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# A NEUTROSOPHICAL MODEL FOR OPTIMAL SUSTAINABLE CLOSED-LOOP SUPPLY CHAIN NETWORK WITH CONSIDERING INFLATION AND CARBON EMISSION POLICIES

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**_Abstract:_** *In this paper, a stable CLSC problem is modelled in conditions of uncertainty and indeterminacy. The SCN is designed to maximize NPV and minimize carbon releases by maintaining environment friendly policies and accounting for increase. To achieve a suitable model for designing a stable CLSCN and making important decisions such as selecting the right suppliers, selecting the type of transport, initial the facility, the optimal flow between facilities and accomplishing an efficient solution to the problem decision making, the neutrosophic optimization method is used. The results of experiments that discuss and evaluate different scenarios confirm the efficiency and validity of the proposed model. The findings also show that the effective improvement of the obtained solutions by reducing the solution time up to twenty percent can be responsible for large-scale problems in different scenarios. This paper uses a neutrosophic optimization method to solve the problem of designing a stable CLSCN under uncertainty and indeterminacy.*

**Key words**: *Sustainability, Closed-loop supply chain network (CLSCN), supply chain management (SCM), Net present value (NPV), Neutrosophic optimization, Neutrosophic logic.*

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## 1. Introduction

A sustainable SC is envisaged based on the TBL, including economic, social and environmental. Many academics and artisans have considered SSCM in recent decades. SSCM helps companies reduce their environmental pollution and risks, improve environmental performance, create stronger market benefits, increase brand equity and reputation, lower overall costs, consider wet, and bring better relationships with consumers (Saberi et al., 2019; Ansari & Kant, 2017). While the triple bottom line approach has been adopted in research on performance sustainability in SSCM, research on environmental dimensions has been more prominent (Gimenez et al., 2012; Acquaye et al., 2018). Inquiry on multiple dimensions of stability is very important, because these dimensions simultaneously affect each other and the stability performance (Homayouni et al., 2021). Waste (Ayvaz et al., 2015), Development of new products (Jahani et al., 2017), and humanitarian procurement is considered. On the other hand, with more consumer awareness of environmentally friendly products, adopting ways to reduce adverse environmental impacts on production activities has become essential. This is the problem also in other sectors such as the electronics industry, transportation of hazardous materials (Golpîra et al., 2021; Mohabbati-Kalejahi & Vinel, 2021), medicine distribution (Low et al., 2016), oil (Paydar et al., 2017), and disposable goods (Gholizadeh & Fazlollahtabar, 2020; Gholizadeh et al., 2020) are discussed. On the other hand, due to the short product life cycle and lower profit margins, companies' Closed-loop SC is now a necessity. At the Closed-loop SC, forward and reverse logistics systems are integrated simultaneously. Inverted SC logistics are responsible for managing product returns for recycling, reuse or disposal. Reverse logistics also helps create a competitive advantage and increases the company's profit margin by re-targeting the products used (Govindan & Soleimani, 2017).

In the same way, researchers argue that reverse logistics is essential to the supply chain's environmental and economic issues in today's unstable market (Polo et al., 2019). More interaction between PD and PR is needed with more emphasis on sustainable production. PR helps improve the organization's environmental compatibility and reduce production costs. Research on CLSCN design is important for SSCM (Govindan et al., 2017, 2020). An efficient product recovery process and related closed-loop supply chain configuration encourages customers to return their products at the end of their useful life and, through integrated planning, reduce the environmental impact of landfills and product recovery. Closed-loop SC meets demand through chain operations and value-added processes by collecting return products intended for reuse, recycling or disposal (Darbari et al., 2019). In Closed-loop SC design, the management of reverse logistics operations becomes more difficult when many decision variables and their uncertainties affect the environment. (Sel & Bilgen, 2015; Morganti & Gonzalez-Feliu, 2015).

In this regard, the design of CLSCN in areas such as the dairy industry (Yavari & Geraeli, 2019), plastic recycling industry (de Vargas Mores et al., 2018), energy industry (Mohtashami et al., 2020), gasoline industry (Saedinia et al., 2019), perishable products (Yavari & Zaker, 2020), and engine oil industry (Paydar et al., 2017) were used.

0n the contrary, designing a sustainable CLSCN is a strategic decision. It is difficult to accurately estimate some parameters, such as demand, due to changes in the business environment (Yun et al., 2020). Therefore, some important parameters such as customer demands are completely unclear and appropriate planning to deal with this uncertainty seems necessary. In this connection, studies on the design of a stable

CLSC under uncertainty have attracted the attention of researchers, which can be referred to (De & Giri, 2020; Alegoz et al., 2020). In a stable CLSC, financial factors are important because they have a greater impact on supply, production, distribution, and recycling. All SC decisions affect how allocation and financing are funded (Yang et al., 2021). The inflation expectations, how the budget deficit is met, and the monetary and liquidity base change are important for the industry, as the inflation from exchange rate fluctuations to supply raw materials and production or recycling technology strongly influences SCLSC policies (Wan & Hong, 2019). Based on what has been said, the contribution of this paper in the field of optimization-based decision models, on the one hand, is to consider sustainability factors (economic and environmental) that both sustainability factors with the assumption that facilities can be affected by these goals. In addition, the development of a robust fuzzy optimization model, using appropriate risk measurements, is used to formulate uncertainty changes in the face of market fluctuations, set uncertain parameters whose distribution functions are unknown, and then use a neutrosophical approach for the total problem.

On the other hand, this model selects the most appropriate options according to the existing and potential activities such as supplier selection and selection of the transportation modes and problems related to carbon emission policies. Total relationships, changes, and purchases should be related to process structure and cost. To calculate economic criteria for companies' options, fixed costs include opening or using facilities or technology costs, and variable costs include emissions, transportation, production, distribution, waste disposal, and recycling. On the other hand, the net present value is an optimization criterion in the utility function. Because the NPV compares investment options, where period, cost of capital and inflation are outstanding criteria for evaluating recycled products. Because new recycled products have little or no market access at first, it is important to evaluate different periods in this study. Therefore, considering the demand based on multi-period conditions, it is possible to use the annual compound growth rate attached to certain products, affecting the opening up of technology. This study provides an operational and strategic framework for designing a stable CLSC under uncertainty, minimizing environmental impacts while maximizing the proposed network NPV. This article considers a correct MOMP model with uncertainty with a case study on electronic component chains to achieve these goals. On the other hand, due to the complexity of the MOP nature of the proposed model, a new HM based on a HA with a neutrosophical approach to solve these problems is proposed.

In the continuation of this paper, in Section Two, the literature review is reviewed, and the research gap is identified. In Section Three, the structure of the problem is examined, and the proposed model is shown according to the hypotheses. In Section Four, the uncertain optimization model is discussed. Section Five proposes the Neutrosophical model and defines the hybrid method for the solution. Section Six also discusses the analysis of the proposed model and the proposed solution method. At the end, in Section Seven, conclusions and future suggestions are stated.

## 2. Literature review

### 2.1. Neutrosophic Logic

Crisp set theory can only grip the data having no ambiguity or uncertainty. The crisp set theory comes into play only when the boundary of a piece of information is clear-cut or has sharp boundaries. There is no uncertainty about the location of the set boundaries. The concept of fuzzy set theory is an extension of characteristic functions of crisp sets by enlarging the truth value set of ' grade of membership' from the two-value set {0, 1} to the unit interval [0, 1] of infinite real numbers. Many applications need fuzzy sets (Mendel, 1995; Ross, 2005; Zimmermann, 2011; Merigó et al., 2015; Feng & Chen, 2018; Voskoglou, 2020; Das et al., 2021; Sorourkhah & Edalatpanah, 2022). Although, it has a shortcoming, i.e., it only addresses membership value and is unable to address the non-membership value. It is a fact that not all logical and actual models depend only on evident evaluations of participation and the true value of membership. There may emerge a state of affairs where the level of non-enrollment and grades of non-membership is additionally needed with membership degree. Atanassov (1986) introduced the new idea of a new theory known as the intuitionistic fuzzy set theory that combined this strength of rejection with acceptance strength in new sets. Molodtsov (1999) installed the conception of the theory of soft set that plays an important role in every field of mathematics. Yager (2013) introduces the Pythagorean fuzzy set. These ideas opened a new era towards generalizations of fuzzy sets and were applied in numerous applications (Torra, 2010; Wei, 2016; Wei et al., 2021; Vellapandi & Gunasekaran, 2020; Umoh et al., 2020; Akram et al., 2021; Rayappan & Mohana, 2021). Although these theories can deal with incomplete data in various real-world situations, they cannot deal with all sorts of uncertainty, such as indeterminate and inconsistent data. Florentin Smarandache's neutrosophic theory (Smarandache, 1999) is a further expansion of the previously discussed fuzzy extension sets. The Neutrosophic Set (NS) can deal with uncertain, indeterminate, and discordant information, where the indeterminacy is explicitly quantified, and truth membership, indeterminacy membership, and falsity membership are all fully independent. After that, some types of NSs have been proposed (Lupiáñez, 2009; Wang et al., 2010; Ye, 2014; Ulucay et al., 2018; Liu & Cheng, 2020; Edalatpanah, 2020; Luo al., 2022). Furthermore, in neutrosophical literature, several applications such as facility location and routing (Deveci et al., 2021), SSP (Pamucar et al., 2020), social failure detection (Torkayesh et al., 2022), linear programming (Edalatpanah, 2019; Das et al., 2021) and (Kumar et al., 2021), time series models (Pattanayak et al., 2022), DEA (Mao et al., 2020), SPP (Kumar et al., 2019), MCDM (Deli et al., 2021), etc. have been addressed.

