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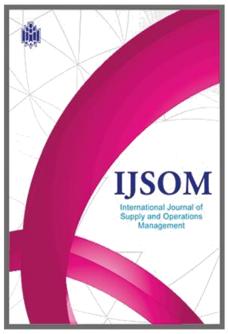

Multiple-Sourcing in Sustainable Closed-loop Supply Chain Network Design: Tire Industry Case Study

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Abstract

The interaction of sustainability and resilience has not been sufficiently addressed in the supply chain literature. Applying sustainability and resilience concepts in a supply chain means the simultaneous optimization of the cost and recourses, including human and environmental ones, in facing possible risks. This paper tries to fill this gap by considering them simultaneously in a closed-loop supply chain. For this, a new mixed-integer programming (MIP) model was formulated for a closed-loop supply chain. In this research, different dimensions of sustainable development have been taken into account through reducing the total cost, energy consumption, and pollution and increasing job opportunities, and multiple-sourcing strategy has been applied for the resiliency of the supply chain. To validate the proposed model, the real data of a tire industry was used and the model was solved using the ε-Constraint method. The results emphasized the necessity of combining sustainability and resilience in a closed-loop supply chain, where the high amounts of demand, in addition to increasing the cost, energy consumption, and pollution, increase job opportunities and the need to backup suppliers for raw materials.

Keywords: Multiple-sourcing, resilience, sustainability, tire closed-loop supply chain, ε-Constraint

1. Introduction

Supply chain problems are becoming more complex and more comprehensive. New features are included every day in supply chain models, which makes them closer to real-world conditions. In this paper, the problem evolution begins with the introduction of closed-loop supply chains. Due to environmental concerns and economic aspects in supply chain management (SCM), closed-loop supply chain (CLSC) emerges as a helpful strategy. It includes forward and reverse flows such that it produces added value for the manufacture (Guide & Van Wassenhove, 2003). A tire CLSC is a multi-level supply chain including suppliers, manufacturers, distributors, markets, collection centers, and recycling centers. Recycling centers prevent the extra burring of reusable wastes and provide a part of raw materials for manufacturing centers. Later, social considerations were added to environmental and economic dimensions, which resulted in the advent of a new concept as sustainable development. There is a strong correlation between the threefold dimensions of sustainability and applying them simultaneously brings about better supply chain management (SCM). Sustainability objective functions generally seek the reduction of cost and environmental effects and the improvement of social circumstances through making job opportunities or reducing lost workdays. A supply chain network may encounter disruptions. To face these disruptions, a supply chain has to be resilient. Resiliency is the ability to recover the initial state and have better conditions after a disruption (Christopher & Peck, 2004). Disruptions, which are a kind of risk, have several drivers such as natural disasters, workers' encounters, supplier bankruptcy, wars, terrorist attacks, etc. (Chopra & Sodhi, 2004). From the other disruption causes, changes in the rules, sanctions, and disorders of the transportation sector can be mentioned.

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In a supply chain, sustainability tries to manage natural resources appropriately and improve economic and social conditions by eliminating excessive costs and providing job opportunities for labors. Resiliency, on the other hand, focuses on the system responsiveness under disruptions. Thus, integrating sustainability and resilience concepts, as a new approach in supply chain management, can solve the mentioned problems.

To study the interaction of resilience and sustainability, the closed-loop supply chain of tire industry was selected as the case study of this research. Tire industry is a developing industry, where based on a prediction, the world market of this industry experiences a 3.8% yearly growth up to 2025 (http:researchandmarkets.com). By this rate of growth, more tires and, in turn, more scraps are produced. Therefore, some researchers have considered only environmental and economic dimensions in their models. For example, Sabulan et al. (2015) developed a two-objective model for a tire closed-loop supply chain. They used Taguchi design experiments to evaluate the effects of some factors on the profit and loss functions. Some researchers have sought profit increase in closed-loop supply chains (Pedram et al., 2017; Amin et al., 2017). In tire industry, there has also been some research on the simultaneous inclusion of the three dimensions of sustainability (Dehghanian and Mansour 2009; Sahebjamnia et al., 2018).

Up to now, no research has considered the integration of sustainability and resilience concepts in a closed-loop supply chain. To address this, this research integrates sustainability and resilience in a tire closed-loop supply chain. The main contributions of this research are as follows:

- Applying sustainability and resilience simultaneously to a closed-loop supply chain
- Investigating the role of multiple-sourcing in making a supply chain network resilient
- Solving the proposed model using the ε-Constraint method
- Applying the proposed model in the case of tire industry

The remaining sections of this paper are as follows. In Section 2, the literature of sustainable closed-loop supply chain and sustainable and resilient supply chains are reviewed. The problem definition and mathematical model are provided in Section 3. Section 4 presents the case study. In Section 5, the proposed method and computational results are illustrated. Section 6 is dedicated to sensitivity analysis. The conclusion and future research suggestions are given in Section 7.

2. The literature review

Each supply chain network has its unique components, constraints, and flows. As a result, the design of a supply chain network is a challenging part of SCM. In this regard, the related literature is divided into two categories: 1) sustainable closed-loop supply chain and 2) sustainable and resilient supply chain.

2.1. Sustainable closed-loop supply chain

In the past, the different dimensions of sustainability were addressed separately. However, it was known later that a considerable interaction exists among climate change, health, and poverty; climate change can jeopardize biodiversity, which, in turn, disturbs the supply of some products (Bouchery et al., 2016). Recent studies on sustainable CLSC indicates that the sustainability dimensions are in close interaction.

It should be noted that all reviewed studies of this section have considered the economic dimension, and some of them, by maximizing the profit of the total supply chain network, focused only on the economic dimension. Pedram et al. (2017) investigated the effects of demand uncertainty on CLSCs. They used the scenario analysis method to deal with uncertainty. Amin et al. (2017) developed a mixed-integer linear programming (MILP) model to maximize the profit of the whole supply chain network. They modeled the uncertainty using the decision tree approach, which calculated the total profit in multiple periods. Gaur et al. (2017) formulated a mixed-integer non-linear programming model for an integrated CLSC. To represent the applicability of their model, they used the real date of a battery producer, and to solve the proposed model, they applied outer approximation/equality relaxation/augmented penalty approaches.

Considering the environmental and economic dimensions of sustainable development, some researchers have focused on the green aspect of CLSCs. Zhen et al. (2019) designed a green and sustainable CLSC considering demand uncertainty. Talaei et al. (2016) developed an MILP model to minimize the total cost and CO_2 emission for a CLSC. Including some factors such as being multi-product and uncertainty of variable costs and demand, they tried to make their model much closer to the real world. Aiming at environmental effect reduction and total profit maximization, Subulan et al. (2015) studied a tire CLSC as their case study. They investigated different alternatives of recovery, including reproduction, recycling, and energy recovering. Concentrating on cost and environmental effect reduction, Yavari & Geraeli (2019) applied an MILP model for dairy products. They developed a heuristic approach to solve this model. The results showed that the life cycle of perishable goods and demand uncertainty rates are effective in their objective functions.

