m\in M} Y5^{n}_{fktm} \le Capf_{f}\ \ W4_{f} \quad \forall f \in F, t \in T \quad (15)$$

$$\sum_{r\in R}\sum_{n\in N}\sum_{m\in M} Y7^{n}_{brtm} \le Cap_{b}\, W5_{b} \qquad \forall b \in B, t \in T \quad (16)$$

Constraint (17) guarantees the minimum flow to the production center. Constraint (18) shows that the total flow amount to the next stage and the remaining amount is precisely equivalent to the amount of production in that stage. Constraints (19)-(22) show the necessity of establishing at least one facility at each level.

$$\sum_{i\in I}\sum_{m\in M} Y2_{jptm} \geq U_p\, W3_p \qquad \forall p \in P, t \in T \tag{17}$$
$$\sum_{f\in F}\sum_{m\in M} Y3^n_{pftm} + EX1^n_{pt} = X2^n_{pt} \qquad \forall p \in P, n \in N, t \in T \tag{18}$$
$$\sum_{i\in I} W1_i \geq 1 \tag{19}$$
$$\sum_{j\in J} W2_j \geq 1 \tag{20}$$
$$\sum_{p\in P} W3_P \geq 1 \tag{21}$$
$$\sum_{f\in F} W4_f \geq 1 \tag{22}$$

Constraints (23) and (24) refer to the lack of necessity in estimating export and domestic demand.

$$(1-R_t)\sum_{f\in F}\sum_{m\in M} Y4^n_{frtm} + \sum_{b\in B}\sum_{m\in M} Y7^n_{brtm} \geq Din_r \qquad \forall r \in \mathrm{R}, n \in N, t \in T \tag{23}$$
$$\sum_{f\in F}\sum_{m\in M} Y5^n_{fktm} \geq Dex_k \qquad \forall k \in K, n \in N, t \in T \tag{24}$$

The necessity of striking a balance in the flow between levels is given in the constraints (25)-(27).

$$\sum_{i\in I}\sum_{m\in M} Y1_{ijtm} \geq \sum_{p\in P}\sum_{m\in M} Y2_{jptm} \qquad \forall j \in J, t \in T \tag{25}$$
$$\sum_{j\in J}\sum_{m\in M} Y2_{jptm}\,(1-Dec2_{jt}) \geq \sum_{n\in \mathrm{N}} X2^n_{pt}\, Qu^n \qquad \forall p \in P, t \in T \tag{26}$$
$$\sum_{p\in P}\sum_{m\in M} Y3^n_{pftm} + \sum_{j\in J}\sum_{m\in M} Y6^s_{jftm} = \sum_{r\in R}\sum_{m\in M} Y4^n_{frtm} + \sum_{k\in K}\sum_{m\in M} Y5^n_{fktm} + EX2^n_{ft} \quad \forall n, s \in N, f \in F, t \in T \tag{27}$$

Allocation constraints between stages are as mentioned below (28)-(33).

$$A1_{ij} \leq W1_i \qquad \forall i \in I, j \in J \tag{28}$$
$$\sum_{i\in I} A1_{ij} = \alpha \qquad \forall j \in J \tag{29}$$
$$A2_{jp} \leq W2_j \qquad \forall p \in P, j \in J \tag{30}$$
$$\sum_{j\in J} A2_{jp} = \beta \qquad \forall p \in P \tag{31}$$
$$A3_{pf} \leq W3_p \qquad \forall p \in P, f \in F \tag{32}$$
$$\sum_{r\in R} A3_{rf} = \gamma \qquad \forall f \in F \tag{33}$$

Constraints (34) to (36) are considered to prevent the model from allocating flow amounts for facilities that have not yet been built.

$$\sum_{m\in M} Y1_{ijtm} \leq Cu_i A1_{ij} \qquad \forall i \in I, j \in J, t \in T \tag{34}$$

$$\sum_{m \in M} Y2_{jptm} \leq Capj_j \ A2_{jp} \qquad \forall j \in J, p \in P, t \in T \tag{35}$$

$$\sum_{m \in M} Y3^n_{pftm} \leq Capp_p \ A3_{pf} \qquad \forall p \in P, n \in N, f \in F, t \in T \tag{36}$$