## 2.2. CLSCN

The design of a CLSCN for decisions such as the flow of materials and products, location of facilities, production, distribution and product recycling has attracted the attention of many researchers in the last decade. However, some studies have focused on maximizing profits in the CLSC. Others have focused on minimizing a CLSCN (Nayeri et al., 2020). In addition, several researchers have focused on minimizing environmental impacts (Talaei et al., 2016), minimizing the loss of working days (Soleimani et al., 2017), maximizing social accountability (Heydari & Rafiei, 2020), maximizing demand coverage (Wang & Lee, 2015), maximizing economic value added (Polo et al., 2019), maximizing net present value (Amin et al., 2017; Polo et al., 2019), maximizing recycling production and production quality (Liu et al., 2019). Most studies have examined network costs, namely location/relocation costs/facility allocation, operating cost, transportation cost, and other air pollution costs (Fathollahi-Fard et al., 2018). Some studies have considered variables such as the number of raw materials required and unmet demand (Farrokh et al., 2018).

(Yun et al., 2020) recently designed a stable CLSCN for mobile phones. They proposed a MOM to maximize grid profit, minimize total carbon emissions, and maximize social impact to increase the stability of the proposed grid. They considered three types of distribution channels and proposed a hybrid GA to solve the model. Their review proved the validity of the proposed model and network and showed the effect of distribution channels on the stated goals. (Ghahremani-Nahr et al., 2021) developed a hybrid approach based on FDM and MP to assimilate supplier selection and SCLSC design problems. The authors used the fuzzy method to solve the proposed model. Their study showed the impact of suppliers on sustainable network design. Also, they showed that by choosing a supplier, sustainable growth could improve net profits.

In a recent study, (Zahedi et al. 2021) designed a CLSCN related to the walnut industry and focused on the agricultural chain. They proposed a complex ILPM to reduce the total cost of the walnut industry and used metaheuristic and HA to solve the proposed model. Their research showed that the proposed reverse flow network in the walnut industry, in addition to meeting market demands, prepares the returned product with usability and efficiency for reuse. (Gholizadeh et al., 2021), in a study focused on designing a SCLSCN for the dairy industry to maximize profits and minimize environmental impacts in different scenarios, following the possible impact of optimistic scenarios and pessimistically focused on recycling dairy products with a case study in Iran. They solved their complex model by presenting a two-objective MILPM with an improved heuristic and ε-constraint combined method. Then they showed their results with the efficiency of the proposed solution method and the effects of scenario probabilities. To demonstrate the importance of sustainable development (Nayeri et al., 2020), they proposed a SCLSCN for the water reservoir and, at the same time, examined the optimization of financial, environmental and social impacts on the sustainable reservoir network. In addition, their proposed network was subject to uncertainties in the cost and demand parameters of transportation. They used strong fuzzy optimization and three different purposes of the multi-option ideal planning method with the utility function to solve this problem. This study showed the impact of sustainable development on SCN design. Since achieving competitive advantages over competitors in the market requires balancing the supply chain's social, environmental, and economic aspects, (Pourmehdi et al., 2020) considered the design of a stable Closed-loop SC in the steel industry under uncertain conditions. Their research showed that reducing the profit of the proposed chain up to 1% reduces carbon emissions up to 5%.

### 2.3. The research gap

After reviewing the recent literature on SCLSC design, the main contribution of this article is summarized as follow:

- To our knowledge, no studies have simultaneously considered the concepts of supplier selection, shipping modes, and carbon emission policies under uncertainty and indeterminacy.
- One of the most important features of this study is the consideration of net present value and inflation in the design of a SSCN under uncertainty, which makes this study special compared to the recent literature.

## 3. Problem definition

Here's a CLSC for computer mouse electronics. The proposed operational network consists of four levels at the forward operational levels (raw material suppliers, manufacturers, distributors, and customers). The operational process with the supply of materials, production and distribution and customer demand. Reverse network operating levels include four levels (collection centers, separation centers, recycling centers, disposal centers) in which, in reverse flow, mainly electronic components related to computer mice, in separation centers to reusable components and equipment and recycling and is not usable, which is used in other centers. However, the price of these parts or materials is affected by inflation and supply and demand. Therefore, the uncertainty of the parameters is inevitable. Because the decision to separate, reuse, or recycle with a particular technology is useful (each technology has its opening costs, operating costs, and carbon emissions), present value analysis to control the cost and cost margin. Useful for making decisions about separation, reuse or recycling decisions. In addition, the transfer of components of this product through reverse flow requires a comprehensive model of material transportation. A percentage of these components are transferred to recycling centers, a percentage to production centers for reuse and a percentage to disposal centers. The recycled materials are then sent to supply centers and the rest to disposal centers.

On the other hand, capacity and trade policies have been used to limit the organization to carbon emissions. It restricts this policy to production, recycling, transportation and even landfill activities that lead to carbon emissions. This allows the organization to sell the number of unused carbon emissions in proportion to its designated carbon capacity. Also, when the carbon emitted by the organization exceeds the designated carbon capacity, a carbon emission credit is purchased for supply chain activities.

Economic stability and reducing inflation can provide the basis for improving productive performance and significantly reducing environmental corruption. In the current situation, green GDP is calculated in some developed countries. Of course, some countries do not announce this figure, but they inform the official. In this regard, in addition to direct and indirect tax policies have also been used; Like the tax on carbon and the tax on energy rates, this tax is charged on the inputs of production or consumer goods, the use of which is detrimental to the environment and can be seen as a signal for achieving an efficient level of social emissions. Environmental change is also important for most of these factories, and they demand the least conflict of interest with environmental officials. Hence, we are prepared for economic tensions such as exchange rate instability, sudden changes in energy rates, etc. In this study, we used the limitation of point-to-point inflation calculation, which in addition to considering the benefits of the plant, can optimize the frequency of purchases, reduce transportation and, consequently, reduce carbon emissions.

To model the proposed network, the following assumptions are considered:

- All facilities face capacity constraints.
- Uncertainty in tactical parameters of demand, costs and carbon emission capacity.
- The cost of purchasing technology and raw materials and the price of products are affected by inflation.
- The location of the facility in the proposed network is predetermined.
- Issues of carbon emissions are addressed under carbon capacity policies and trade policy.

### 3.1. Mathematical model

In this section, indicators, sets, variables, and parameters are defined, then according to the problem ahead, and with the defined assumptions, the necessary model and constraint are written.

| | |
|---|---|
| Indicators | |
| $S$ | A set of suppliers marked by $s$ index |
| $M$ | A set of manufacturers marked by $m$ index |
| $D$ | A set of distribution centers with index $d$ |
| $K$ | A set of customers with index k |
| $C$ | Collection centers with index c |
| $B$ | A set of separation centers with index b |
| $R$ | A set of recycling centers marked by index r |
| $I$ | Set of raw materials marked by index i |
| $J$ | A set of disposal centers marked by index j |
| $T$ | A set of recycling technologies marked by index t |
| $Q$ | A set of transport modes with index q |
| $P$ | A set of products with index p |
| $L$ | Time set with index l |
| $G$ | A set of product components with index g |
| $e,e'$ | A set of all levels of the chain $e,e' \in \{s,m,d,k,c,r,b,j,f\}$ |
| $f,f'$ | Set of facilities at chain levels $f,f' \in \{1,\dots,F_e\}$ |
| Parameters | |
| $fcs_s$ | Fixed cost related to supplier s |
| $pct_{tl}$ | Cost of purchasing technology t in the period l |
| $fcr_{rt}$ | Fixed cost of opening recycling centers r marked by technology t |
| $fco_{f_e}$ | Fixed cost of opening the facility $(f_e \mid e \in \{d,c,b\})$ |
| $Cap_{f_el}$ | Facility capacity $f_e \mid e \in \{s,m,d,c,b,r,j\}$ in time period l |
| $De_{kpl}$ | Customer demand k for product p in time period l |
| $sp_{pl}$ | The sales price of product p in time period l |
| $pr_{isl}$ | Price of raw materials i purchased from suppliers s in period l |
| $spr_{sl}$ | The sale price of recycled materials to suppliers s in period l |
| $Co_{fel}$ | Operating costs in facilities $f_e \mid e \in \{m,d,c,b,j\}$ in time period l |
| $Cr_{rtl}$ | Recycling cost of recycling center r marked by technology t in time period l |
| $TC_{ee'ql}$ | Shipping cost from facility $f_e$ to facility $f_{e'}$ with shipping mode q، $e,e' \in \{s,m,k,b,c,r,j,d\}$ in time period $l$ |
| $dis_{ee'}$ | Distance between facilities $f_e$ and facilities $f_{e'}$( $e,e' \in \{s,m,k,b,c,r,j,d\}$) |
| $\sigma_{ipl}$ | Consumption of raw materials i per unit of product p in time period l |
| $\alpha_{pkl}$ | Product return rate p from customer K in time period l |
| $\beta_{gbl}$ | Number of reusable components g in the separation center b in time period l |
| $\tau_{gbl}$ | NO, of recyclable components g Separation center b in TP l |
| $\mu_{gbl}$ | NO, of disposable components g in the separation center b in TP l |
| $\delta_{grtl}$ | The recycling rate of g components in recycling center r with t technology in TP l |
| $\theta_{grtl}$ | The rate of waste of components g in the recycling center r with technology t in time period l |
| $TCap_{ee'q}$ | Transport mode capacity $q$ between facility $f_e$and facility $f_{e'}$( $e,e' \in \{s,m,k,b,c,r,j,d\}$) |
| $\lambda_m$ | Carbon emission rate from the manufacturer $m$ |
| $\lambda_{rt}$ | Carbon emission rate from recycling center r with t technology. |
| $\lambda_{ee'}^{q}$ | Carbon emission rate from transport from facility $f_e$to facility $f_{e'}$ with transport mode $e,e' \in \{s,m,k,b,c,r,j,d\}$ |
| $\delta^+$ | The purchase price per carbon credit unit |
| $\delta^-$ | The selling price of each carbon credit unit |
| $CapCE$ | Carbon capacity on carbon emissions on the planning horizon |
| $\pi$ | Interest rate |
| $Mbig$ | A large number above the demand limit |
| $SI$ | The inflation rate |
| Variables | |
| $Q_{ee'p}^{ql}$ | The value of products p is transferred from the facility $f_e$ to facility $f_{e'}$transport mode $e,e' \in \{m,d,k,c,b\}$ in time l |
| $Q_{ee'g}^{ql}$ | The value of the components g is transferred from the facility $f_e$ to the facility $f_{e'}$ with the transport mode $e,e' \in \{b,r,m,j\}$ in time interval l |