Some researchers of the CLSC context, however, considered all dimensions of sustainability. Sahebjamnia et al. (2018) used life-cycle assessment (LCA) to consider environmental effects on CLSCs. To deal with the problem NP-hardness, they used four hybrid metaheuristic algorithms. Soleimani et al. (2018) studied sustainability effects in mining industry using mathematical modeling. Their proposed model was aimed at minimizing energy consumption and maximizing the total profit. The social dimension was considered in their model as well. Using the real data of Travertine mining industry, they validated their model. Soleimani et al. (2017) designed a green and sustainable CLSC considering multiple-products, multiple raw materials, multiple parts, and multiple periods. Devika et al. (2014) and Fard & Hajiaghaei-Keshteli (2018) conducted studies applying the three sustainability dimensions in glass industry. Rezaei & Kheirkhah (2018) concentrated on inventory problems. They applied cross-docking strategy through the storage and warehousing of products where the products are directly delivered to customers. Kadambala et al. (2017) proposed a MILP model maximizing welfare level and minimizing energy consumption. Dehghanian and Mansour (2009) used LCA to assess environmental effects. They also used the analytical hierarchy process (AHP) to investigate social criteria. Considering mixed uncertainty, Zhalechian et al. (2016) integrated inventory-routing-location problems in CLSC networks. They used stochastic-possibility approach in dealing with network uncertainty.

2.2. Sustainable and resilient supply chain

The findings of the recent studies provide convincing reasons for integrating sustainability and resilience. For example, designing a sustainable and resilient supply chain by considering Carbon emission constraint brings about the reduction of procurement cost (Kaur & Singh, 2016). It was also revealed that cost-reduction activities of many factories result in the vulnerability of supply chain (Azevedo et al., 2013). Some of the other researchers tried to investigate the other aspects of interactions between sustainability and resilience; as an example, Pavlov et al. (2019) studied the contingency plan optimization for seaport operations. They consider both supply and network structural dynamics as an interchange between resilience supply chain and sustainable resource usage. This shows the necessity of integrating sustainability and resilience in SCM. Each industry faces some risks depending on its features and its conditions. The results of a study demonstrated that distribution problems and supply limitations may leave a crucial effect on supply chain vulnerability (Kaviani et al., 2016). Ivanov (2018) investigated resilience factors on the sustainability of supply chains, and the results showed that facility protection improves sustainability. So, integrating sustainability and resilience is a strong competitive advantage, because, on one hand, resilience reduces vulnerability, and on the other hand, sustainability tries to maintain a balance between three goals of economic, environmental, and social.

Some papers have explored the effects of resilience on sustainability in designing supply chain networks. For example, Zahiri et al. (2017) found that backup technology in drug supply chains requires considerable investment. Moreover, it was shown that the increase of capacity level leads to flow complexity and node complexity. Jabbarzadeh et al. (2018) found that three resilience strategies including contracting backup suppliers, multiple resourcing, and increasing excessive capacities results in the reduction of total cost of supply chains, which indicates the interaction between the economic dimension of sustainability and resilience. Fahiminia and Jabbarzadeh (2016) observed that in case of disruptions the demand for products could be satisfied through simultaneously applying sustainability and resilience. Kaur et al. (2018) investigated the decisions of procurement and product once separately and once in whole. The results indicated that the integration of sustainability and resilience leads to reduction in cost. Margolis et al. (2018) studied the interaction between the connectivity, as a resilience factor, and cost in a supply chain. Mohammed et al., (2019) developed a fuzzy multi-objective programming model for a green and resilient supply chain network. The three objectives of their model aimed to reduce cost and environmental effects and enhance resilience pillars such as agility, redundancy, leanness, and flexibility. Based on the reviewed papers, the design of a sustainable and resilient CLSC is a research gap, which we address in the following.

3. The problem definition and mathematical modeling

3.1. The problem definition

Based on the reviewed studies, no research has yet simultaneously considered sustainability and resilience concepts in a CLSC. By including sustainability, we seek supply chain improvement from economic, environmental, and social perspectives. On the other hand, resilience is actually the ability of a complex supply chain to survive, accommodate, and progress against sudden changes (Ponis & Koronis, 2012). For making a supply chain resilient, there are some strategies, which may affect industries differently depending on their supply chain characteristics and current conditions. In light of the growing demand for tire, providing raw material can be one of the challenging parts of this industry; according to this, the multiple-sourcing strategy is selected to overcome this risk. In the following section, the sustainability dimensions and selected strategy for making a CLSC resilient are described.

3.1.1. Boosting resilience through Multiple-sourcing strategy

Multiple-sourcing strategy is one of the most common strategies in making resilient a supply chain in facing disruptions (Jabbarzadeh et al., 2018). Some researchers have investigated the effect of single sourcing and multiple-sourcing on supply chains. For example, Burke et al. (2009) showed that single sourcing is suitable when demand average is low, but multiple-sourcing is helpful for high demand average. Thus, the second rank is reasonable for multiple-sourcing since tire demand is increasing due to different causes such as the increase of car manufacturing. The global demand for tires has reached from 1335 million in 2012 to 1626 million in 2018 (http:statista.com); Figure 1 displays the growth of global demand for car tires. The findings of other studies also basically confirm the preference of multiple sourcing to single sourcing. Namdar et al. (2018) for instance found that multiple-sourcing provides a better service level than single sourcing. Sawik (2014) discovered that for higher significance levels, single sourcing results in higher conditional value at risk (CVAR) than multiple-sourcing. All of the reviewed studies confirm the importance of multiple-sourcing strategy for supply chain resilience.

Multiple-sourcing strategy is of special importance when suppliers encounter disruptions and are not able to supply the required raw materials. A tire is composed of six major raw materials: caoutchouc, chemical materials, types of oils, soot, wire and fiber. These raw materials may engage more than 10 suppliers. This indicates the sensitivity of this issue in tire industry where in case of any disruption in supplier operations, the whole supply chain runs into trouble.

