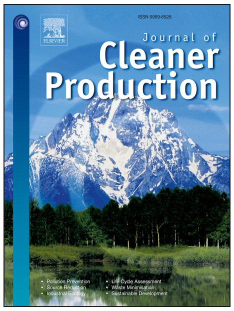

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Abstract

Enhancing social and economic effects along with reducing environmental effect has gained significant consideration in reverse logistics network design. Electronic waste management raises serious concerns due to its increasing quantity and hazardous nature in global business. The developed model is a multi-objective reverse logistics network for electronic waste management, and the concept of the triple bottom line approach has been considered in the proposed study. The suggested study makes a trade-off between conflicting objectives. The research considers first customers, collection centers, distribution centers, second customers and reprocessing centers consisting of return evaluation centers, recycling centers and refurbishing centers. The carbon cap-and-trade policy has also been incorporated into the model. The objective of the formulated model is to maximize the profit and minimize the carbon emissions as well as maximizing the job opportunities in a reverse logistics network. To deal with the uncertainty, neutrosophic optimization has been applied to avoid unrealistic modeling. A related numerical example has been performed and the results show that the transportation cost contributes to the major fraction of the total cost. The reprocessing at the return evaluation and recycling centers are the main source of carbon emissions. Sensitivity analysis has also been conducted to assess the application of the proposed model. It shows that a drastic increase of 42.6% occurs in profit value when the per-unit carbon trading price is increased by 40% and vice-versa. Also, a variation is seen in the parameters like carbon emission at recycling centers with a change in total emissions value and the average number of units processed by one worker at return evaluation center with a variation in the number of job creation value.

Keywords: Sustainable reverse logistics; E-waste management; Carbon cap-and-trade; Social uplift; Neutrosophic approach

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1 Introduction

The conservation of resources needs to be considered in terms of end-of-life electrical products, electricity usage, technology usage, labor utilization, emission of carbon dioxide and increased electrical waste. The need for resource conservation in electrical products can be justified by the increasing levels

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of global climatic changes, e-waste and carbon emissions. World Meteorological Organization reported that 2015-2019 has been the warmest period with an increased global climate change of 0.2% as compared to the climate change in 2011-2015 (WMO, 2019). One of the reasons behind this change was the 20% increase in the level of carbon emissions globally, which will eventually become 410 ppm of carbon emissions at the end of 2019. However, emissions of carbon from transportation constitute around 25% of total carbon emissions. Similarly, the increase in e-waste rationalizes the importance of the reuse and recovery of the electrical products, for not only conservation purposes but also for creating a cost-saving option for the industry. Besides reuse and recovery operations, the recycling of electrical products is also important as the Waste Electrical and Electronic Equipment (WEEE) Ordinance for waste management of electrical products and electronic equipment, specifies that at least 75% of the electrical products need to be recycled to conserve the resources and to reduce the e-waste (Laner and Rechberger, 2007). It was estimated that throughout the world, around 50 million tons of electrical waste is disposed-off each year and only 20% of this waste from electrical products is recycled each year (Baldé et al., 2017). Resource conservation also incorporates how the greenhouse emissions of carbon dioxide and other pollutants should be reduced. The increase in e-waste has also shifted the interest of researchers toward reducing carbon usage and emissions which could help in reducing global warming (Xiao et al., 2019). Emissions of carbon from transportation constitute around 25% of total carbon dioxide emissions (Nanaki and Koroneos, 2016). When considering the need for reuse, recovery, and recycling operations, the social perspective must be considered as well, in terms of job creation. However, globally the rate of unemployment was 5% which can be decreased in the future due to a rise in the number of jobs created worldwide (Kühn, 2019). This shows that an increase in the implementation of reuse, recycling and recovery operations will not only improve resource conservation but will also lead to an increase in job creation and a decrease in the unemployment rate, globally.