Nonnegative variables are set by the constraint (37) and binary ones are defined by the constraint (38).

$$Y1_{ijtm}, Y2_{jptm}, Y3^n_{pftm}, Y4^n_{frtm}, Y5^n_{fktm}, Y6^s_{jftm}, Y7^n_{brtm}, X1_{it}, X2^n_{pt}, EX1^n_{pt}, EX2^n_{ft} \geq 0 \tag{37}$$

$$W1_i, W2_j, W3_p, W4_f, W5_b, A1_{ij}, A2_{jp}, A3_{pf} \in \{0, 1\} \tag{38}$$

Solution method

The proposed bi-objective optimization model must be solved using suitable methods. The use of Goal Programming (GP) for solving multi-objective linear programming problems offers significant advantages in terms of simplicity, flexibility, and computational efficiency (Hu et al., 2007). GP allows for the clear incorporation of decision-maker preferences and priorities, enabling a structured approach to achieving multiple goals simultaneously (Munro and Aouni, 2012). Compared to the ε-constraint method and other Multi-Objective Decision Making (MODM) techniques, GP provides a more straightforward solution process, avoids the complexity of parameter tuning, and produces results that are easier to interpret and implement. Specifically unlike the ε-constraint method, GP achieves closely with the decision-maker's aspirations by explicitly incorporating their goals and priorities into the optimization process. This is particularly advantageous in real-world case studies where decision-maker preferences are crucial and should be directly reflected in the model. In comparison with other methods, GP stands out as an effective and practical tool for addressing the complexities of multi-objective optimization, particularly in real-world scenarios where decision-maker preferences play a crucial role. It ensures that the solutions are not only optimal but also aligned with the decision-maker's goals, providing a tailored and efficient approach to decision-making. Charnes et al. (1955) were the first to use GP. Furthermore, it was developed in 1961 by the researchers Charnes and Cooper (1961). All GP does is minimize the deviations of the objective functions and provide an optimal solution. Furthermore, it is relatively capable of dealing with a large number of constraints and decision variables (Jolai et al. 2011; Dubey et al. 2012). As a result, in this study, the GP approach is used to solve the model. First, the status of objective function variation must be normalized. The GP is familiar with this technique. Many researchers have discussed the significance of normalization in GP. Furthermore, several approaches to standardization have been proposed (Arabi et al. 2019). Normalization should be performed to scale the goals onto identical units of dimension (Jones and Tamiz, 2010). Hence, Equations (34) and (35) show this model's normalized status of objective function variation. Z_1^* is the optimal solution for the first objective function, that aims to maximize the profit of SC, d_1^+ is the percentage of objective function variation that is less than Z_1^*, and d_1^- is the percentage of objective function variation that is more than Z_1^*. Likewise, for the second objective, Z_2^* is the optimal amount which is minimizing CO_2 emissions. Contrariwise, $d_2^+$and $d_2^-$are the objective function variation amounts that are higher and lower than Z_2^*, respectively.

$$\frac{Z_1^* - Z_1}{Z_1^*} = d_1^+ - d_1^- \tag{34}$$

$$\frac{Z_2^* - Z_2}{Z_2^*} = d_2^+ - d_2^- \tag{35}$$

The new objective function is shown in equation (36) which minimizes the total objective functions variation amounts that are higher than their objective functions (it is obvious that d_1^-

and d_2^- cannot take value). Weight parameters w_1^+ and w_2^+ are defined according to the importance of each goal and are allocated to d_1^+ and d_2^+, respectively.

$$Z = w_1^+ d_1^+ + w_2^+ d_2^+ \tag{36}$$

Case study

Because the broiler industry is regarded as one of the most important economic sectors in the country, some statistics show that investment in the poultry industry ranks second only to that in the oil industry. Now that chicken meat has become a public demand and a general and stable food need, managers and breeders' primary concern has become the production of white meat in sufficient quantity, of high quality, and, of course, at a reasonable price.