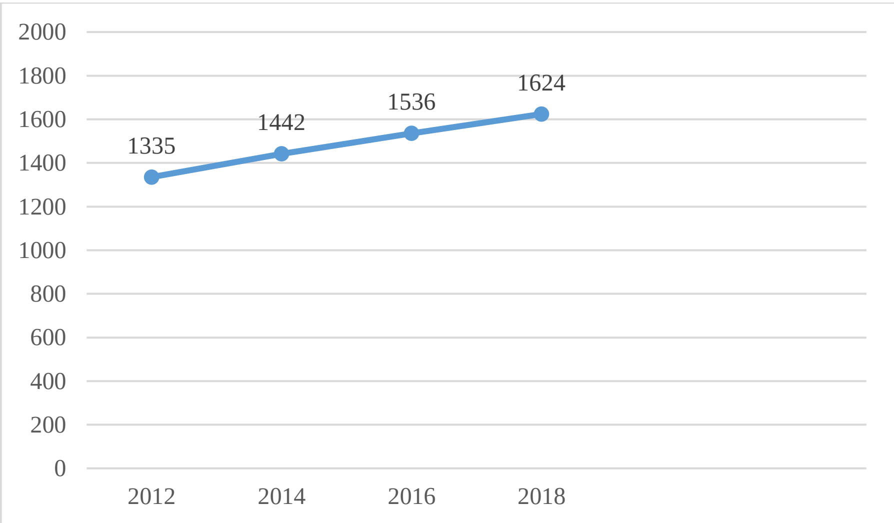

Figure 1. The global demand for car tires for the years 2012 to 2018 (in million)

3.1.2. Sustainability dimensions

Designing a sustainable supply chain network, managers must check the effects of supply chain operations on the environment and society because of the increasing green regulations, and social responsibility (Janatyan et al., 2018). The framework of the triple bottom line in this paper is discussed in the following.

- Economic dimension

Depending on the features considered for the supply chain, each member has different costs. For example, the primary and backup suppliers have costs such as the fixed cost of contracting the suppliers and raw materials. The costs of establishing information sharing system and information security system, manufacturing the final product (a tire ring), transportation between the supply chain members, opening manufacturing, distribution, collection, and recycling centers, and finally, purchasing the final product from different members are other costs of the supply chain network, which the objective function aims to minimize .

- Environmental dimension

To realize the environmental dimension of sustainability, recycling centers have been included in CLSCs. Recycling centers prevent scrapped tires from being buried in the environment. In the developed model, emitted pollutants, electric energy consumption, and water consumption are included. By pollutants we mean greenhouse gases such as CO_2 produced by the transportations between supply chain members and by some activities at manufacturing and recycling centers. In manufacturing centers, the majority of pollutants are emitted by boilers. On the other hand, the pollutants produced by the transportation sector should not be neglected since they are considerable in larger scales. Zhen et al. (2019) stated that the pollutant emitted by the transportation sector is greater than that of the industrial facilities. The amount of CO_2 emitted by ground, sea, and air transportations is respectively 62, 10, and 600 g CO_2/tonne.km (Jofred & Öster, 2011). The energy consumption at manufacturing centers is the electricity required for manufacturing salons and some processes, and water consumption is required for washing, drinking, and toilet use.

- Social dimension

In terms of job creation, tire industry is promising. In this research, the social dimension is realized through the fixed and variable job opportunities in manufacturing, distribution, collection, and recycling centers, and those of the raw material suppliers. Fixed job opportunities mean the facility primary employees, while variable ones are those the facilities indirectly contribute to and take different values under different scenarios. These variable job opportunities include the tutors for teaching guidelines, standards, and occasionally new technologies, drivers for employees' services, and drivers for raw material transportation and final products of the contractors.

3.1.3. Integrating sustainability and resilience in a CLSC

As was mentioned before, no research has addressed the interaction between sustainability and resilience in CLSCs. A research study in 2003 showed that the daily costs of a typical disruption in a supply chain are between 50 and 100 million dollars (Rice & Caniato, 2003). Such an enormous cost indicates the critical role of integrating sustainability and resilience because disruptions entail heavy costs, and the economic dimension of sustainability seeks cost reduction. Sustainability can be assessed through supply chain risk management, flexibility, and demand fluctuation (Tannous & Yoon, 2018); this confirms that sustainability and resilience are aligned.

3.2. The mathematical model

Based on the studies on sustainable CLSC and sustainable-resilient supply chain (Table 1), an MILP model is developed considering the three dimensions of sustainability and applying information sharing and multiple sourcing strategies in dealing with the disruptions of CLSCs. To approach the real world, some features such as having multiple products and multiple raw materials are added to the model, and the performance of the supply chain is evaluated under different scenarios.

Table 1. The reviewed papers in the context of CLSCs and sustainable-resilient SCs

Reference	Sustainability			Resiliency Measures	Solution method	Type of SC	Case Study
	Eco	Soc	Env				
Dehghanian and Mansour (2009)	✓	✓	✓	-	M	CLSC	Tire
Devika et al., (2014)	✓	✓	✓	-	M	CLSC	Glass
Subulan et al., (2015)	✓		✓	-	E	CLSC	Tire
Zhalechian et al., (2016)	✓	✓	✓	-	M	CLSC	LCD and LED TVs
Talaei et al., (2016)	✓		✓	-	E	CLSC	Electronics products
Fahimnia and Jabbarzadeh (2016)	✓	✓	✓	SBD	E	FSC	Sportswear
Kaur and Singh (2016)	✓		✓	P	E	FSC	-
Pedram et al., (2017)	✓			-	E	CLSC	Tire
Soleimani et al., (2017)	✓	✓	✓	-	M	CLSC	-
Amin et al., (2017)	✓			-	E	CLSC	Tire
Kadambala et al., (2017)	✓	✓	✓	-	M	CLSC	-
Gaur et al., (2017)	✓			-	H	CLSC	Battery
Zahiri et al., (2017)	✓	✓	✓	NCr, MS, FC, NC, CDL	M	FSC	Pharmaceutical
Fard and Hajiaghaei-Keshteli (2018)	✓	✓	✓	-	M	CLSC	Glass
Rezaei and Kheirkhah (2018)	✓	✓	✓	-	M	CLSC	-
Soleimani (2018)	✓	✓	✓	-	E	CLSC	Travertine stone
Sahebjamnia et al., (2018)	✓	✓	✓	-	M	CLSC	Tire
Jabbarzadeh et al., (2018)	✓	✓	✓	CB, MS, AE	M	FSC	Plastic pipe
Kaur et al., (2018)	✓		✓	P	E	FSC	-
Margolis et al., (2018)	✓			C	E	FSC	Food
Zhen et al., (2019)	✓		✓	-	E	CLSC	-
Yavari and Geraeli (2019)	✓		✓	-	H	CLSC	Dairy products
Mohammed et al., (2019)	✓		✓	RP	E	FSC	Meat supply chain
This study	✓	✓	✓	MS, AE	E	CLSC	Tire

Notes: AE: Adding extra supply/production capacities, C: Connectivity, CB: Contracting with backup suppliers/facilities, CDL: Customer de-service Level, CLSC: Closed-loop supply chain, E: Exact, Eco: Economic, Env: Environmental, FC: Flow complexity, FSC: Forward supply chain, H: Heuristic, M: Metaheuristic, MS: Multiple sourcing, NC: Node complexity, NCr: Node criticality, P: Procurement, RP: Resilience pillars, SBD: Scenario-based disruption, SC: Supply chain, Soc: Social.