Reverse logistic operations are playing a significant role in making the existing supply chains greener in terms of reduction in environmental pollution and the implementation of proper waste management practices. The applicability of reverse logistic operation is enhanced due to the option that is given to the customers to return products, that are either defective or are some end of life products with a remaining warranty period. Similarly, firms are also shifting their focus towards reverse logistics due to current environmental regulations, shorter product lifecycles and more waste generation (O'Reilly and Kumar, 2016). The notion of reverse logistics is gaining attention in both academia and practice, in terms of how environmental and economic perspectives should be incorporated to enhance the performance of reverse logistic operations (John et al., 2017). Also, firms have started realizing that the implementation of reverse logistic operations has a potential for generating a huge amount of revenue or profit while minimizing costs, to remain sustainable and competitive in the market (Morgan et al., 2018). The use of reverse logistics was also justified by Khor et al. (2016) in terms of economic benefits of profit maximization and growth in sales, that are associated with the reuse, recovery, recycling and remanufacturing strategies used in a reverse logistic network. All these options available for the treatment of returned products are considered as agents whose performance should remain as a cost-effective option for the practical implementation of reverse logistics (Pandian and Abdul-Kader, 2017). To reduce the increasing electronic waste, it is crucial to follow proper recovery processes. For this purpose, reverse logistics is applied for the recycling and refurbishment of the used returned product. Moreover, electronic waste recycling has to deal with the uncertainty related to the quality and quantity of the used returned product. Kilic et al. (2015) developed a reverse logistics network for electronic waste and considered different sorts of recycling centers in the model. Kumar et al. (2017) presented a study based on the significance of recycling electronic wastes while describing the methods used for recycling in centers. Wang and Radovilsky (2017) designed a reverse logistics network model considering the cost minimization, for optimally determine the location of refurbishing facilities. Resmi and Fasila (2017) presented a model for refurbishing industries based on the prediction system, to refurbish electronic waste.

A reverse logistics network for electrical products is designed in this research by formulating a mathematical model consisting of three objectives related to the economic uplift, environmental safety, and social welfare. As the proposed multi-objective model is based on the three objectives of the triple bottom line, so it will help in developing a sustainable reverse logistic network for electrical products. The major goal of formulating this multi-objective model is to develop the economic, social and environmental strategies for managing reverse logistic activities of collection, evaluation, reprocessing and transportation of the returned electrical products. The proposed reverse logistics network is optimized by using the neutrosophic optimization approach which can optimize a multi-objective network. This research aims to expand the existing reverse logistics literature by developing a multi-objective reverse logistic network for the electrical products, by considering the effect of carbon cap-and-trade in profit maximization and environmental impact. The model provides the total profit incurred in the reverse logistics of electrical products, by incorporating the revenue earned from selling the reprocessed second-hand electrical products and extra allowable emissions on credit basis in the trading market, and the total costs of reprocessing and transportation. The environmental and social aspects are also considered in terms of the carbon emissions and the jobs created in the collection, evaluation, recycling, refurbishing and distribution centers and for transportation between all these centers, respectively. In this research, the concept of having a separate return evaluation center and a reprocessing unit consisting of the return evaluation, recycling and refurbishing centers, has also been incorporated in the model.

The structure of the paper is as follows: Section 2 presents the Literature review. Section 3 provides the problem description, model assumptions, and notations. The mathematical model formulation is given in Section 4. Section 5 provides the solution methodology and numerical example. Results and discussion, sensitivity analysis and managerial insights are presented in Section 6. Section 7 provides the conclusion, limitations and future directions of this study.

2 Literature review

The demand for designing the reverse logistic network in various industries, based on economic, social and environmental sustainability, has shown an increasing trend in the previous years. Basic awareness and understanding about designing a reverse logistics network and making it sustainable with time is needed. Reverse logistics is a process consisting of a chain of activities that starts from collecting the returned products from the consumers and ends when those returned products are reprocessed and are ready to be sold again. To design a sustainable reverse logistic network, the concept of triple bottom line introduced by Elkington (1997) needs to be addressed, which focuses on achieving social wellbeing, economic uplift, and environmental safety. Sarkis et al. (2010) highlighted that besides achieving economic and environmental sustainability, the role of social indicators in designing and managing a reverse logistic network should also be considered. Devika et al. (2014) also focused on creating a closed-loop supply chain that is sustainable due to the consideration of minimizing the cost and environmental aspects and maximizing social welfare. However, it is important to consider the barriers that might hinder while implementing a designed network for the reverse logistic operations. Prakash et al. (2015) highlighted implementation barriers like coordination issues, unavailability of a proper system for assessing returned products and customer beliefs about the importance of reverse logistics. Furthermore, Garg et al. (2016) highlighted barriers at the financial, regulatory and management levels.