Everyone is looking for a way to produce sustainable and affordable chicken meat. The completion of the chicken production chain is one of the most important events that must occur in the country's poultry industry. In this section, data from related organizations in Iran were used and imported into the model to demonstrate the rational efficacy of the proposed broiler supply chain network design problem. The main data was collected from the Statistical Centre of Iran (https://www.amar.org.ir/) and the Ministry of Agriculture Jihad (https://www.maj.ir/). According to the results of the 2020 census, the country has 20,520 chicken farms, of which 16,452 are active and 4,068 are inactive. Furthermore, among all provinces in Iran, Mazandaran, Isfahan, and Razavi Khorasan have the greatest number of chicken farms. The number of active broiler farms in 2020 is 18,276 units, the number of day-old chicks laid in the halls is 1,461 million pieces, and the weight of live chickens raised for this number of active broiler farms is 3,198 thousand tons, according to project implementation results.

To incorporate this SC into the proposed model, all of a province's facilities, including farms, slaughterhouses, production centers, and distribution centers, are assumed to be a point in the province's center hub. Furthermore, there are three types of refrigerated vehicles and two types of not refrigerated vehicles. Only between farms and slaughterhouses is the second type used. Table 2 defines the provinces of the country and Table 3 Shows the values of scalar parameters. Moreover, some results of the model are provided in Table 4, Table 5, and Table 6.

Table 2 Introduction of candidate provinces

sign	province	sign	province	sign	province
1	East Azerbaijan	12	North Khorasan	23	Kohgiluyeh and Boyer-Ahmad
2	West Azerbaijan	13	Khuzestan	24	Golestan
3	Ardabil	14	Zanjan	25	Gilan
4	Isfahan	15	Semnan	26	Lorestan
5	Alborz	16	Sistan and Baluchistan	27	Mazandaran
6	Ilam	17	Fars	28	Markazi
7	Bushehr	18	Qazvin	29	Hormozgan
8	Tehran	19	Qom	30	Hamadan
9	Chaharmahal and Bakhtiari	20	Kurdistan	31	Yazd
10	South Khorasan	21	Kerman		
11	Razavi Khorasan	22	Kermanshah		

Table 3 Considered value for parameters

parameter	Considered value
ψ	0.5
CE1	20
CE2	20
CE3	20
CE4	20
CE5	20
CE6	20
CE7	100
W_1^+	10
W_2^+	1

Table 4 Results of establishment of aviculture's, slaughterhouses and distribution centers in optimized model

Province	Establishment variables	Province	Establishment variables	Province	Establishment variables
1	A,S	12	A,S,DC	23	A,S
2	A,S	13	A,S,DC	24	A,S
3	A,S	14	A,S	25	A,S
4	A,S	15	A,S	26	A,S
5	A,S	16	A,S	27	A,S
6	A,S,DC	17	A,S	28	A,S
7	A,S	18	A,S	29	A,S
8	A,S,DC	19	A,S	30	A,S
9	A,S,DC	20	A,S	31	A,S
10	A,S	21	A,S		
11	A,S	22	A,S		

A:aviculture, S:slaughterhouse, DC: distribution center

Table 5 Some results of allocating aviculture's to slaughterhouses in optimized model

A_{ij}	1	2	3	4	5	6
1	✓	✓			✓	
2					✓	
4			✓			
6		✓				
9						✓
12				✓		
14	✓					
15			✓			
19				✓		
22						✓

Table 6 Results of establishing factories

	Candidate Province	Establishment variables of factories
1	East Azerbaijan	
2	Isfahan	
3	Tehran	
4	South Khorasan	
5	Razavi Khorasan	
6	Khuzestan	✓
7	Fars	
8	Qazvin	✓
9	Kurdistan	✓
10	Kerman	
11	Kermanshah	
12	Golestan	✓
13	Gilan	✓
14	Mazandaran	
15	Yazd	

Fig. 2 depicts the results of the ε-constraint method for calculating Pareto frontiers. Because one of our objective functions is maximization and the other is minimization, it is expected that increasing one will increase the other or vice versa. This conflict is represented in the graph by a decrease in both objective functions at 18 different points, and this decrease in both objective functions represents the conflict between the objectives.