Our designed CLSC network includes forward and backward flows. The primary and the backup suppliers, of course in case of disruptions, deliver the raw materials to the manufacturing centers. The tire products are manufactured there and delivered to distributors. They offer them to the target markets. Then, some scrapped tires in these markets are collected by collection centers and transferred to the recycling centers. Finally, by transforming the scrapped tires to raw materials, the recycling centers provide a part of required raw materials for making new tires. It is obvious that the recycling centers cannot provide all types of raw materials; thus, for the capacity of the recycling centers (CAP_r^s), the quantity shipped from the recycling centers to the manufacturing centers (Q_{rm}^s), and the purchasing price from the recyclers, no raw material index (w) has been considered. Figure 2 illustrates the designed CLSC. The major part of this modeling relates to integrating sustainability and resilience in a CLSC.

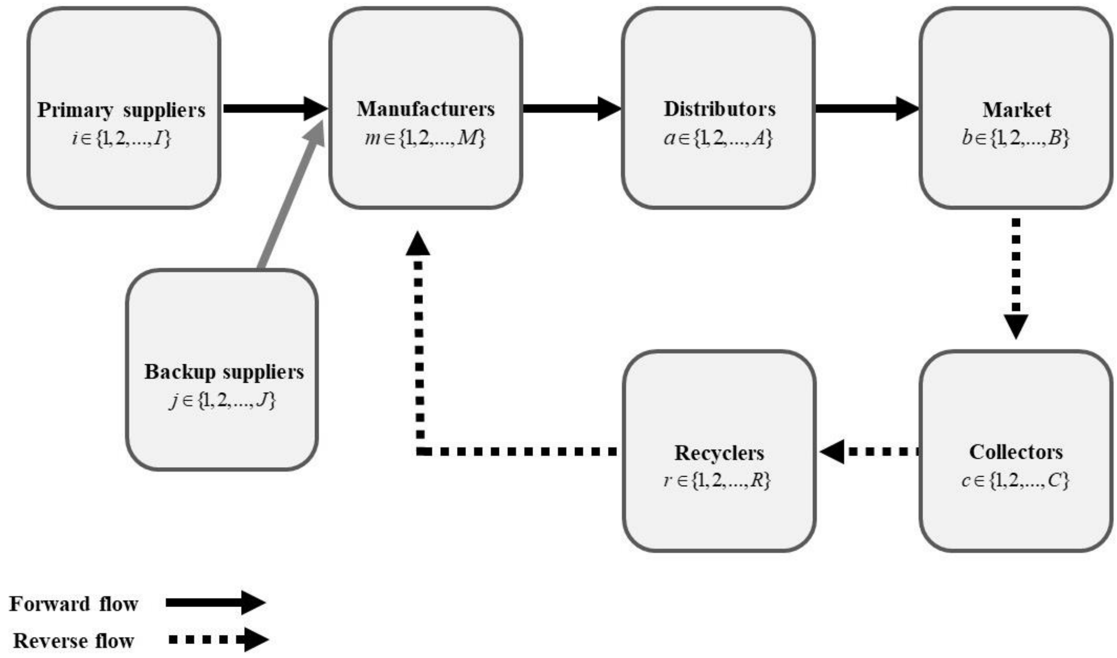

Figure 2. The tire closed-loop supply chain network

Based on the above explanations, a new multi-product multi-raw material MILP model is developed to integrate sustainability and resilience for a tire CLSC.

Assumptions:

- The raw materials for the two manufacturing centers are the same.
- The demand for the tire is assumed the same for all markets.
- The backup suppliers are always in access.
- The disruption probability for the backup suppliers is very small. Thus, the capacity of the backup suppliers is assumed larger than the primary ones.
- The disruptions have different drivers to which the primary suppliers face.

Indices

i	Index of the primary suppliers
j	Index of the backup suppliers
m	Index of the manufacturing centers
a	Index of the distribution centers
b	Index of the markets
c	Index of the collection centers
r	Index of the recycling centers

p	Index of the tire type
w	Index of the raw material type
s	Index of the potential disruption scenario

Parameters

RC_{wi}	The purchasing price of raw material w from primary supplier i
RC_{wj}	The purchasing price of raw material w from backup supplier j
CC_i	The fixed cost of contracting primary supplier i
CC_j	The fixed cost of contracting backup supplier i
LC_{pm}	The production cost for a tire of type p at manufacturing center m
ρ_s	The disruption probability in scenario s
N_i^s	The disrupted capacity of primary supplier i in scenario s
G_w	The quantity of raw material w for producing one final product
T_{wim}^s	The transportation cost of raw material w from primary supplier i to manufacturing center m in scenario s
T_{wjm}^s	The transportation cost of raw material w from backup supplier i to manufacturing center m in scenario s
T_{pma}^s	The transportation cost of one tire of type p from manufacturing center m to distribution center a in scenario s
T_{pab}^s	The transportation cost of one tire of type p from distribution center a to market b in scenario s
T_{pbc}^s	The transportation cost of one tire of type p from market b to collection center c in scenario s
T_{pcr}^s	The transportation cost of one tire of type p from collection center c to recycling center r in scenario s
T_{rm}^s	The transportation cost from recycling center r to manufacturing center m in scenario s
FC_m	The fixed cost of opening manufacturing center m
FC_a	The fixed cost of opening distribution center a
FC_c	The fixed cost of opening collection center c
FC_r	The fixed cost of opening recycling center r
CAP_{wi}^s	The capacity of primary center i for raw material w in scenario s
CAP_{wj}^s	The capacity of backup center j for raw material w in scenario s
CAP_{pm}^s	The capacity of manufacturing center m for the tire of type p in scenario s
CAP_{pa}^s	The capacity of distribution center a for the tire of type p in scenario s
CAP_{pc}^s	The capacity of collection center m for the tire of type p in scenario s
CAP_r^s	The capacity of recycling center r in scenario s
PUR_{pm}^s	The purchasing price of one tire of type p from manufacturing center m in scenario s
PUR_{pa}^s	The purchasing price of one tire of type p from distribution center a in scenario s
PUR_{pb}^s	The purchasing price of one tire of type p from market b in scenario s
PUR_{pc}^s	The purchasing price of one tire of type p from collection center c in scenario s
PUR_r^s	The purchasing price from recycling center r in scenario s