The economic aspect of the triple bottom line approach focuses on how fluctuations in various cost elements can lead to an overall rise or decline in the financial performance of a reverse logistic network. Yu and Solvang (2017) considered the economic objective of profit maximization for a reverse logistics network, in which the cost elements included the fixed cost of operations along with the cost of transporting and processing the product. Govindan et al. (2016) and Lee et al. (2015) also incorporated the economic aspect in reverse logistics by considering the fixed cost in terms of opening a facility along with the cost incurred for transporting and processing the returned product. Pourjavad and Mayorga (2019) minimized the total cost of a closed-loop supply chain through minimization of the fixed cost of building a facility, processing cost at a collection center and all the reprocessing centers, cost of manufacturing and material, shortage cost, and the transportation cost between nodes. For sustainability purposes, all these costs except the shortage cost; are considered along with the costs of handling the products and the savings made due to selling the products for reuse or sending a product or any component back to the manufacturing unit (Devika et al., 2014). Galvez et al. (2015) designed a network for reverse logistic operations carried out for the management of waste for which they have focused on the economic dimension by minimizing the cost of buying or hiring a vehicle and then using that vehicle for transportation purposes. Alshamsi and Diabat (2017) developed a reverse logistics network for household appliances considering the economic aspect. Mota et al. (2015) designed a supply chain network considering the economic sustainability in terms of minimizing the total cost which includes the fixed cost of building a facility, cost of material, cost of transportation, human resource cost and the cost of recovering a product. Khademikia et al. (2016) developed a hybrid model for predicting and managing the wastewater treatment plant for preserving the environmental standards along with achieving the economic goal.

To gain sustainability through the triple bottom line, the effect of emission cost in the economic dimension of total cost minimization needs to be addressed. In a cap-and-trade policy, an organization or a supply chain is subjected to a minimum cap for allowable carbon emissions that cannot be exceeded (Drake et al., 2016). If this allowable amount for carbon is exceeded, then the organization has the option to buy extra credits for carbon emissions which will increase the total costs. However, if the total carbon emitted by an organization is less than the allowable amount for carbon, then they have the option to sell the extra credit for carbon emissions in the trading market which eventually minimizes the total cost (Song et al., 2017). Sarkar et al. (2018a) and Tiwari et al. (2019) have linked the total profitability of a firm to the amount of carbon emitted at various ends. Zhang et al. (2018) used cap-and-trade policy in terms of the carbon emitted for determining the optimal level of quantities that should be produced, stored in inventory and delivered to the customers. Bing et al. (2015) redesigned a reverse logistic network for managing the household waste of plastic material under the policy of emission trading, to reduce the total cost and the emissions during the transportation and reprocessing processes. They also included a trading cost of emissions in the total cost function. Trochu et al. (2020) designed a reverse logistics network based on eco-efficiency, with the goal of profit maximization for the demolition, construction and the renovation industry. However, the concept of cap-and-trade has also been used for a manufacturer who is capital constrained and wants to maximize profit by maximizing the yield (Wang et al., 2017).