| | |
|---|---|
| $Q_{ism}^{ql}$ | The amount of raw material i that is transferred from the supplier s to the manufacturer m with the transport mode q in period l |
| $Q_{irtj}^{ql}$ | The amount of raw material i that is transferred from the recycling center r by technology t with the transport mode q to the disposal center j in time period l |
| $Q_{irts}^{ql}$ | The amount of raw material i that is transferred from the recycling center r by technology t with transport mode q to the supplier s in period l |
| $e^{+}$ | Validity of carbon purchased |
| $e^{-}$ | Carbon sales credit |
| $Su_s$ | A binary variable, if supplier s is selected 1 otherwise, 0 |
| $FY_{fe}$ | A binary variable, if the facility $f_e$\|$e \in \{ d, c, b \}$ is opened 1, otherwise 0 |
| $FY_{rt}$ | A binary variable, if the recycling center r is opened with technology t 1, otherwise 0 |
| $TX_{ee'q}$ | A binary variable, if transport mode $q$ is used between facility $f_e$ to facility $f_{e'}$‘, 1 Otherwise, 0 |

### 3.1.1. Economic objective

This section examines and defines the first OBJ function of the problem ahead, namely the maximized NPV of the proposed network shown in Equation (1).

$$MaxZ_1 = \frac{(Total\ revenue_l - Total\ cost_l)}{(1+\pi)^l} \tag{1}$$

According to Equation (2), total revenue is relative to the positive cash flow from the sale of manufactured products, carbon to customers and recycled materials to suppliers. The amount of product or carbon transferred to customers is multiplied by its price and inflation.

$$\begin{aligned} \text{Total revenue} = & \sum_{d}\sum_{k}\sum_{p}\sum_{q}\sum_{l}\left(sp_{pl} + SI.sp_{pl}\right).Q_{dkp}^{ql} \\ & + \sum_{i}\sum_{r}\sum_{s}\sum_{q}\sum_{l}\sum_{t}\left(spr_{sl} + SI.spr_{sl}\right).Q_{irts}^{ql} + \delta^{-}.e^{-}.SI \end{aligned} \tag{2}$$

According to Equation Three, the total cost has four sub-sections. The first part includes fixed costs related to reopening facilities (separation centers, collection centers, distribution centers and recycling centers with different technologies) and fixed costs of cooperation with suppliers. Is. The second section shows the operating costs incurred in each facility. In the third section, transportation costs between facilities are discussed. The fourth section considers the cost of purchasing technology, raw materials and carbon credibility.

$$
\begin{aligned}
\text{Total cost } = & \sum_{f_e\in\{d,c,b\}} fco_{f_e}.FY_{fe} + \sum_{t}\sum_{r} fcr_{rt}.FY_{rt} + \sum_{s} fcs_s\,.Su_s \\
& + \sum_{q}\sum_{p}\sum_{fe\in\{m,d,c\}}\sum_{l} Co_{fel}.\,Q^{ql}_{ee'p} \\
& + \sum_{g}\sum_{q}\sum_{fe\in\{b,j\}}\sum_{l} Co_{fel}.\,Q^{ql}_{ee'g} \\
& + \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l} Cr_{rtl}.\,Q^{ql}_{irtj} \\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l} Cr_{rtl}.\,Q^{ql}_{irts} \\
& + \sum_{q}\sum_{p}\sum_{fe\in\{m,d,k,c,b\}}\sum_{l} TC_{ee'ql}.\,Q^{ql}_{ee'p}.\,dis_{ee'} \\
& + \sum_{q}\sum_{g}\sum_{fe\in\{b,r,m,j\}}\sum_{l} TC_{ee'ql}.\,Q^{ql}_{ee'g}.\,dis_{ee'} \\
& + \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l} TC_{rjql}.\,Q^{ql}_{irtj}.\,dis_{rj} \\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l} TC_{rsql}.\,Q^{ql}_{irts}.\,dis_{rs} \\
& + \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l} TC_{smql}.\,Q^{ql}_{ism}.\,dis_{sm} \\
& + \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l} (pr_{isl}.SI + pr_{isl}).\,Q^{ql}_{ism} \\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l} (pct_{tl}.SI + pct_{tl}).\,Q^{ql}_{irts} \\
& + \delta^{+}.\,e^{+}.SI
\end{aligned}
\qquad (3)
$$

### *3.1.2. Environmental purpose*

This section, the second OBJ function of the problem is the Equation (4), i.e., minimizing carbon emissions in the proposed CLSCN, which includes carbon emissions through transport between facilities, production operations and recycling.

$$
\begin{aligned}
\min Z_2 = {} & \sum_{m}\sum_{d}\sum_{p}\sum_{q}\sum_{l}\lambda_{m}.Q^{ql}_{mdp} + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rt}.Q^{ql}_{irts} \qquad (4)\\
& + \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rt}.Q^{ql}_{irtj}\\
& + \sum_{p}\sum_{q}\sum_{l}\sum_{fe\in\{m,d,k,c,b\}}\lambda^{q}_{ee'}.Q^{ql}_{ee'p}.dis_{ee'}\\
& + \sum_{q}\sum_{g}\sum_{l}\sum_{fe\in\{b,r,m,j\}}\lambda^{q}_{ee'}.Q^{ql}_{ee'g}.dis_{ee'}\\
& + \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l}\lambda^{q}_{sm}.Q^{ql}_{ism}.dis_{sm}\\
& + \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda^{q}_{rj}.Q^{ql}_{irtj}.dis_{rj}\\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda^{q}_{rs}.Q^{ql}_{irts}.dis_{rs}
\end{aligned}
$$

### *3.1.3. Model constraints*

In this section, we discuss model constraints, including facility capacity constraints, flow balance constraints, facility location constraints, transport mode capacity constraints, carbon policy constraints, and inflation constraints.

$$\sum_{m}\sum_{q}Q^{ql}_{ism} \le Cap_{sil}.Su_{s} \qquad \forall i,s,l \qquad (5)$$

$$\sum_{d}\sum_{q}Q^{ql}_{mdp} \le Cap_{mpl} \qquad \forall m,p,l \qquad (6)$$

$$\sum_{k}\sum_{q}Q^{ql}_{dkp} \le Cap_{dpl}.FY_{d} \qquad \forall d,p,l \qquad (7)$$

$$\sum_{k}\sum_{q}Q^{ql}_{kcp} + \sum_{b}\sum_{q}Q^{ql}_{cbp} \le Cap_{cpl}.FY_{c} \qquad \forall c,p,l \qquad (8)$$

$$\sum_{m}\sum_{q}Q^{ql}_{bmg} + \sum_{r}\sum_{q}Q^{ql}_{brg} + \sum_{j}\sum_{q}Q^{ql}_{bjg} \le Cap_{bgl}.FY_{b} \qquad \forall b,g,l \qquad (9)$$

$$\sum_{s}\sum_{q}Q^{ql}_{rsit} + \sum_{q}\sum_{j}Q^{ql}_{rjit} \le FY_{rt}.Cap_{irtl} \qquad \forall r,i,t,l \qquad (10)$$

$$\sum_{t}FY_{rt} \le 1 \qquad \forall r \qquad (11)$$

As we can see, the constraints (5, 6) refer to the supplier and producer capacity. Constraint (7) states that the amount of product sent to the distributor cannot exceed the capacity of the distribution center. Constraint (8) refers to the capacity of collection centers. Constraint (9) indicates the capacity of disassembly centers. Constraint (10) deals with the capacity of recycling centers according to the type of technology. Constraint (11) ensures that a recycling center opens with only one technology.