D_{pb}^{s}	The demand of market *b* for the tire of type *p*
α_{pb}^{s}	The percent of scrapped tires of type *p* returned from market *b* in scenario *s*
E_{im}^{s}	The pollution emitted by the transportation between primary supplier *i* and manufacturing center *m* in scenario *s*
E_{jm}^{s}	The pollution emitted by the transportation between backup supplier *j* and manufacturing center *m* in scenario *s*
E_{ma}^{s}	The pollution emitted by the transportation between manufacturing center *m* to distribution center *a* in scenario *s*
E_{ab}^{s}	The pollution emitted by the transportation between distribution center *a* and market *b* in scenario *s*
E_{bc}^{s}	The pollution emitted by the transportation between market *b* and collection center *c* in scenario *s*
E_{cr}^{s}	The pollution emitted by the transportation between collection center *c* and recycling center *r* in scenario *s*
E_{rm}^{s}	The pollution emitted by the transportation between recycling center *r* and manufacturing center *m* in scenario *s*
WU_{m}	Water consumption at manufacturing center *m*
WU_{r}	Water consumption at recycling center *r*
EE_{m}	Electric energy consumption at manufacturing center *m*
EE_{r}	Electric energy consumption at recycling center *r*
PE_{m}	The pollution emitted at manufacturing center *m*
PE_{r}	The pollution emitted at recycling center *m*
FJO_{i}	The fixed job opportunities created by selecting primary supplier *i*
FJO_{j}	The fixed job opportunities created by selecting backup supplier *j*
FJO_{m}	The fixed job opportunities created by opening manufacturing center *m*
FJO_{a}	The fixed job opportunities created by opening distribution center *a*
FJO_{c}	The fixed job opportunities created by opening collection center *c*
FJO_{r}	The fixed job opportunities created by opening recycling center *r*
VJO_{i}^{s}	The variable job opportunities created by selecting primary supplier *i* in scenario s
VJO_{j}^{s}	The variable job opportunities created by selecting backup supplier *j* in scenario s
VJO_{m}^{s}	The variable job opportunities created by opening manufacturing center *m* in scenario s
VJO_{a}^{s}	The variable job opportunities created by opening distribution center *a* in scenario s
VJO_{c}^{s}	The variable job opportunities created by opening collection center *c* in scenario s
VJO_{r}^{s}	The variable job opportunities created by opening recycling center *r* in scenario s

Decision variables

L_{pm}^{s}	The production quantity of tire of type *p* at manufacturing center *m* in scenario *s*
Q_{wim}^{s}	The quantity of raw material *w* transferred from primary supplier *i* to manufacturing center *m* in scenario *s*
Q_{wjm}^{s}	The quantity of raw material *w* transferred from backup supplier *j* to manufacturing center *m* in scenario *s*
Q_{pma}^{s}	The quantity of product *p* transferred from manufacturing center *m* to distribution center *a* in scenario *s*
Q_{pab}^{s}	The quantity of product *p* transferred from distribution center *a* to market *b* in scenario *s*

Q^{s}_{pbc}	The quantity of product *p* transferred from market *b* to collection center *c* in scenario *s*
Q^{s}_{pcr}	The quantity of product *p* transferred from collection center *c* to recycling *r* in scenario *s*
Q^{s}_{rm}	The quantity of recycled tire scraps transferred from recycling center *r* to manufacturing center *m* in scenario *s*
PS_i	If primary supplier *i* is selected, it is 1; otherwise 0.
BS_j	If backup supplier *i* is selected, it is 1; otherwise 0.
EST_m	If manufacturing center *i* is established, it is 1; otherwise 0.
EST_a	If distribution center *a* is established, it is 1; otherwise 0.
EST_c	If collection center *i* is established, it is 1; otherwise 0.
EST_r	If recycling center *r* is established, it is 1; otherwise 0.

$$Min\ Z_{Economic} = Z_1^F + Z_1^T + Z_1^V \tag{1}$$

$$Z_1^F = \sum_{m=1}^{M} FC_m * EST_m + \sum_{a=1}^{A} FC_a * EST_a + \sum_{c=1}^{C} FC_C * EST_c + \sum_{r=1}^{R} FC_r * EST_r + \sum_{i=1}^{I} CC_i * PS_i + \sum_{j=1}^{J} CC_j * BS_j + \sum_{w=1}^{W}\sum_{i=1}^{I} RC_{wi} * PS_i + \sum_{w=1}^{W}\sum_{j=1}^{J} RC_{wj} * BS_j \tag{2}$$

$$Z_1^T = \sum_{s=1}^{S} \rho_s \left[\sum_{w=1}^{W}\sum_{i=1}^{I}\sum_{m=1}^{M} T^s_{wim} * Q^s_{wim} + \sum_{w=1}^{W}\sum_{j=1}^{J}\sum_{m=1}^{M} T^s_{wjm} * Q^s_{wjm} + \sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{a=1}^{A} T^s_{pma} * Q^s_{pma} + \sum_{p=1}^{P}\sum_{a=1}^{A}\sum_{b=1}^{B} T^s_{pab} * Q^s_{pab} + \sum_{p=1}^{P}\sum_{b=1}^{B}\sum_{c=1}^{C} T^s_{pbc} * Q^s_{pbc} + \sum_{p=1}^{P}\sum_{c=1}^{C}\sum_{r=1}^{R} T^s_{pcr} * Q^s_{pcr} + \sum_{r=1}^{R}\sum_{m=1}^{M} T^s_{rm} * Q^s_{rm} \right] \tag{3}$$

$$Z_1^V = \sum_{s=1}^{S} \rho_s \left[\sum_{p=1}^{P}\sum_{m=1}^{M} L^s_{pm} * LC_{pm} + \sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{a=1}^{A} PUR^s_{pm} * Q^s_{pma} + \sum_{p=1}^{P}\sum_{a=1}^{A}\sum_{b=1}^{B} PUR^s_{pa} * Q^s_{pab} + \sum_{p=1}^{P}\sum_{b=1}^{B}\sum_{c=1}^{C} PUR^s_{pb} * Q^s_{pbc} + \sum_{p=1}^{P}\sum_{c=1}^{C}\sum_{r=1}^{R} PUR^s_{pc} * Q^s_{pcr} + \sum_{r=1}^{R}\sum_{m=1}^{M} PUR^s_{pr} * Q^s_{rm} \right] \tag{4}$$

The objective function (1) consists of three parts: 1) fixed costs of the CLSC Z_1^F ; 2) variable costs of the CLSC Z_1^V ; and 3) transportation costs between the CLSC members Z_1^T . The fixed costs include the establishment costs for manufacturing, distribution, collecting, and recycling centers, contracting the primary and backup suppliers, and raw material purchasing costs from the primary and backup suppliers. The variable costs include production cost of one tire, cost of purchasing the product from manufacturing and distribution centers, markets, and collection centers, and cost of purchasing from recycling centers.