The environmental aspect of the triple bottom line approach pertains to the reduction of greenhouse gas emissions and resource conservation that affects the environmental performance of a reverse logistics network. In this context, Kyere et al. (2018) stated that e-waste recycling causes substantial environmental damages. Tiwari et al. (2018) have developed a model for green production. Yu, H. and Solvang, W.D. (2016) presented a model considering both the economic and environmental objectives and provided a trade-off between the operational cost and the environmental influences of a reverse logistics system. Bing et al. (2014) developed a reverse logistics network considering the environmental aspect based on the reduction of carbon dioxide emission costs from the processing and the transportation of plastic waste products. Ahmed and Sarkar (2018) developed a model that considers the cost of carbon emissions at various phases of supply chain. Furthermore, John et al. (2017) proposed a mathematical model for a reverse logistics network design and included the environmental impact of a reverse supply chain decision while considering the emission costs from transportation for the entire network. Sarkar et al. (2018b) formulated a supply chain model that considers the cost of carbon emissions related to the transportation sector for cost minimization. Similarly, Rahimi and Ghezavati (2018) designed a mathematical model while considering risk aversion and incorporated the environmental impacts due to the opening of the recycling facility, waste recycling process and product transportation for a reverse logistics network. Gao (2019) developed a reverse logistics network by proposing some hybrid processing units based on the restructuring of the existing units for the forward logistics network. Yu and Solvang (2017) proposed a mathematical model for the economic value improvement with the consideration of the carbon emission requirement for the economic and environmental sustainability of the reverse logistics network design.

To date, little attention has been paid to collectively consider the economic, environmental and social aspects of the triple bottom line approach, to evaluate the performance of a reverse logistics network. Ramos et al. (2014) incorporated the social objective in reverse logistics network design by aiming to minimize the maximum driver's working hours. Bal and Satoglu (2018) proposed a reverse supply chain model considering the social perspective in terms of workforce balance to provide some work opportunities regularly. Soleimani et al. (2017) developed a closed-loop supply chain network and incorporated social responsibility while considering occupational accidents. Pedram et al. (2017) proposed a mathematical model for a closed-loop supply chain to increase social responsibility relating to job opportunity creation due to the establishment of the facilities. Arampantzi and Minis (2017) incorporated the social objective for designing a supply chain network based on various social factors, including the creation of work opportunities, the development of the societal community and the improvement of working conditions. Ahmed and Sarkar (2019) incorporated the social dimension for the development of the next-generation biofuel supply chain. Govindan et al. (2016) considered two indicators for including social responsibility into a reverse logistics network design model. The first indicator is based on job creation that deals with both the societal improvement and better working conditions and the second indicator is based on the working days lost from the harm caused to the employees due to poor working conditions. Rahimi and Ghezavati (2018) also accounted for the social objective while developing a sustainable reverse logistics system in which they considered social wellbeing by including factors like fixed employment opportunities creation depending on the opening of a recycling unit, variable employment opportunities creation based on capacity expansion and lost jobs during work damages.

During the last decades, the Electrical and Electronics Industry has expanded significantly. However, this has also considerably increased the amount of electronic product waste because of the rapid technological innovation and decreasing product lifecycles. In this regard, reverse logistics has become crucial for the management and processing electronic product waste (Isernia et al., 2019). The formulated model aims at minimization of the logistics cost. Kilic et al. (2015) developed an optimized reverse logistic system for the handling of waste from electrical and electronic products. Dat et al. (2012) presented a reverse logistics model that accounted for multiple cost factors including the collection cost, treatment cost, transportation cost and the income from returned product sales to minimize the processing cost of different types of electrical and electronic products. Furthermore, Darbari et al. (2017) developed a reverse logistics network model for the electronic returned products that focus on the minimization of reverse logistics cost and the maximization of the recovery facility's' performance sustainability. Similarly, Ayvaz et al. (2015) designed a reverse logistics system for the recycling of electrical and electronic waste, along with the consideration of profit maximization. Yu, H. and Solvang, W. (2016) designed a reverse logistics model for the electronic and electrical product waste management. The model considers both the economic and environmental factors by linking the carbon trading cost with the objective of cost minimization. Accordingly, Zarbakhshnia et al. (2019) developed a forward and reverse logistics model for home appliances that consider both the economic and environmental aspects.