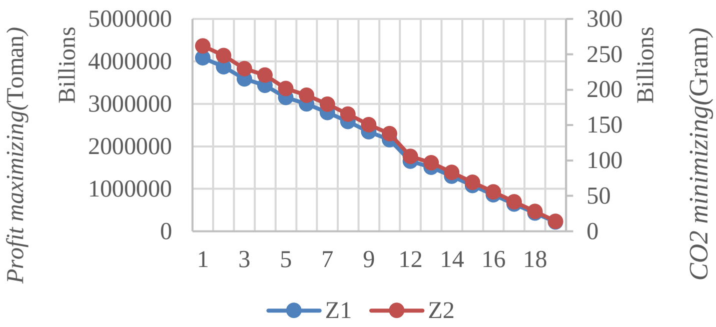

Fig. 2 The Pareto frontier solution

Validation

The outcomes of the unsustainable problem are used as a criterion for the sustainable model to test its validity. As a result, it is clear what will happen if the proposed model is not sustainable. To accomplish this, both objectives of the sustainable model are used as indicators in the models to measure the economic, environmental, and social dimensions of sustainability. Fig. 3 depicts the outcomes of both sustainable and unsustainable models. Because the sustainable model takes some social and environmental constraints into account, the unsustainable mathematical model is logically superior to the sustainable model. Similarly, the second objective function is greater than the sustainable one, implying that the unsustainable model produces more CO_2 emissions.

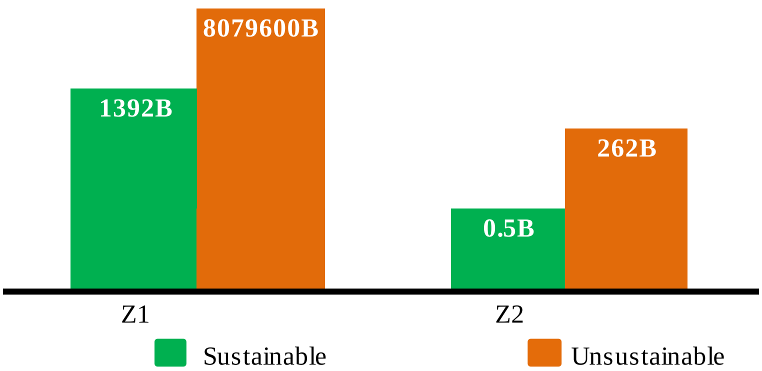

Fig. 3 The results of sustainable and unsustainable models (B=Billion)

This bi-objective optimization method was solved using GAMS 24.1.2 software (CPLEX solver) and numerical investigations are performed on a PC with Core i7 CPU and 6 gigabyte of RAM.

Sensitivity analysis

To display the impacts of most critical parameters of this model on the objective functions, the changes in the amounts of these parameters are imposed in this section. The significance of these parameters is shown by this analysis and the results helps managers in comprehending the cases whenever there is a change in the current values of each parameter and deal with them. First, the chicken meat percentage of products is fluctuated in the range of [-50%, 50%] to display the impacts of parameters on the solution. The second significant topic is the volume of demand of country and export; then the percentage of accruing disruption is analyzed. The other necessary analysis is on the cost of transportation and then the cost of deterioration. Naturally, these amounts are changing in unpredictable behaviors and the results are shown by the curves in each situation. Finally, the amount of CO_2 emitted per product is shown and the interpretation of the behavior of each is explained.

Fig. 4 shows that lowering the percentage of meat in the products results in more chicken meat being used and lower profits. However, more chickens must be transported between transportation levels to produce the same amount of the desired product, resulting in a linear increase in the amount of the second objective function. The profit objective function reaches a peak at point 1.25, indicating that this percentage is the best proportion for the model. As a result, finding a percentage that can keep the cost and amount of CO_2 emissions at an acceptable level is important in terms of management.