$$Min\ Z_{Environmental} = Z_2^F + Z_2^V$$

$$Z_2^F = \left[\sum_{m=1}^{M} WU_m * EST_m + \sum_{r=1}^{R} WU_r * EST_r + \sum_{m=1}^{M} EE_m * EST_m + \sum_{r=1}^{R} EE_r * EST_r + \right.$$
$$\left. \sum_{m=1}^{M} PE_m * EST_m + \sum_{r=1}^{R} PE_r * EST_r \right]$$

$$Z_2^V = \sum_{s=1}^{S} \rho_s \left[\sum_{w=1}^{W} \sum_{i=1}^{I} \sum_{m=1}^{M} E_{im}^s * \mathrm{Q}_{wim}^s + \sum_{w=1}^{W} \sum_{j=1}^{J} \sum_{m=1}^{M} E_{jm}^s * \mathrm{Q}_{wjm}^s + \sum_{p=1}^{P} \sum_{m=1}^{M} \sum_{a=1}^{A} E_{ma}^s * \mathrm{Q}_{\mathrm{pma}}^{\mathrm{s}} + \right.$$
$$\left. \sum_{p=1}^{\mathrm{P}} \sum_{a=1}^{A} \sum_{b=1}^{B} E_{ab}^s * \mathrm{Q}_{\mathrm{pab}}^{\mathrm{s}} + \sum_{p=1}^{\mathrm{P}} \sum_{b=1}^{B} \sum_{c=1}^{C} E_{bc}^s * \mathrm{Q}_{\mathrm{pbc}}^{\mathrm{s}} * \alpha_{pb}^s + \sum_{p=1}^{P} \sum_{c=1}^{C} \sum_{r=1}^{R} E_{cr}^s * \mathrm{Q}_{\mathrm{pcr}}^{\mathrm{s}} + \sum_{r=1}^{R} \sum_{m=1}^{M} E_{rm}^s * \mathrm{Q}_{\mathrm{rm}}^{\mathrm{s}} \right]$$

The objective function (2) is comprised of two parts: Z_2^F is the pollution emitted at manufacturing and recycling centers and water and electricity energy consumption at these centers, and Z_2^V denotes the pollution emitted by the transportation between the supply chain members.

$$Max\, Z_{Social} = Z_3^F + Z_3^V$$

$$Z_3^F = \left[\sum_{i=1}^{I} FJO_i * PS_i + \sum_{j=1}^{J} FJO_j * BS_j + \sum_{m=1}^{M} FJO_m * EST_m + \sum_{a=1}^{A} FJO_a * + EST_a + \right.$$
$$\left. \sum_{c=1}^{C} FJO_c * EST_c + \sum_{r=1}^{R} FJO_r * EST_r \right]$$

$$Z_3^V = \sum_{s=1}^{S} \rho_s \left[\sum_{i=1}^{I} VJO_i^s * (\mathrm{Q}_{wim}^s / CAP_{wi}^s * (1 - N_i^s)) + \sum_{j=1}^{J} VJO_j^s * (\mathrm{Q}_{wjm}^s / CAP_{wj}^s) + \right.$$
$$\sum_{m=1}^{M} VJO_m^s * (\mathrm{Q}_{\mathrm{pma}}^{\mathrm{s}} / CAP_{pm}^s) + \sum_{a=1}^{A} VJO_a^s * (\mathrm{Q}_{\mathrm{pab}}^{\mathrm{s}} / CAP_{pa}^s) + \sum_{c=1}^{C} VJO_c^s * (\mathrm{Q}_{\mathrm{pcr}}^{\mathrm{s}} / CAP_{pc}^s) +$$
$$\left. \sum_{r=1}^{R} VJO_r^s * (\mathrm{Q}_{\mathrm{rm}}^{\mathrm{s}} / CAP_r^s) \right]$$

The objective function (3) is divided into two parts: 1) Z_3^F which includes fixed job opportunities created by the establishment of manufacturing, distribution, collecting, and recycling as well as by the selection of the primary and backup suppliers; and 2) Z_3^V which are the variable job opportunities, taking different values under different scenarios.

Subject to

$$\sum_{w=1}^{W} \sum_{i=1}^{I} (1\text{-}\rho_s) * \mathrm{Q}_{wim}^s + \sum_{w=1}^{W} \sum_{j=1}^{J} \mathrm{Q}_{wjm}^s = \sum_{w=1}^{W} \sum_{p=1}^{P} L_{\mathrm{pm}}^{\mathrm{s}} * G_w \quad \forall s \in S, m \in M \tag{11}$$

Constraint (11) identifies the raw materials required for one unit of the product. In this constraint, ρ_s , the occurred disruption scenario, is multiplied at Q^{s}_{wjm}, the quantity of raw materials transferred from the backup suppliers to the manufacturing centers, to obtain the quantity of raw materials based on the occurred scenario.

$$\sum_{c=1}^{C} Q^{s}_{pbc} \le D^{s}_{pb} * \alpha^{s}_{pb} \quad \forall s \in S, p \in P, b \in B \tag{12}$$

Constraint (12) ensures that only a part of scrapped tires can be collected by the collection centers from the markets.

$$\sum_{p=1}^{P} L^{s}_{pm} + \sum_{r=1}^{R} Q^{s}_{rm} = \sum_{p=1}^{P}\sum_{a=1}^{A} Q^{s}_{pma} \quad \forall s \in S, m \in M \tag{13}$$

$$\sum_{m=1}^{M} Q^{s}_{pma} = \sum_{b=1}^{B} Q^{s}_{pab} \quad \forall s \in S, p \in P, a \in A \tag{14}$$

$$\sum_{a=1}^{A} Q^{s}_{pab} = D^{s}_{pb} \quad \forall s \in S, p \in P, b \in B \tag{15}$$

$$\sum_{a=1}^{A} Q^{s}_{pab} \ge \sum_{c=1}^{C} Q^{s}_{pbc} * \alpha^{s}_{pb} \quad \forall s \in S, p \in P, b \in B \tag{16}$$

$$\sum_{b=1}^{B} Q^{s}_{pbc} * \alpha^{s}_{pb} = \sum_{r=1}^{R} Q^{s}_{pcr} \quad \forall s \in S, p \in P, c \in C \tag{17}$$

$$\sum_{p=1}^{P}\sum_{c=1}^{C} Q^{s}_{pcr} = \sum_{m=1}^{M} Q^{s}_{rm} \quad \forall s \in S, r \in R \tag{18}$$

Constraints (13) to (18) are the flow constraints. The raw materials transferred from the primary and backup suppliers to the manufacturing centers. The products are produced at manufacturing centers, and then, delivered to the distributors. They deliver them to the markets. The amount of the product delivered by the distributors to the market is actually the demand. Then, a part of the scrapped tires is collected by the collection centers from these markets and are transferred to the recycling centers. They are converted there to raw material and transferred to the manufacturing centers

$$L^{s}_{pm} \le CAP^{s}_{pm} \quad \forall s \in S, p \in P, m \in M \tag{19}$$

Constraint (19) indicates that the product produced at a manufacturing center is less than its capacity.

$$\sum_{m=1}^{M} Q^{s}_{wim} \le CAP^{s}_{wi} * \left(1 - N^{s}_{i}\right) \quad \forall s \in S, w \in W, i \in I \tag{20}$$

$$\sum_{m=1}^{M} Q^{s}_{wjm} \le CAP^{s}_{wj} \quad \forall s \in S, w \in W, j \in J \tag{21}$$

Constraints (20) and (21) specifies the capacity of the primary and backup suppliers.