$$\sum_{s}\sum_{m}\sum_{q}Q^{ql}_{smi} = \sum_{m}\sum_{d}\sum_{q}\sigma_{ipl}.Q^{ql}_{mdp} \qquad \forall i,p,l \qquad (12)$$

$$\sum_{d}\sum_{q} Q^{ql}_{dkp}.\alpha_{pkl} = \sum_{c}\sum_{q} Q^{ql}_{kcp} \qquad \forall p,k,l \qquad (13)$$

$$\sum_{m}\sum_{d}\sum_{q} Q^{ql}_{mdp} = \sum_{d}\sum_{k}\sum_{q} Q^{ql}_{dkp} \qquad \forall p,l \qquad (14)$$

$$\begin{aligned}\sum_{c}\sum_{b}\sum_{q} Q^{ql}_{cbp} &= \sum_{b}\sum_{m}\sum_{q} Q^{ql}_{bmg} + \sum_{b}\sum_{r}\sum_{q} Q^{ql}_{brg} \\ &+ \sum_{b}\sum_{j}\sum_{q} Q^{ql}_{bjg}\end{aligned} \qquad \forall p,g,l \qquad (15)$$

$$\sum_{b}\sum_{m}\sum_{q} Q^{ql}_{bmg} = \sum_{c}\sum_{b}\sum_{q} Q^{ql}_{cbp}\,.\,\beta_{gbl} \qquad \forall p,g,l \qquad (16)$$

$$\sum_{b}\sum_{r}\sum_{q} Q^{ql}_{brg} = \sum_{c}\sum_{b}\sum_{q} Q^{ql}_{cbp}\,.\,\tau_{gbl} \qquad \forall p,g,l \qquad (17)$$

$$\sum_{b}\sum_{j}\sum_{q} Q^{ql}_{bjg} = \sum_{c}\sum_{b}\sum_{q} Q^{ql}_{cbp}\,.\,\mu_{gbl} \qquad \forall p,g,l \qquad (18)$$

$$\sum_{r}\sum_{s}\sum_{q} Q^{ql}_{rsit} = \sum_{b}\sum_{r}\sum_{q} Q^{ql}_{brg}\,.\,\delta_{grtl} \qquad \forall i,g,l,t \qquad (19)$$

$$\sum_{r}\sum_{j}\sum_{q} Q^{ql}_{rjit} = \sum_{b}\sum_{r}\sum_{q} Q^{ql}_{brg}\,.\,\theta_{grtl} \qquad \forall i,g,l,t \qquad (20)$$

$$\sum_{d}\sum_{q} Q^{ql}_{dkp} \leq De_{kpl} \qquad \forall k,p,l \qquad (21)$$

The flow constraints for the proposed model Equations (12 to 21) are presented to achieve the goals. The constraint (12) shows the number of raw materials sent to the manufacturer, proportional to the number consumed in each product. Constraint (13) refers to the amount of product returned from customers. Constraints (14 to 20) show the flow balance between facilities, considering the set rate. Constraint (21) refers to customer demand, i.e., the relationship between the amount of product delivery from the distributor to the customer relative to customer demand.

$$\sum_{p}\sum_{l} Q^{ql}_{ee'p} \leq Tcap_{ee'q}.TX_{ee'q} \qquad \forall e,e' \in \{m,d,k,c,b\} \qquad (22)$$

$$\sum_{g}\sum_{l} Q^{ql}_{ee'g} \leq Tcap_{ee'q}.TX_{ee'q} \qquad \forall e,e' \in \{b,r,m,j\} \qquad (23)$$

$$\sum_{i}\sum_{l} Q^{ql}_{smi} \leq Tcap_{smq}.TX_{smq} \qquad \forall q,s,m \qquad (24)$$

$$\sum_{i}\sum_{t}\sum_{l} Q^{ql}_{rjit} \leq Tcap_{rjq}.TX_{rjq} \qquad \forall r,j,q \qquad (25)$$

$$\sum_{i}\sum_{t}\sum_{l} Q^{ql}_{rsit} \leq Tcap_{rsq}.TX_{rsq} \qquad \forall q,r,s \qquad (26)$$

As you can see, the constraints (22 to 26) indicate the capacity of material and product transport modes between facilities. Constraint (22) refers to the forward current of the network, and constraints (23 to 26) refer to the reverse forward current (reverse current) of the proposed network.

$$
\begin{aligned}
&\sum_{m}\sum_{d}\sum_{p}\sum_{q}\sum_{l}\lambda_{m}.Q_{mdp}^{ql}+\sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rt}.Q_{irts}^{ql}\\
&\quad+\sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rt}.Q_{irtj}^{ql}\\
&\quad+\sum_{p}\sum_{q}\sum_{l}\sum_{fe\in\{m,d,k,c,b\}}\lambda_{ee'}^{q}.Q_{ee'p}^{ql}.dis_{ee'}\\
&\quad+\sum_{q}\sum_{g}\sum_{l}\sum_{fe\in\{b,r,m,j\}}\lambda_{ee'}^{q}.Q_{ee'g}^{ql}.dis_{ee'}\\
&\quad+\sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l}\lambda_{sm}^{q}.Q_{ism}^{ql}.dis_{sm}\\
&\quad+\sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rj}^{q}.Q_{irtj}^{ql}.dis_{rj}\\
&\quad+\sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rs}^{q}.Q_{irts}^{ql}.dis_{rs}+e^{-}\leq CapCE+e^{+}
\end{aligned}
\qquad (27)
$$

Constraint (27) reflects the carbon policies adopted in this study, based on carbon capacity and trade policies.

$$\sum_{d}\sum_{q}(sp_{pl}+SI.sp_{pl}).Q_{dkp}^{ql}\leq De_{kpl} \qquad \forall k,p,l \qquad (28)$$

$$\sum_{i}\sum_{m}\sum_{q}\sum_{l}(pr_{isl}.SI+pr_{isl}).Q_{ism}^{ql}\leq Mbig.Su_{s} \qquad \forall s \qquad (29)$$

Following the effect of inflation on the selling price of the product and the purchase of raw materials, we examine the effect of inflation on the constraints (28 and 29).

$$TX_{ee'q}\leq FY_{e''} \qquad \begin{matrix}\forall e,e'\in\{m,d,k,c,b\}\\ \forall e''\in\{d,c,b\}\end{matrix} \qquad (30)$$

$$TX_{rsq}\leq\sum_{t}FY_{rt} \qquad \forall r,s,q \qquad (31)$$

$$TX_{rjq}\leq\sum_{t}FY_{rt} \qquad \forall j,r,q \qquad (32)$$

$$Q_{ee'p}^{ql},Q_{ee'g}^{ql},Q_{ism}^{ql},Q_{irst}^{ql},Q_{irjt}^{ql},e^{+},e^{-}\geq 0 \qquad (33)$$

$$Su_{s},FY_{fe},TX_{ee'q},FY_{rt}\ \in\{0,1\} \qquad (34)$$

Constraints (30-32) show the relationship between transport of facilities and the reopening of facilities, i.e., the flow of transport occurs when the facility is opened. Finally, the range of decision variables of the proposed model is shown in constraints (33 and 34).

## 4. Uncertainty of the model

Given the fluctuations in the business environment, such as demand and operational and tactical costs, the nature of uncertainty in the design of a stable CLSCN is undeniable. On the other hand, different types of uncertainties are divided into epistemological, random and deep uncertainties based on access to data. In this study, epistemological and random uncertainties are used. Solid optimization is used to deal with this type of uncertainty. Using studies (Talaei et al., 2016), this study offers an efficient approach based on a robust fuzzy planning approach that allows decisionmakers to control conservatism to satisfy constraints. The approach used in this study is a broad form of the chance-limited fuzzy planning model, which is implemented on the proposed model as follows, which is taken from the study (Talaei et al., 2016).

$$\begin{aligned}
\text{Total cost}
&= \sum_{f_e \in \{d,c,b\}} fco_{f_e}.FY_{fe} + \sum_{t}\sum_{r} fcr_{rt}.FY_{rt} + \sum_{s} fcs_s\,.Su_s \\
&+ \sum_{q}\sum_{p}\sum_{fe\in\{m,d,c\}}\sum_{l}\left[\frac{Co_{fel(1)} + Co_{fel(2)} + Co_{fel(3)} + Co_{fel(4)}}{4}\right].Q_{ee'p}^{ql} \\
&+ \sum_{g}\sum_{q}\sum_{fe\in\{b,j\}}\sum_{l}\left[\frac{Co_{fel(1)} + Co_{fel(2)} + Co_{fel(3)} + Co_{fel(4)}}{4}\right].Q_{ee'g}^{ql} \\
&+ \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\left[\frac{Cr_{rtl(1)} + Cr_{rtl(2)} + Cr_{rtl(3)} + Cr_{rtl(4)}}{4}\right].Q_{irtj}^{ql} \\
&+ \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\left[\frac{Cr_{rtl(1)} + Cr_{rtl(2)} + Cr_{rtl(3)} + Cr_{rtl(4)}}{4}\right].Q_{irts}^{ql} \\
&+ \sum_{q}\sum_{p}\sum_{fe\in\{m,d,k,c,b\}}\sum_{l}\left[\frac{TC_{ee'ql(1)} + TC_{ee'ql(2)} + TC_{ee'ql(3)} + TC_{ee'ql(4)}}{4}\right].Q_{ee'p}^{ql}.dis_{ee'} \\
&+ \sum_{q}\sum_{g}\sum_{fe\in\{b,r,m,j\}}\sum_{l}\left[\frac{TC_{ee'ql(1)} + TC_{ee'ql(2)} + TC_{ee'ql(3)} + TC_{ee'ql(4)}}{4}\right].Q_{ee'g}^{ql}.dis_{ee'} \\
&+ \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\left[\frac{TC_{rjql(1)} + TC_{rjql(2)} + TC_{rjql(3)} + TC_{rjql(4)}}{4}\right].Q_{irtj}^{ql}.dis_{rj} \\
&+ \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\left[\frac{TC_{rsql(1)} + TC_{rsql(2)} + TC_{rsql(3)} + TC_{rsql(4)}}{4}\right].Q_{irts}^{ql}.dis_{rs} \\
&+ \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l}\left[\frac{TC_{smql(1)} + TC_{smql(2)} + TC_{smql(3)} + TC_{smql(4)}}{4}\right].Q_{ism}^{ql}.dis_{sm} \\
&+ \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l}(pr_{isl}.SI + pr_{isl}).Q_{ism}^{ql} \\
&+ \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}(pct_{tl}.SI + pct_{tl}).Q_{irts}^{ql} + \delta^{+}.e^{+}.SI
\end{aligned} \tag{35}$$