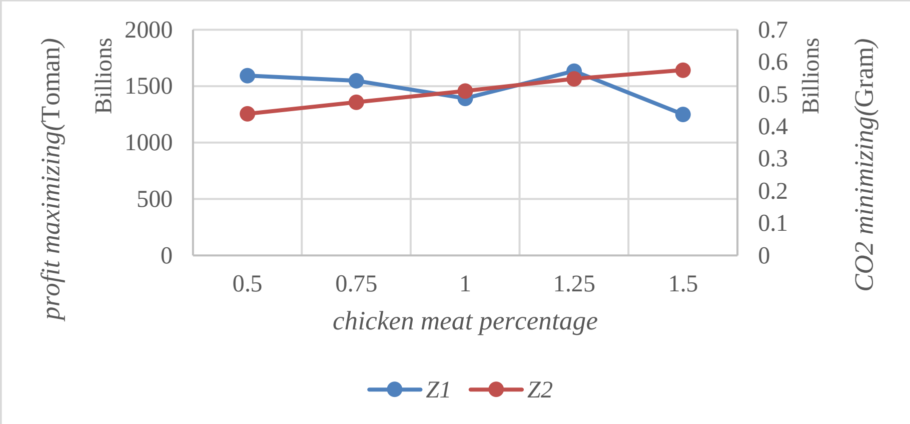

Fig. 4 Changes in chicken meat percentage of products parameter

Fig. 5 illustrates growth in demand concerns both objective functions at almost the same pace. This decrease in the economic objective is because of an upsurge in selling products and gaining more profit. Growing the second objective function due to an increase in domestic demand is significantly evident because of the increase in the transportation rate. Besides, by doubling this parameter, the environmental objective function is also doubled.

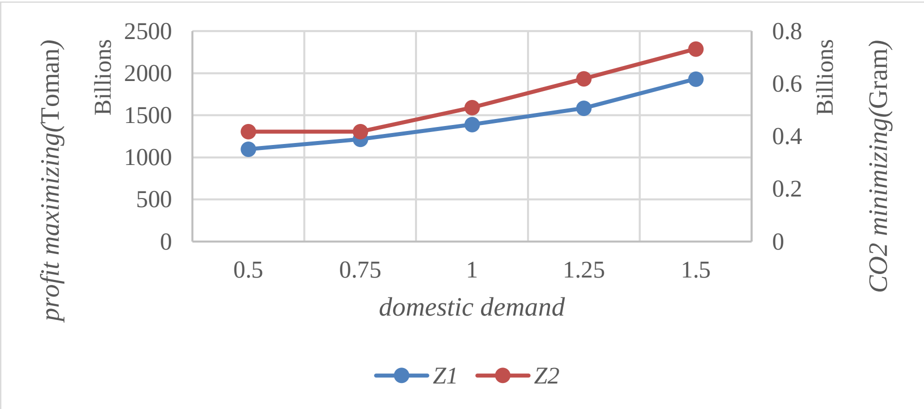

Fig. 5 Changes in domestic demand parameter

While changes in export demand have the same effect on the two objective functions, according to Fig. 6, the profit objective function decreases by 20% when export is halved and increases by 35% when it is doubled by 1.5. Furthermore, as the desired parameter is increased, the environmental function shows an upward trend. However, the changes in this objective function are much smaller than those in the first. Given that production capacity remains constant under all conditions, if export demand falls, the remaining capacity will supply the domestic market, activating more backup facilities. As a result, transportation emissions from backup facilities will increase, significantly more than primary facilities, increasing the environmental objective function. This process is repeated until more backup facilities are activated to meet the export demand, at which point the amount of CO_2 emissions begins to increase in proportion to the amount of export.