Linear programming is an operations research method that is extensively used to solve practical problems. This method is based on the formulation of a linear mathematical model, comprising of some objective function and constraints (Uko et al., 2017). The linear programming models require precise data but the data available for practical problems is extremely imprecise that alters the optimal results (Abdel-Basset et al., 2019). Zadeh (1965) presented the notion of fuzzy sets that considers truth membership function and is used to address the inexact and vague information. In addition, Turksen (1986) proposed the theory of interval valued of a fuzzy set. Furthermore, Atanassov (1986) gave the concept of an intuitionistic fuzzy set which is an extension of the fuzzy sets that includes both the truth function and the falsity function. Smarandache (1999) developed the neutrosophic set approach to deal with the uncertain, inaccurate and ambiguous information presented by the real-world problems. Accordingly, Das and Roy (2015) also stated that the intuitionistic fuzzy set can deal with partial information but cannot account for the unreliable and uncertain information. The neutrosophic set approach takes in to account all facets of decision making and enables to present reality in a better way. This approach is a simplification of the fuzzy set and the intuitionistic fuzzy set. The neutrosophic set approach consists of the truth membership function, the indeterminacy membership function and the falsity membership function for each element of the set. Therefore, the indefinite, vague and inexplicit information can be assimilated precisely through the neutrosophic sets (Deli, 2017; Deli and Şubaş, 2017).

Table 1

Literature contribution for reverse logistic network design of electronic products

Author(s)	Economic aspect	Environmental aspect	Social aspect	Cap-and-trade policy	E-waste management	Neutrosophic approach
Elkington (1997)	✓	✓	✓			
Smarandache (1999)						✓
Sarkis et al. (2010)	✓	✓	✓			
Dat et al. (2012)	✓				✓	
Lee et al. (2015)	✓					
Galvez et al. (2015)	✓	✓				
Bing et al. (2015)	✓	✓		✓		
Ayvaz et al. (2015)	✓				✓	
Govindan et al. (2016)	✓	✓	✓			
Drake et al. (2016)	✓	✓		✓		
Yu, H. and Solvang, W.D. (2016)	✓	✓				
Yu and Solvang (2017)	✓	✓				
Song et al. (2017)	✓	✓		✓		
Darbari et al. (2017)	✓				✓	
Deli and Şubaş, 2017a						✓
Deli and Şubaş, 2017b						✓
Bal and Satoglu (2018)	✓	✓	✓		✓	
Rahimi and Ghezavati (2018)	✓	✓	✓			
Abdel-Basset et al., 2019						✓
Proposed Research	✓	✓	✓	✓	✓	✓

After an in-depth analysis of the existing literature related to reverse logistics, triple bottom line, and electrical products, a sustainable reverse logistics network for electrical products is proposed. The proposed network considers all the three aspects of the triple bottom line in the form of an economic function of profit maximization, and the environmental function of carbon emission minimization and a social impact maximization function. Second-hand electrical products are the end products of this reverse logistics network that are sold in the secondary market and will in return minimize the total cost and carbon emission while maximizing the impact of reverse logistics on social welfare in terms of employment creation. Limited research has been previously conducted on designing a reverse logistics network specifically for electrical products, considering all the three aspects of the triple bottom line approach. Also, there is limited research regarding the consideration of cap-and-trade policy and how it will affect the economic condition of a firm by giving the option to sell the extra allowable emissions to other firms in the trading market and in return getting an additional amount in its revenue. The proposed model also incorporates a carbon cap constraint by setting a maximum allowable limit on the carbon emissions that can be emitted by a firm, which was previously not given much attention. The social aspect is considered in terms of the number of jobs created at the collection, return evaluation, recycling, refurbishing, and distribution centers and transportation purposes, with respect to a worker’s ability to process and the number of operators needed on one truck, respectively. Additionally, a return evaluation center is introduced to categorize and grade all the returned products collected by the regional collection centers, against a standard set of rules to minimize the chances of error. Lastly, the proposed model has a consideration of having the return evaluation, recycling and refurbishing centers at the same location in the form of a reprocessing unit, to minimize the overall transportation cost. In the end, the proposed model with economic, social and environmental objectives is optimized using the multi-objective neutrosophic optimization approach and is solved using a case study.

3 Problem Description and Assumptions

This section provides a detailed problem description and the assumptions for the designed multi-objective reverse logistics network.