S.t:

$$\sum_{d}\sum_{q} Q_{dkp}^{ql} \le (1-\alpha_1).De_{kpl(2)} + \alpha_1.De_{kpl(1)} \qquad \forall k,p,l \tag{36}$$

$$
\begin{aligned}
&\sum_{m}\sum_{d}\sum_{p}\sum_{q}\sum_{l}\lambda_{m}.Q_{mdp}^{ql}+\sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rt}.Q_{irts}^{ql}\\
&\qquad+\sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rt}.Q_{irtj}^{ql}\\
&\qquad+\sum_{p}\sum_{q}\sum_{l}\sum_{fe\in\{m,d,k,c,b\}}\lambda_{ee'}^{q}.Q_{ee'p}^{ql}.dis_{ee'}\\
&\qquad+\sum_{q}\sum_{g}\sum_{l}\sum_{fe\in\{b,r,m,j\}}\lambda_{ee'}^{q}.Q_{ee'g}^{ql}.dis_{ee'}\\
&\qquad+\sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l}\lambda_{sm}^{q}.Q_{ism}^{ql}.dis_{sm}\\
&\qquad+\sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rj}^{q}.Q_{irtj}^{ql}.dis_{rj}\\
&\qquad+\sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l}\lambda_{rs}^{q}.Q_{irts}^{ql}.dis_{rs}\\
&\qquad+e^{-}(1-\alpha\quad).CapCE_{(2)}+\alpha_{2}.CapCE_{(1)}+e^{+}
\end{aligned}
\tag{37}
$$

$$
\sum_{d}\sum_{q}\left(sp_{pl}+SI.sp_{pl}\right).Q_{dkp}^{ql}\leq(1-\alpha_{3}).De_{kpl(2)}+\alpha_{3}.De_{kpl(1)}\qquad\forall k,p,l \tag{38}
$$

$$
0.5\leq\alpha_{\mathrm{i}}\leq 1,\qquad \mathrm{i}=1,2,3 \tag{39}
$$

Set of of constraints (5 -21)-(22-26), (29)-(30 - 34)

According to the study by Talaei et al. (2016), the uncertainty model is formulated as follows:

$$
\begin{aligned}
&max\ E[Z_1]+\eta(Z_{max}-E[Z_1])\\
&+\xi_1.\left(\sum_{k}\sum_{p}\sum_{l}(1-\alpha_1).De_{kpl(2)}+\ \alpha_1.De_{kpl(1)}-De_{kpl(1)}\right)\\
&+\xi_2.\left((1-\alpha_2).CapCE_{(2)}+\alpha_2.CapCE_{(1)}-CapCE_{(1)}\right)\\
&+\xi_3.\left(\sum_{k}\sum_{p}\sum_{l}(1-\alpha_3).De_{kpl(2)}+\ \alpha_3.De_{kpl(1)}-De_{kpl(1)}\right)
\end{aligned}
\tag{40}
$$

Set of constraints (36)-(40)

Where $E[Z_1]$ is the expected value of the first OBJ function, η and ξ represent coefficients that regulate the optimal strength and feasibility of the solution vector, respectively $Z_{max}$ also defines:

$$
\begin{aligned}
Z_{max} = {} & \sum_{f_e \in \{d,c,b\}} fco_{f_e}.FY_{fe} + \sum_{t}\sum_{r} fcr_{rt}.FY_{rt} + \sum_{s} fcs_s\,.Su_s \\
& + \sum_{q}\sum_{p}\sum_{fe\in\{m,d,c\}}\sum_{l} Co_{fel(4)}.\,Q^{ql}_{ee'p} \\
& + \sum_{g}\sum_{q}\sum_{fe\in\{b,j\}}\sum_{l} Co_{fel(4)}.\,Q^{ql}_{ee'g} \\
& + \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l} Cr_{rtl(4)}.\,Q^{ql}_{irtj} \\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l} Cr_{rtl(4)}.\,Q^{ql}_{irts} \\
& + \sum_{q}\sum_{p}\sum_{fe\in\{m,d,k,c,b\}}\sum_{l} TC_{ee'ql(4)}.\,Q^{ql}_{ee'p}.\,dis_{ee'} \\
& + \sum_{q}\sum_{g}\sum_{fe\in\{b,r,m,j\}}\sum_{l} TC_{ee'ql(4)}.\,Q^{ql}_{ee'g}.\,dis_{ee'} \\
& + \sum_{r}\sum_{j}\sum_{t}\sum_{q}\sum_{i}\sum_{l} TC_{rjql(4)}.\,Q^{ql}_{irtj}.\,dis_{rj} \\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l} TC_{rsql(4)}.\,Q^{ql}_{irts}.\,dis_{rs} \\
& + \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l} TC_{smql(4)}.\,Q^{ql}_{ism}.\,dis_{sm} \\
& + \sum_{i}\sum_{s}\sum_{m}\sum_{q}\sum_{l} (pr_{isl}.SI + pr_{isl}).\,Q^{ql}_{ism} \\
& + \sum_{r}\sum_{s}\sum_{t}\sum_{q}\sum_{i}\sum_{l} (pct_{tl}.SI + pct_{tl}).\,Q^{ql}_{irts} + \delta^{+}.e^{+}.SI
\end{aligned}
\tag{41}
$$

## 5. Proposed approach: Neutrosophic model

Since our model is a multi-objective problem, we establish a neutrosophical strategy to solve it. The most prevalent mathematical model with competing goals is the multi-objective model (MOM). The goal in such instances is to obtain the optimal value of all conflicting objective functions concurrently. In such situations, the decision-maker conveys the importance of their preferences by giving each objective function an ideal weight between zero and one. As a result, decision-maker preferences in an objective function with a high weight value are higher in that objective function. recently, living circumstances have been noticed to have neutral thoughts regarding an element in the information. Thoughts concerning the elements that are neutral or indeterminate fall somewhere between falsehood and truth. As a result, Smarandache (1999) developed the neutrosophic logic, which consists of three membership sets: truth (membership degree), indeterminacy, and falsehood (non-membership degree). The model of a SCLSCN with inflation and carbon emission policies with some conflicting objective functions is addressed in this section using the concept of neutrosophic programming.

As a result, each OBJ function performs three tasks: falsehood function (F), truth membership function (T), and indeterminacy function (I). As a result, the neutrosophic programming method plays a significant and relible role in MOM by considering neutral thoughts.

Consider a MOM in which (ND) represents a set of neutrosophic decisions, (NOF) a set of neutrosophic OBJ functions, and neutrosophic constraints (NC). Therefore, the set of neutrosophic decisions is represented as:

$$ND = \left(\bigcap_{i=1}^{m} NOF_i\right)\left(\bigcap_{j=1}^{n} NC_j\right) = \left(x, T_{ND}(x), I_{ND}(x), F_{ND}(x)\right)$$

$s.t.$:

$$\begin{aligned} T_{ND}(x) &= \min\left(T_{NOF_1}, T_{NOF_2}, \ldots, T_{NOF_m}; T_{NC_1}, T_{NC_2}, \ldots, T_{NC_n}\right), \\ I_{ND}(x) &= \max\left(I_{NOF_1}, I_{NOF_2}, \ldots, I_{NOF_m}; I_{NC_1}, I_{NC_2}, \ldots, I_{NC_n}\right), \\ F_{ND}(x) &= \max\left(F_{NOF_1}, F_{NOF_2}, \ldots, F_{NOF_m}; F_{NC_1}, F_{NC_2}, \ldots, F_{NC_n}\right). \end{aligned} \tag{42}$$

Where, $m$ and $n$ represent the number of objective functions and constraints, respectively. Also, $T_{ND}(x), I_{ND}(x)$, and $F_{ND}(x)$ are the truth membership, indeterminacy, and falsehood membership functions, respectively.

The upper and lower ranges for each OBJ function are generated by the solution of each single goal under the provided set of constraints and are denoted as $U_i$ and $L_i$ with a set of decision variables $X$, respectively.

$$\begin{aligned} U_i &= max\left(Z_i(X)\right), \forall i = 1,2,\ldots,m \\ L_i &= min\left(Z_i(X)\right), \forall i = 1,2,\ldots,m \end{aligned} \tag{43}$$

Under the neutrosophic situation, for truth, non-determination, and falsehood membership functions, the upper and lower bounds for $m$ objective function can be obtained as follows:

$$\begin{aligned} &U_i^T = U_i, \quad L_i^T = L_i \\ &U_i^I = L_i^T + p_i, \quad L_i^I = L_i \\ &U_i^F = U_i^T, \quad L_i^F = L_i^T + q_i \end{aligned} \tag{44}$$

Wherein the relationship mentioned above, $p_i$ and $q_i$ are predetermined values between 0 and 1. So, based on the preceding components, the linear membership function for a neutrosophic context is as follows:

$$ND = \left(\bigcap_{i=1}^{m} NOF_i\right)\left(\bigcap_{j=1}^{n} NC_j\right) = \left(x, T_{ND}(x), I_{ND}(x), F_{ND}(x)\right)$$

$s.t.$:

$$T_i\left(Z_i(X)\right) = \left\{\begin{matrix} 1 & if & Z_i(X) < L_i^T \\ \dfrac{U_i^T - Z_i(X)}{U_i^T - L_i^T} & if & L_i^T \le Z_i(X) \le U_i^T \\ 0 & if & Z_i(X) > U_i^T \end{matrix}\right\} \tag{45}$$

$$I_i\big(Z_i(X)\big) = \begin{cases} 1 & if \quad Z_o(X) < L_i^I \\ \dfrac{U_i^I - Z_i(X)}{U_i^I - L_i^I} & if \quad L_i^I \le Z_i(X) \le U_i^I \\ 0 & if \quad Z_i(X) > U_i^I \end{cases}$$

$$F_i\big(Z_i(X)\big) = \begin{cases} 1 & if \quad Z_i(X) > U_i^F \\ \dfrac{Z_i(X) - L_i^F}{U_i^F - L_i^F} & if \quad L_i^F \le Z_i(X) \le U_i^F \\ 0 & if \quad Z_i(X) < L_i^F \end{cases}$$