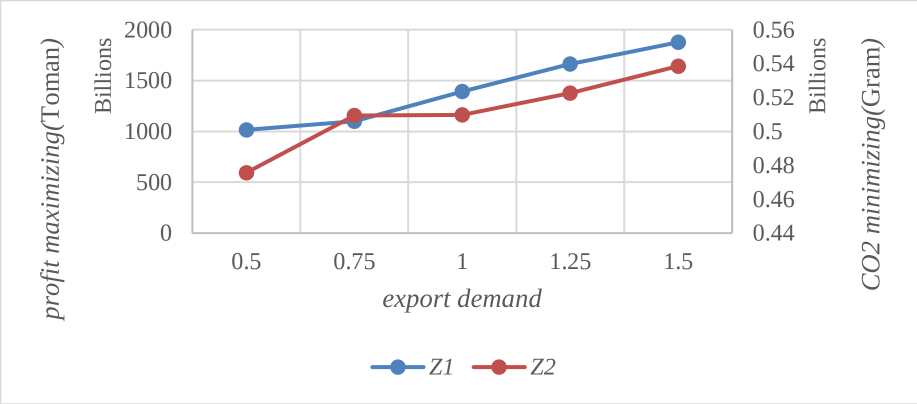

Fig. 6 Changes in export demand parameter

The results were obtained using the transportation cost parameter for the objective functions shown in Fig. 7. The total profit decreases almost linearly when the milling costs are changed. Because the changes in the environmental dimension differ from those in the first objective function, this function shows no changes with a 0.5 to 1.25 times decrease in transportation cost. As transportation costs rise, the amount of production and thus the ability to meet demand falls. The amount of CO_2emissions along the chain, however, is unaffected by the decrease in these costs. This means that the model prioritizes demand satisfaction over environmental concerns. However, point 1.5 in this graph is noticed because both objectives try to meet each other's goals.

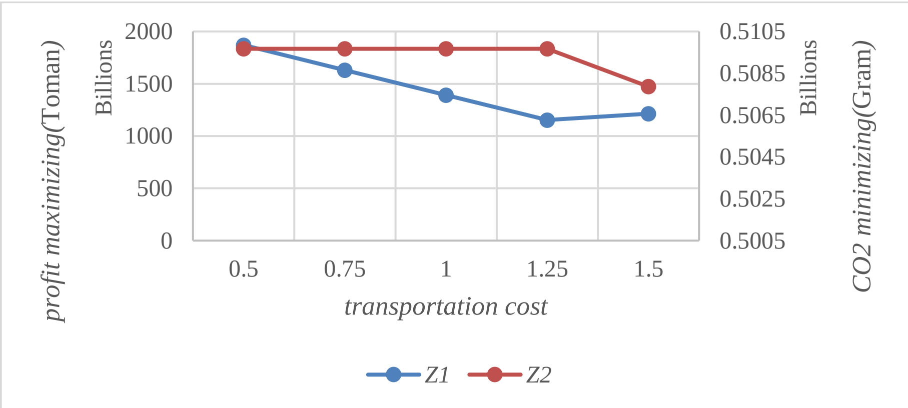

Fig. 7 Changes in transportation cost parameter

The level of corruption in factories and distribution centers yields interesting results to the changes in Fig. 8. By lowering this cost, the factory, and distribution center's desire to move the product to the next stage and sell it decreases. On the other hand, ensuring the quality and desirability of sustainability will incur additional costs. As a result, the chain's costs rise while its profit falls. This situation improves in the model's optimal state, but with the cost of corruption doubling, the expenditure along the chain return to the previous level. The environmental objective function, on the contrary side, works exactly opposite to the first function, with the difference that the ratio of changes in this function is significantly lower.

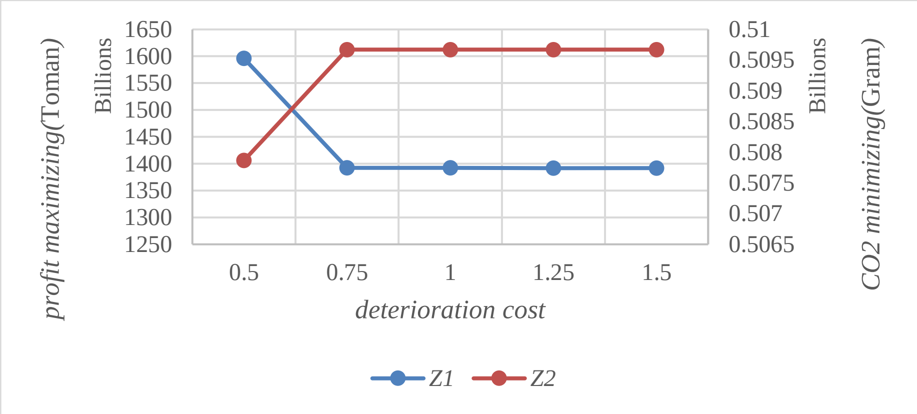

Fig. 8 Changes in deterioration cost parameter

One of the most critical parameters in this issue is the amount of CO_2 emitted. Its change will affect the behavior of both objective functions in nearly the same proportion as shown in Fig. 9. However, the economic objective function becomes more profitable as carbon dioxide emissions are reduced. On the other hand, as emissions rise, profits fall due to decreases in transportation and production.