$$\sum_{a=1}^{A} Q^{s}_{pma} \le CAP^{s}_{pm} * EST_{m} \quad \forall s \in S, p \in P, m \in M \tag{22}$$

$$\sum_{b=1}^{B} Q^{s}_{pab} \le CAP^{s}_{pa} * EST_{a} \quad \forall s \in S, p \in P, a \in A \tag{23}$$

$$\sum_{r=1}^{R} Q^{s}_{pcr} \le CAP^{s}_{pc} * EST_{c} \quad \forall s \in S, p \in P, c \in C \tag{24}$$

$$\sum_{m=1}^{M} Q^{s}_{rm} \le CAP^{s}_{r} * EST_{r} \quad \forall s \in S, r \in R \tag{25}$$

Constraints (22) to (25) are the capacity constraints for the manufacturing, distribution, collecting, and recycling centers.

$$PS_{i}, BS_{j}, EST_{m}, EST_{a}, EST_{c}, EST_{r} \in \{0,1\} \tag{26}$$

$$L^{s}_{pm}, Q^{s}_{wim}, Q^{s}_{wjm}, Q^{s}_{pma}, Q^{s}_{pab}, Q^{s}_{pbc}, Q^{s}_{pcr}, Q^{s}_{rm} \ge 0 \tag{27}$$

Binary and nonnegative variables are imposed by constraints (26) and (27).

4. Case study

Tire industry is an interdisciplinary industry employing petrochemical and vehicle technologies. In Iran, it is a prospering industry, wherein there are nine tire factories; the largest production share with 36.4% belongs to Barez factory`. The shares of different tire factories of Iran in 2017 has been shown in Figure 3. (http:babc.ir).

Barez factory has two manufacturing centers, one in Kerman and the other in Kurdistan State. In this research, to validate the proposed model, real data of Kurdistan's Barez factory is used. These data are shown in Table 2. It should be noted that the cost data in Rial currency has been converted to the US dollar (https:x-rates.com).

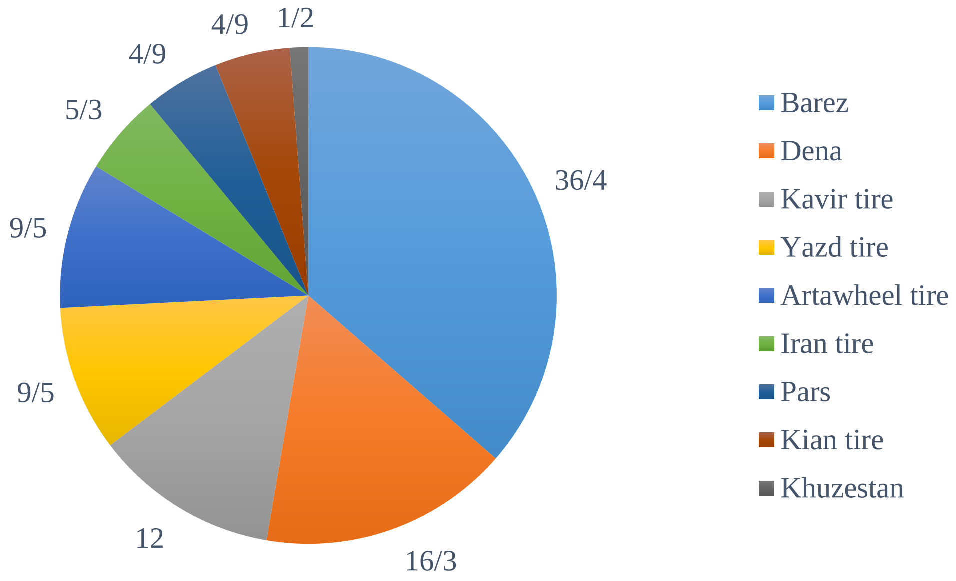

Figure 3. The production share of different tire factories in Iran

The tires produced in Barez factories are technologically divided into radial and bias tires. The radial tires are the major production, and their technology is newer than that of bias tires. In radial tires, the fibers are placed 90^{0c} and are made from rayon, while in bias tires, the layers are placed cross-ply, and the fiber used is made from nylon.

Table 2. The real data of the case study

Parameter	Value in model	Notes
CAP_{pm}^{s}	6,000,000 tire ring	This study
FJO_{m}	600 person	This study
VJO_{m}^{s}	2,000-2,500 person	This study
WU_{m}	50 Litr/h	This study
EE_{m}	11 MW.h	This study
PE_{m}	5,000 m^3/h	This study
LC_{pm}	37 $-1,980 $	This study
PUR_{pm}^{s}	41 $-2,194 $	This study
FC_{m}	168,000,000 $-192,000,000 $	This study
G_{w}	8 kg	Pedram et al., (2017)
FC_{c}	1,200,000-2,000,000 $	Pedram et al., (2017)
FC_{a}	900,000-2,100,000 $	Pedram et al., (2017)

5. The solving approach and computational results

In this research, the ε-Constraint approach is used for generating Pareto optimal solutions. This approach was originally developed in 1971 for multi-objective models (Haimes et al., 1971). It is a multi-objective decision making method that generates a Pareto optimal set as follows:

$$
\begin{aligned}
& Min\ f(x_1) \\
& s.t. \\
& f(x_2) \le \varepsilon_1 \\
& f(x_3) \ge \varepsilon_2 \\
& \min f(x_2) \le \varepsilon_1 \le \max f(x_2) \\
& \min f(x_3) \le \varepsilon_2 \le \max f(x_3)
\end{aligned}
\tag{28}
$$

where $f(x_1)$, $f(x_2)$, and $f(x_3)$ are respectively the first to third objective functions. In this structure, one of the objective functions is optimized and the others operate as a constraint.

For solving the proposed model using the ε-Constraint approach, GAMS software of version 24.1.3 and CPLEX solver were used. The Pareto optimal solutions were calculated in 15 iterations. The set of these Pareto solutions is shown in Table 3.

Table 3. Pareto optimal solutions of the objective functions

Itteration	Value of objective functions		
	$Z_{Economic}$	$Z_{Environmental}$	Z_{Social}
1	2024068333.96	758504903.92	87916.90
2	2008997331.21	729233848.53	84017.46
3	1994361803.52	699962793.13	78014.19
4	1979726275.82	670691737.73	72852.40
5	1965090748.12	641420682.33	66849.99
6	1950455220.42	612149626.94	61747.27
7	1935819692.72	582878571.54	55653.58
8	1921184165.02	553607516.14	53160.14
9	1915695924.19	537418844.15	58291.22
10	1928828907.22	563684810.20	63422.30
11	1942237699.54	590502394.84	68553.38
12	1956426440.83	618879877.43	73684.46
13	1971154578.60	648336152.96	78815.54
14	1987491885.42	681010766.59	83946.62
15	2005867795.16	717762586.09	89077.70

6. The sensitivity analysis of market demand changes

Sensitivity analysis is necessary for finding the best possible solution so that we can reach a more acceptable performance in facing difficulties of real-world problems. Change in the demand of a tire product (D^{s}_{pb}) has different impacts on the designed CLSC:

- It increases the total cost of the entire supply chain.
- It increases the energy consumption and pollution.
- It creates more job opportunities.
- With the increase of the demand, the manufacturers need more backup suppliers of raw materials in case of disruptions (considering $\rho_s = 0.95$, $i = 10$, $j = 10$). Considering the high demand of the tire, this result is in line with that of Burke et al. (2009) that multiple sourcing is an appropriate strategy for high demand products.