Fundamentally, the goal of establishing multiple accomplishment functions is to reach the highest degree or level of pleasure based on the decision maker's preferences. As a result, we have conveniently specified the individual completion factors for each membership function, such as maximization of truth membership, maximization of indeterminacy degree, and minimization of a falsity degree. Therefore, the controlled neutrosophic mathematical programming paradigm using linear truth, indeterminacy, and falsity membership functions in neutrosophic surroundings can be expressed as follows:

$$\begin{aligned} & max \sum_{i=1}^{m} (\tau_i + \iota_i - \xi_i) \\ & s.t.: \\ & T_i\big(Z_i(X)\big) \ge \tau_i, \quad \forall i \\ & I_i\big(Z_i(X)\big) \ge \iota_i, \quad \forall i \\ & F_i\big(Z_i(X)\big) \le \xi_i, \quad \forall i \\ & \tau_i \ge \iota_i, \quad \forall i \\ & \tau_i \ge \xi_i, \quad \forall i \\ & 0 \le \tau_i + \iota_i + \xi_i \le 3, \quad \forall i \\ & \tau_i, \iota_i, \xi_i \in (0,1) \\ & Eqs(43-44) \end{aligned} \tag{46}$$

Where$\tau_i$,$\iota_i$, and $\xi_i$ are the truth, indeterminacy, and falsity membership functions' auxiliary accomplishment variables, respectively. Therefore, this neutrosophical approach is a well-suited contemporary optimization technique preferred solely by others due to its degree of independent indeterminacy. Moreover, for solving the model efficiently, we presented an innovative strategy to the proposed model called the hybrid method. Since the computation time for each model of MIL /NLP increases with increasing variables and the presence of data, no acceptable solution is obtained even in some cases. Hence, an exploratory method based on the relaxation of a binary variable is proposed.

At the first, we consider the binary variable greater than zero and solve the optimization model with only non-zero binary variables. Then, as a new constraint, we add a MI to the model and solve the optimization model again. The main advantages of this method are that it leads to a drastic reduction of problem-solving time and can also achieve higher quality solutions.

The steps of the hybrid approach:

Step (1): Release the zero and one constraint by converting the proposed binary variables to a continuous positive variable. Solve the released model.

Step (2): Then hold the binary variable as a continuous variable and use it in the new model and solve it.

Step (3): Report or record all non-zero values for the released variable

Step (4): Set any non-zero values of the released variables to 1 and place them in the original mixed linear programming model. And solve the model again.

Step (5): Finally, report the decision variables.

## 6. Numerical experiments

One of the electronic devices we are constantly dealing with is the computer and laptop that we use to improve our work. A set of computer and laptop components such as keyboards, mice, and cables break down after a while, called computer junk. In general, there is a plastic material in computer accessories and even the computer monitor itself that can be reused by removing all computer parts and recycling computer waste and plastic, silicon, iron, lead, and even. It is interesting to know that precious metals such as gold, silver, and palladium in computer parts can be recycled to extract gold, silver, and other metals such as copper. This article considers one of the international companies in Iran as its case study, Located in South Tehran province, the center of Iran. The study company is a private Iranian company that designs, manufactures, and markets computers, electronics, and information technology equipment. The company's products are frames, mini bags, tablets, speakers, mice and keyboards, headphones and headsets, power banks, and even products such as digital receivers. This study focuses specifically on one of the company's products, the computer mouse, and designs and examines a stable CLSC for this product.

The data needed to solve the proposed model, such as problem size, number of transport modes with capacity, and carbon emissions, are described below. It should be noted that it was not possible to share information about it due to company policies. Therefore, according to the performance of company’s data, we use random data based on the uniform distribution function to implement the proposed model. It should be noted that this distribution is based on real data of the company. Table 1 shows the production of real data based on the data behavior of the company. Furthermore, the proposed chain for the company has (potential suppliers (S = 5), manufacturer (M = 1), potential distribution centers (D = 5), customers (K = 15), potential collection centers (C = 5)) The probable centers of separation are (B = 4), recycling centers (R = 2), disposal centers (J = 1)). The company uses four modes of transport for its chain, including (Nissan with capacity (kg) = 2000 and with carbon emission coefficient (kg / km) = 0.031, light truck with capacity (kg) = 30.000 and with Carbon emission coefficient (kg / km) = 0.048, medium truck with capacity (kg) = 60,000 and with carbon emission coefficient (kg / km) = 0.0252 and heavy trucks with capacity (kg) = 100000 and with carbon emission coefficient (kg) / Km) = 0.297.

**Table 1.** Production of problem data based on the actual behavior of company data

| Parameters | | Period | | | |
|---|---|---|---|---|---|
| | | Fuzzy parameter ($\theta = \theta_{(1)}, \theta_{(2)}, \theta_{(3)}, \theta_{(4)}$) | | | |
| | | $\theta_{(1)}$ | $\theta_{(2)}$ | $\theta_{(3)}$ | $\theta_{(4)}$ |
| $De_{kpl}$ | | DU[100 250] | DU[250 400] | DU[450 600] | DU[650 800] |
| $Co_{fel}$($*10^3) | | DU[0.250 0.255] | DU[0.255 0.260] | DU[0.260 0.265] | DU[0.265 0.270] |
| $Cr_{rtl}$($*10^3) | | DU[0.225 0.230] | DU[0.230 0.235] | DU[0.235 0.240] | DU[0.240 0.245] |
| $TC_{ee'ql}$($*10^3) | Nissan | DU [0.75 0.80] | DU [0.80 0.85] | DU [0.85 0.90] | DU [0.95 0.100] |
| | Light truck | DU [0.115 0.120] | DU [0.120 0.125] | DU [0.125 0.130] | DU [0.135 0.140] |
| | Medium truck | DU [0.125 0.135] | DU [0.135 0.145] | DU [0.150 0.155] | DU [0.160 0.165] |
| | Heavy truck | DU [0.140 0.145] | DU [0.145 0.150] | DU [0.155 0.160] | DU [0.165 0.170] |
| $CapCE$ (ton) | | DU [30 40] | DU [40 50] | DU [50 60] | DU [60 65] |
| $fcs_s$($*10^3) | | DU[0.00714 0.0142] | | | |
| $pct_{tl}$($*10^3) | | DU[9.55 11.32] | | | |
| $fcr_{rt}$($*10^3) | | DU[19.2 22.1] | | | |
| $fco_{f_e}$($*10^3) | | DU[15.5 18.6] | | | |
| $sp_{pl}$($*10^3) | | DU[3 15] | | | |
| $pr_{isl}$($*10^3) | | DU[3 15] | | | |
| $spr_{sl}$($*10^3) | | DU[3 15] | | | |
| $dis_{ee'}$(km) | | DU[3 15] | | | |
| $\sigma_{ipl}$ | | 0.65 | | | |
| $\alpha_{pkl}$ | | 0.19 | | | |
| $\beta_{gbl}$ | | 0.4 | | | |
| $\tau_{gbl}$ | | 0.4 | | | |
| $\mu_{gbl}$ | | 0.2 | | | |
| $\delta_{grtl}$ | | 0.6 | | | |
| $\theta_{grtl}$ | | 0.4 | | | |
| $\lambda_m$(kg / km) | | DU [0.185 0.225] | | | |
| $\lambda_{rt}$(kg / km) | | DU [0.234 0.258] | | | |
| $\delta^+$($*10^3) | | DU [0.0120 0.0125] | | | |
| $\delta^-$($*10^3) | | DU [0.0125 0.0130] | | | |

This study is based on a hypothesis for two types of technology used in recycling centers. The first type of technology has low cost but high carbon emissions, and the second type of technology has a high cost but low carbon emissions. This assumption is based on the opinions of company experts.

### 6.1. Validation of the model

In this section, the validity of the proposed model is first examined. For this purpose, 20 experimental problems for the proposed model are solved by the neutronsophical model (46) and the proposed hybrid method, and the outcomes are shown in Table 2. To display the efficiency of the proposed processes, two essential factors of model solution time and the optimal gap based on Equation (47) are obtained.

$$\frac{Hybrid_{sol} - MCGP - \mathrm{UF}_{sol}}{MCGP - \mathrm{UF}_{sol}} \times 100 \qquad (47)$$

According to Table 2, it can be seen that the results of 20 test samples show the validity of the proposed models. On the other hand, to show the optimal gap between the solutions obtained from the two methods according to the results of Table 3 and Figure 1, we have shown that the average percentage of the optimal gap in the acceptable range is less than 5% and this proves the validity of the proposed methods. In Figure 2, a comparison of the model solution time between two models shows that the hybrid method has reduced the solution time by 25%.