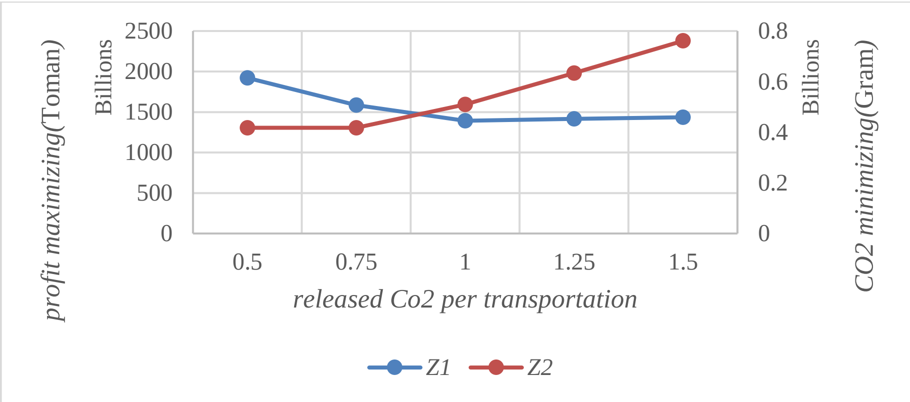

Fig. 9 Changes in released Co2 per transportation

We can easily comprehend why the first objective will be more affected than the other one by rising export demand and falling carbon dioxide. However, in comparison to other parameters, the cost of deterioration has a smaller influence on both objectives. Unexpectedly, another crucial factor that significantly influences the definition of the economic goal is the transportation cost parameter. When the parameter is halved, it results in an almost 35% increase. To find the best solution, it is crucial to make the right trade-offs between the parameters. Another comparison is provided in Table 7, which shows the shares of each part in the profit objective function. There is a significant difference between the sections dealing with quality satisfaction and export income.

Table 7 The values of each part in objective functions

variable	value (Billions)
z1	1390
z2	0.5
TF	416
TRQ	135
TRN	1034
TRD	1936
TC	956
TX	71
TEX	0.5
TSAT	0.1

Conclusion

A multi-objective and multi-period mathematical model of designing the broiler supply chain network of the real case study is suggested in this research. The economic and environmental objective functions are maximizing total SC profits and minimizing CO_2 absorption. In a world full of uncertainties, resiliency as one of the noteworthy issues is proposed in the offered model by the backup facility and multiple sourcing strategies. These strategies are implemented as a backup distribution center in every province and assigning multiple sources to slaughterhouses, production centers, and distribution centers. They have significantly reduced the impact of disruption in the supply chain.

According to the sensitivity analysis, there is a clear trade-off between environmental and economic objective functions in some parameters. Changes in an interval of [0.5, 1.5] to parameters such as chicken meat percentage, deterioration cost, and transportation cost produce the opposite behavior, such that if one increases, the other decreases. However, in the remaining parameters, the objectives exhibit nearly identical behavior, indicating the existence of a link between two objective functions. The most significant changes are in export demand, resulting in a significant disparity in objectives. Aside from the percentage of contribution of each part of the economic objective, the balance in the model's costs is revealed.

We aim to provide suggestions for future studies such as considering uncertainty in the parameters which are potentially uncertain in the real world like demand rate, disruption rate, etc. To solve these models, there would be several appropriate approaches to deal with uncertainty. Furthermore, the social objective function can be developed by adding different aspects along with economic and environmental objective functions. In addition, in the real world, import plays a major role in the production, supply, and distribution of chicken meat in the country, which is not considered in the proposed model. This variable can enter the model as the first level of decision-making under the role of the government and affect the second level which is the supply chain.

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Competing Interests

"The authors have no relevant financial or non-financial interests to disclose."

Author Contributions

"All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Niloufar Mostaghim, Mohammad Reza Gholamian and Mahsa Arabi. The first draft of the manuscript was written by Niloufar Mostaghim and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript."

Data Availability

"The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request."

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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