With the increase of the demand, more raw materials are required for producing tires. On the other hand, backup suppliers are essential for supplying raw materials under disruptions. Thus, as the demand increase, more backup suppliers are needed. Providing backup suppliers entails costs such as signing the contract, purchasing the raw materials, and transporting them. Besides, higher demands result in higher production, which not only increases the cost of the entire network but also increases the energy consumption and the pollutions made by the facilities and transportations. Moreover, more human labor is needed in this case. Generally, in the designed CLSC, the demand changes affect both sustainability and resilience aspects, verifying the necessity of combining these concepts. The outcomes of demand changes for 15th iteration are represented in Table 4. Figure 4 illustrates the interaction of the demand and objective functions.

Table 4. The transported raw materials from the suppliers to the manufacturers

ρ_s	Demand	Raw material	Backup supplier	Manufacturer	
				1	2
0.95	5000	Type 1	1	9000000	-
		Type 2	1	2310507.54	-
	25000	Type 1	1		9000000
		Type 1	2	5905255,62	2150000
		Type 2	1		9000000
		Type 3	1		9000000
		Type 4	1	9000000	
		Type 5	1	9000000	
		Type 6	1	9000000	

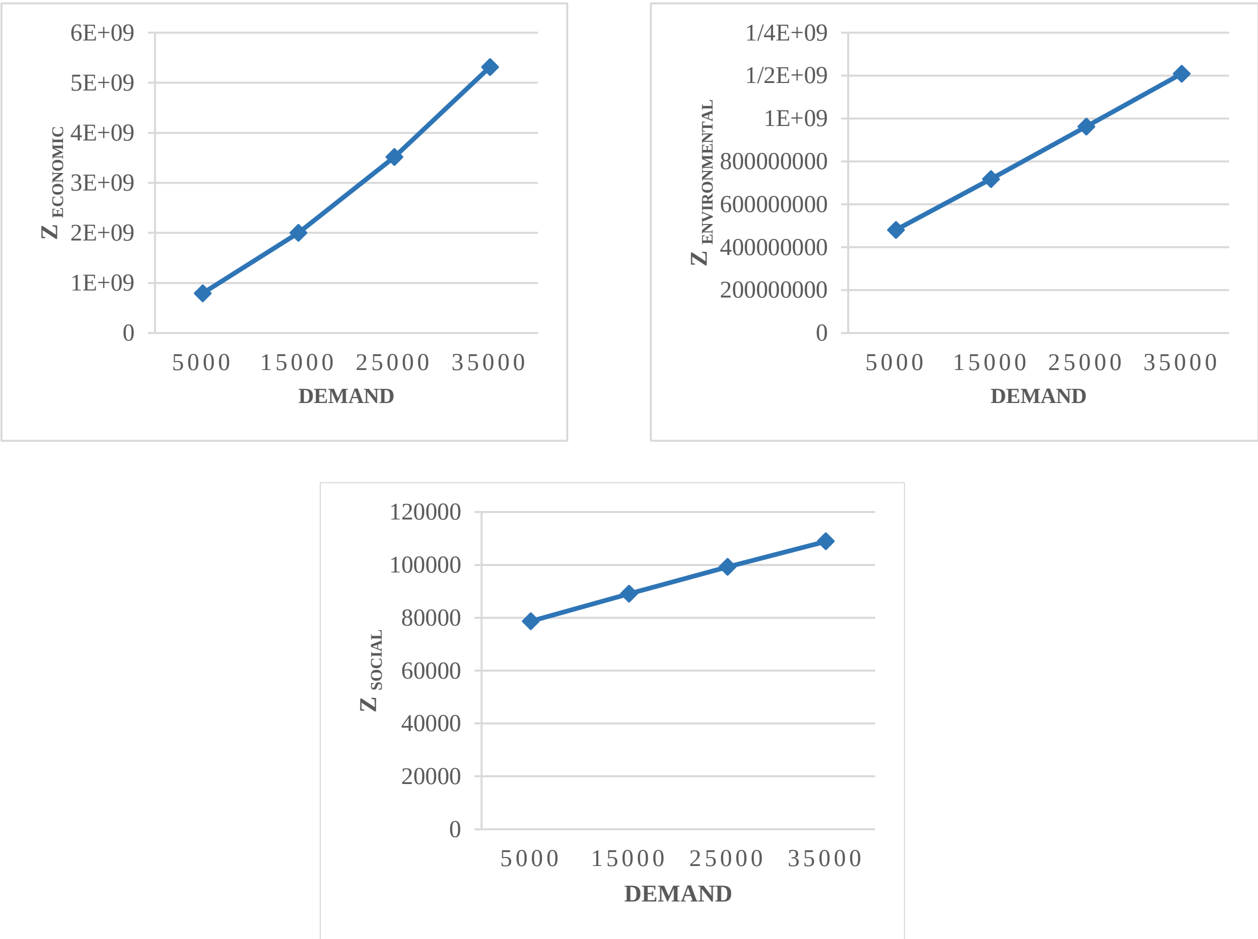

Figure 4. The relationship between the demand parameter and the sustainability objective functions ($Z_{Economic}$, $Z_{Environmental}$, and Z_{Social})

7. Conclusion

Integrating sustainability and resilience concepts, a new multi-objective MILP model was developed for a closed-loop supply chain. To validate the proposed model, the real data of the Barez factory located at Kurdistan State was applied to the model. Due to the multi-objectivity of the model, the ε-Constraint method was used to solve it. Finally, to study the performance of the model under different conditions, a sensitivity analysis was performed on the demand parameter, and different scenarios were considered to analyze the effect of different resilience strategies. The results showed that the demand changes affect both sustainability and resilience concepts:

- The total cost of the CLSC, energy consumption and pollutant emission, and job opportunities are in line with the demand changes.
- For the high demands of the product, more backup suppliers are needed.

These results confirm that resilience concept should be applied to deal with the disruptions of a sustainable CLSC.

To more develop the studies of this context, some of the study's limitations of this paper should be addressed. Considering disruption for the other elements of the supply chain network such as distributors, recycling centers, and manufacturing centers can be an opportunity for future researches. Applying other strategies to boost resilience in CLSC can be attended in future studies. The effects of integrating sustainability and resilience concepts can be investigated for the CLSCs of other industries. Furthermore, Other problem-solving approaches including heuristic and metaheuristic methods can be applied.

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