**Table 2.** Tests performed on the case study

| Test | $(L)$ | $(P)$ | $(Q)$ | $(J)$ | $(I)$ | $(R)$ | $(B)$ | $(C)$ | $(K)$ | $(D)$ | $(M)$ | $(S)$ | $(G)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 1 | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 12 |
| 2 | 2 | 1 | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 12 |
| 3 | 3 | 1 | 1 | 5 | 2 | 2 | 2 | 3 | 1 | 4 | 1 | 3 | 12 |
| 4 | 3 | 2 | 2 | 5 | 3 | 2 | 2 | 5 | 2 | 4 | 1 | 3 | 12 |
| 5 | 3 | 2 | 2 | 8 | 3 | 3 | 2 | 5 | 2 | 4 | 1 | 4 | 12 |
| 6 | 4 | 2 | 2 | 8 | 4 | 3 | 3 | 5 | 2 | 4 | 2 | 4 | 12 |
| 7 | 4 | 3 | 3 | 12 | 4 | 3 | 3 | 7 | 3 | 4 | 2 | 5 | 12 |
| 8 | 4 | 3 | 3 | 12 | 4 | 4 | 3 | 7 | 3 | 4 | 2 | 5 | 12 |
| 9 | 4 | 3 | 3 | 15 | 5 | 4 | 2 | 7 | 3 | 4 | 2 | 6 | 12 |
| 10 | 5 | 3 | 4 | 15 | 5 | 4 | 2 | 7 | 4 | 4 | 2 | 6 | 12 |
| 11 | 5 | 4 | 4 | 17 | 4 | 10 | 4 | 7 | 4 | 4 | 2 | 7 | 12 |
| 12 | 5 | 4 | 5 | 17 | 4 | 10 | 4 | 7 | 4 | 4 | 3 | 7 | 12 |
| 13 | 5 | 4 | 5 | 17 | 5 | 10 | 6 | 8 | 5 | 4 | 3 | 8 | 12 |
| 14 | 5 | 5 | 5 | 20 | 5 | 14 | 6 | 8 | 5 | 4 | 3 | 8 | 12 |
| 15 | 6 | 5 | 6 | 20 | 7 | 14 | 8 | 9 | 5 | 4 | 3 | 9 | 12 |
| 16 | 6 | 5 | 6 | 20 | 7 | 16 | 8 | 9 | 6 | 4 | 3 | 9 | 12 |
| 17 | 6 | 5 | 8 | 20 | 9 | 16 | 8 | 10 | 6 | 4 | 4 | 10 | 12 |
| 18 | 7 | 6 | 8 | 23 | 9 | 20 | 10 | 10 | 6 | 4 | 4 | 10 | 12 |
| 19 | 7 | 6 | 10 | 23 | 10 | 20 | 10 | 12 | 7 | 4 | 4 | 12 | 12 |
| 20 | 7 | 6 | 10 | 23 | 10 | 20 | 10 | 12 | 7 | 4 | 4 | 12 | 12 |

**Table 3.** Results from solving the proposed model in different dimensions

| | Model(46) | | | HM | | | SQA | |
|---|---|---|---|---|---|---|---|---|
| Test | 1st. OBJ | 2st. OBJ | Solving time | 1st. OBJ | 2st. OBJ | Solving time | GAP1% | GAP2% |
| 1 | 1058204.24 | 182.14 | 20.3 | 1058204.24 | 182.14 | 18.3 | 0.0 | 0.0 |
| 2 | 1072158.18 | 194.23 | 21.1 | 1072158.18 | 194.23 | 18.8 | 0.0 | 0.0 |
| 3 | 1113640.21 | 205.47 | 22.6 | 1123645.05 | 213.12 | 19.5 | 0.9 | 3.7 |
| 4 | 1154819.36 | 227.07 | 36.14 | 1158590.17 | 235.17 | 19.2 | 0.3 | 3.6 |
| 5 | 1277482.08 | 260.21 | 76.5 | 1328381.21 | 269.05 | 21.4 | 4.0 | 3.4 |
| 6 | 1555510.19 | 289.39 | 103.2 | 1616710.23 | 295.33 | 22.3 | 3.9 | 2.1 |
| 7 | 1766083.45 | 305.12 | 195.7 | 1814110.11 | 315.25 | 22.8 | 2.9 | 3.3 |
| 8 | 1837205.37 | 320.05 | 348.5 | 1857256.50 | 325.15 | 21.9 | 1.1 | 1.6 |
| 9 | 1859876.68 | 331.19 | 736.1 | 1878800.51 | 339.36 | 24.6 | 1.0 | 2.4 |
| 10 | 20147688.55 | 365.20 | 1053.8 | 20979820.7 | 371.14 | 26.7 | 4.1 | 1.6 |
| 11 | 22047205.15 | 378.68 | 1766.5 | 22897805.1 | 385.61 | 28.5 | 3.9 | 1.8 |
| 12 | 25357456.28 | 389.51 | 2623.4 | 25887616.3 | 397.47 | 30.1 | 2.1 | 2.1 |
| 13 | 28147084.15 | 410.25 | 3415.9 | 29158990.3 | 421.13 | 31.6 | 3.6 | 2.7 |
| 14 | 34308460.41 | 435.10 | 4896.1 | 35459806.5 | 441.18 | 33.4 | 3.4 | 1.4 |
| 15 | 39547371.36 | 462.19 | 5623.5 | 41446691.2 | 475.29 | 35 | 4.8 | 2.8 |
| 16 | 45149578.12 | 482.15 | 6854.2 | 47098990.6 | 493.34 | 38.6 | 4.3 | 2.3 |
| 17 | 50648476.45 | 508.07 | 8069.6 | 53038970.6 | 528.17 | 42.1 | 4.7 | 3.9 |
| 18 | - | - | 9345.3 | 59113215.1 | 682.14 | 44.5 | - | - |
| 19 | - | - | 10560.5 | 63154890.4 | 754.23 | 48.3 | - | - |
| 20 | - | - | 12038 | 69278482.2 | 805.47 | 52.7 | - | - |

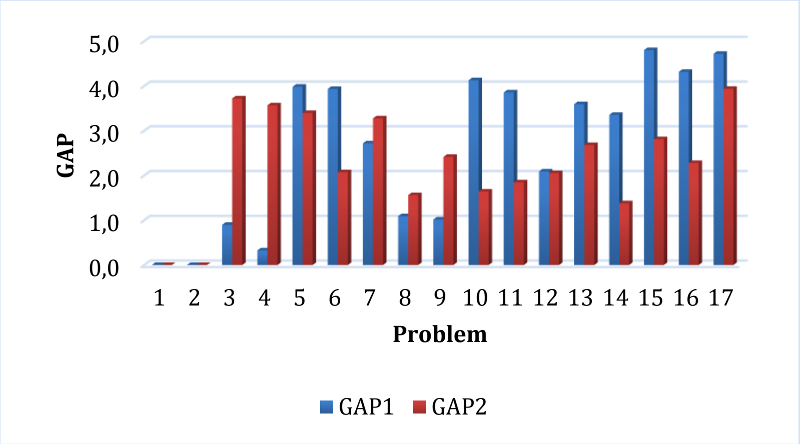

**Figure 1.** Comparison of the optimal gap between the two methods

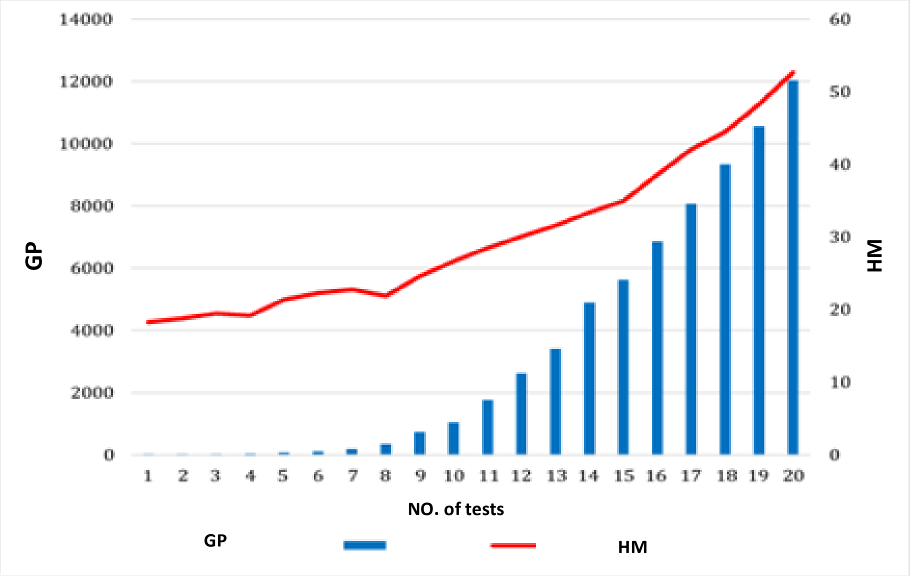

**Figure 2.** Comparison of solution time between two different methods

### 6.2. Sensitivity analysis

This segment discusses the effect of some critical parameters of the proposed model on the designed problem. The three most important parameters studied are demand, inflation, and capacity. We first look at the effect of changes in the inflation parameter. Then the changes in demand and the changes in the capacity parameter are considered. On the other hand, we analyze the robustness of the uncertainty model and its impact on network design. Finally, we discuss sensitivity analysis results and propose appropriate management decisions.

#### *6.2.1. Inflation parameter*

This section examines the effect of inflation on different price strategies (mode 1 = concave price; mode 2 = reference price; mode 3 = convex price). In this way, we solve the problem for different amounts of inflation (from -5% to + 10%). The results of the sensitivity analysis are shown in Figure 3. According to the results in Figure 3, the pricing strategy for suppliers and producers in modes 1 and 3, when inflation values are smaller than 0.195, 0.210, 0.087, 0.090, 0.105, 0.225, respectively, the objectives of the problem Improve. As shown in Figure 3, if the other parameters of the model are constant and inflation changes, for markets that are more sensitive to higher prices, the increasing trend of environmental impacts and the declining trend of NPV in mode 3 under uncertainty are shown.

On the other hand, by reducing the value of inflation, mode 3 improves the target functions. As a result, by opting for Mode 3 pricing policy for markets with inflation changes of -5%, the NPV performance improved by 2.33%, and the environmental performance improved by 1.46% compared to Mode 1. The choice of pricing policy mode 1 for markets with inflation + 5% has an approximately 1.26% improvement in NPV performance and 0.84% improvement in environmental performance compared to mode 3.

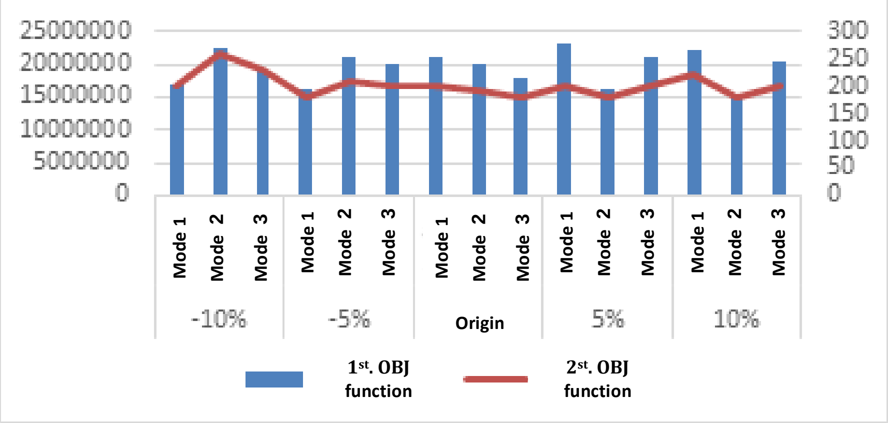

**Figure 3.** The effect of inflation on objectives

### *6.2.2. Demand parameter*

Figure 4 examines the results of the demand parameter analysis relative to the targets. According to this fig, a 5% increase in demand has increased the NPV, but onwards 5%, the target values have been constant, indicating an increase in network costs, and its impact on NPV is targeted. But then, increasing demand is directly related to increasing environmental impact. This is the increase in the amount of transportation with transportation methods, which has led to more environmental impacts.

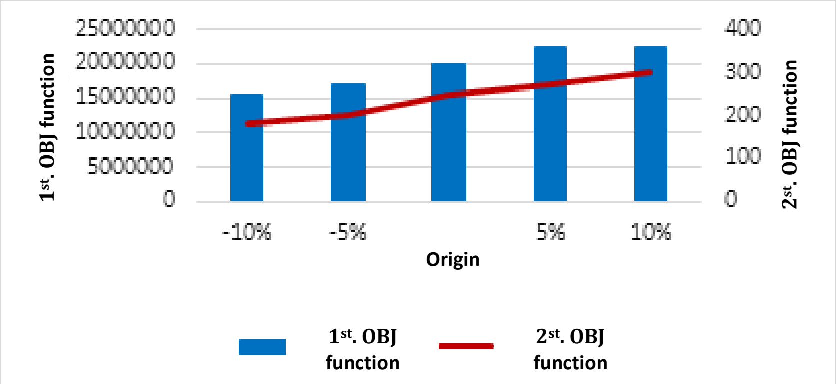

**Figure 4.** Demand parameter sensitivity analysis

### *6.2.3. Capacity parameter*

As shown in Figure 5, the objective functions are directly related to capacity changes. With a 20% increase in capacity, the first objective function increases by 61.59% and the second objective function by 50%. This can be increased production and transportation, but the rate of profitability is affected much more than the environmental goal.

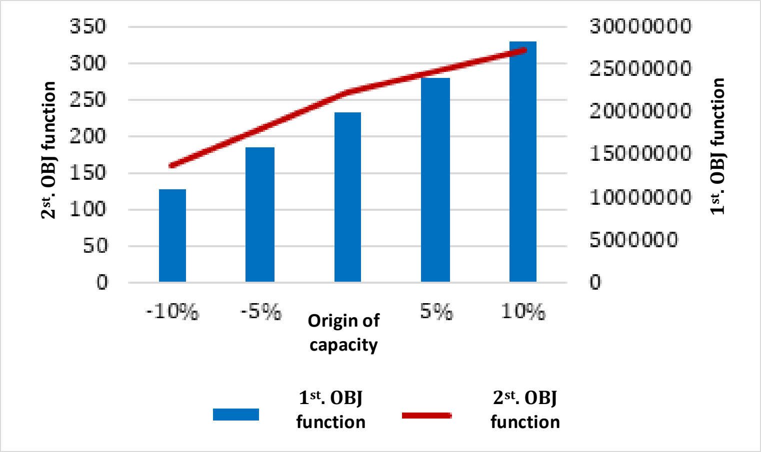

**Figure 5.** Sensitivity analysis of facility capacity on profitability and environmental impact

*6.2.4. Robustness analysis of uncertainty model*

In this section is dedicated to the sensitivity analysis of the parameters of the proposed optimization model. The penalty coefficients used in the RFOM for the first objective function were investigated. As shown in Table 4, as the value of η increases, the value of NPV decreases. Also, no change in NPV is made by changing ξ.

**Table 4.** Sensitivity analysis of robust fuzzy optimization model parameters

| | $\xi_i = 1000$ | | |
|---|---|---|---|
| | $\eta = 0.3$ | $\eta = 0.6$ | $\eta = 0.9$ |
| $\lvert Z1 \rvert$ | 25275812.88 | 20220650.3 | **15110325.15** |

| | $\eta = 0.6$ | | |
|---|---|---|---|
| | $\xi_i = 100$ | $\xi_i = 1000$ | $\xi_i = 2000$ |
| $\lvert Z1 \rvert$ | 20220650.3 | 20220650.3 | **20220650.3** |

According to the analysis, technological foresight informs managers of the challenges and opportunities for expected strategic decisions. One of the essential opportunities created for recycling e-waste in the technological dimension is the creation of suitable opportunities such as rate of return on investment, export potential of local recycling methods, and added value of the investment. Investing in improving production and recycling processes, in the long run, increases the profitability and value of NPVs, but may also increase costs in the short term. Of course, the risk of technology financing for developing countries should not be forgotten because it is one of the government's problems. On the other hand, government incentive policies will be more effective in helping industries manage their financing risk at an annual growth rate. Therefore, the efficiency of SCLSC recycled products is typical, in particular on electronics industry, and can be managed better for NPV value. In addition, an appropriate pricing strategy given the inflation rate in Iran's volatile economy for more sensitive markets to higher prices, inflation can be a factor in determining pricing strategies. In other words, determining the rate of inflation and pricing leads to the choice of profitability range, which considers the environmental and even social effects.

Regarding the policies used to encourage manufacturers to design a stable CLSCN for electronic components, essential elements are proposed to establish an efficient recovery system by formulating the implementation of market-based policy plans. This policy is not macro-level to recover damaged and second-hand equipment by manufacturers or retailers so that at the time of sale, an amount is received as a return from customers. This strengthens and develops the design of a stable CLSCN to recycle electronic components. But on the other hand, this puts more financial burden on customers. Therefore, the role of the government in determining financial incentives for customers to create a green culture in electronics and encourage them to give old and second-hand equipment to manufacturers or retailers is very important. At the macro level, such a policy creates excellent economic opportunities in terms of income, foreign exchange savings, and the country's economic growth.

On the other hand, tax credit policy can also create a direct economic incentive for the tax credit to encourage manufacturers to design a SCLSCN. Of course, given the current economic conditions of the society, the producers may resist the implementation of such a tax. Therefore, the government has used an incentive system in macro-tax policies that forgives producers' VAT for such problems. Establishing a deposit system is an effective policy in developed countries to recycle electronic products, but manufacturers are reluctant to implement such a system due to the inflation in the country. Because they are often afraid of declining sales due to the amount of deposits, this increases the cost of collection and transportation.

## 7. Discussion and conclusion

This article presents an integrated MOMILP model concerning multi-product and multi-period characteristics under uncertainty for configuring a stable CLSC of a computer mouse. The chain sought major back-and-forth stakeholders to recycle components of computer mouse products in response to demand. In addition, the proposed model showed the effect of transportation modes, inflation, carbon emission policies, and supplier selection on the study network. Stable fuzzy optimization was used to deal with the uncertainty of the model parameters. And a new hybrid method was used to solve the complexity and MO nature of the proposed model. The resulting CILP model was systematically solved for a participation in Iran. Several test samples in different dimensions were examined to validate the proposed method. The results were compared with the two factors of optimal gap and solution time, which showed the proper performance of the proposed method. Then, the tactical results and model strategy were presented for a case study. The optimal flow between facilities, selection of suitable suppliers, transportation type, and facilities opening were shown.

Finally, sensitivity analysis on important problem parameters was discussed. The results showed that there is an upward trend in environmental impacts for markets that are more sensitive to higher prices and a downward trend in NPV due to the convex price relative to the reference price. This means that reducing inflation for the convex price improves target performance. In addition, when the concave selling price is equal to the reference price, it enhances the performance of the target functions by increasing inflation. As a result, the impact of green levels on pricing strategy concerning inflation provides the flexibility of current prices in previous periods. Considering the social effects of designing a stable CLSC for electronic components can be a new challenge for future research.

## Abbreviations

| | |
|---|---|
| SSCM | Sustainable supply chain management |
| PD | Product development |
| PR | Product recovery |
| MOMP | Multi-objective mixed programming |
| MOP | Multi-objective problem |
| HM | Hybrid method |
| HA | Heuristic algorithm |
| SSP | Supplier selection problem |
| DEA | Data envelopment analysis |
| SPP | Shortest path problems |
| MCDM | Multicriteria decision making |
| MOM | Multi-objective model |
| GA | Genetic algorithm |
| FDM | Fuzzy decision making |
| MP | Mathematical programming |
| ILPM | Integer linear programming model |
| MILPM | Mixed-integer linear programming model |
| OBJ | Objective |
| MIL | Mixed-integer linear |
| NIL | Nonlinear programming |
| SQA | Solution quality assessment |
| MI | Mixed-integer |
| RFOPM | Robust fuzzy optimization model |
| MOMILP | Multi-objective mixed-integer linear programming |
| MO | Multi-objective |
| CILP | Complex integer linear programming |

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