3.1 Problem Description

A multi-objective mathematical model for the reverse logistic operations of electrical products is presented, based on the concept of the triple bottom line. The proposed model is solved under three main objectives of environmental, economic and social uplift to find out an optimal solution value satisfying all three objectives. The main objective of the model is to propose a reverse logistic network to support various decisions based on (1) inclusion of a return evaluation center for grading and categorization of the returned products, (2) the same location of return evaluation, recycling and refurbishing centers to minimize the transportation cost, (3) social uplift due to increase in the number of jobs created based on a worker's ability, (4) cap-and-trade policy is incorporated to cut the carbon emissions and maximize the profit and (5) use of the neutrosophic approach for multi-objective optimization of the proposed model. The problem definition of reverse logistics network design for electronic waste management is shown in Fig. 1.

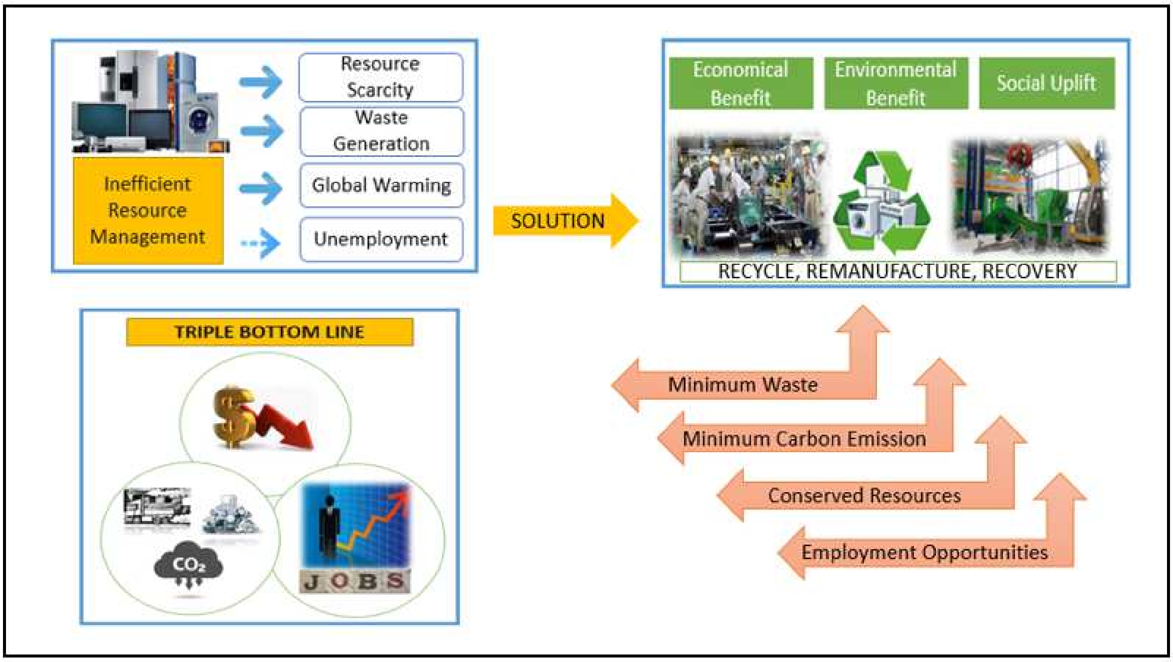


Fig. 1. Reverse logistics network design for e-waste management.

The proposed multi-objective reverse logistics network for electrical products is a single-period and single-product model. The network structure for reverse logistics of returned electrical products is shown in Fig. 2. The proposed model consists of multiple layers in the reverse logistic network, which are collection centers, return evaluation centers, recycling centers, refurbishing centers, distribution centers, and second customers. In this reverse logistics network, it is assumed that the returned products are sent to the collection centers by the first customers that can either be some retailer or the end customer. After collection, the returned products are sent to the return evaluation center for sorting, categorization, and grading of the products. The evaluated products are then provided with one of the two possible treatments; recycling or refurbishing. In the end, the recycled and refurbished products are sent to the distribution center for selling purposes.

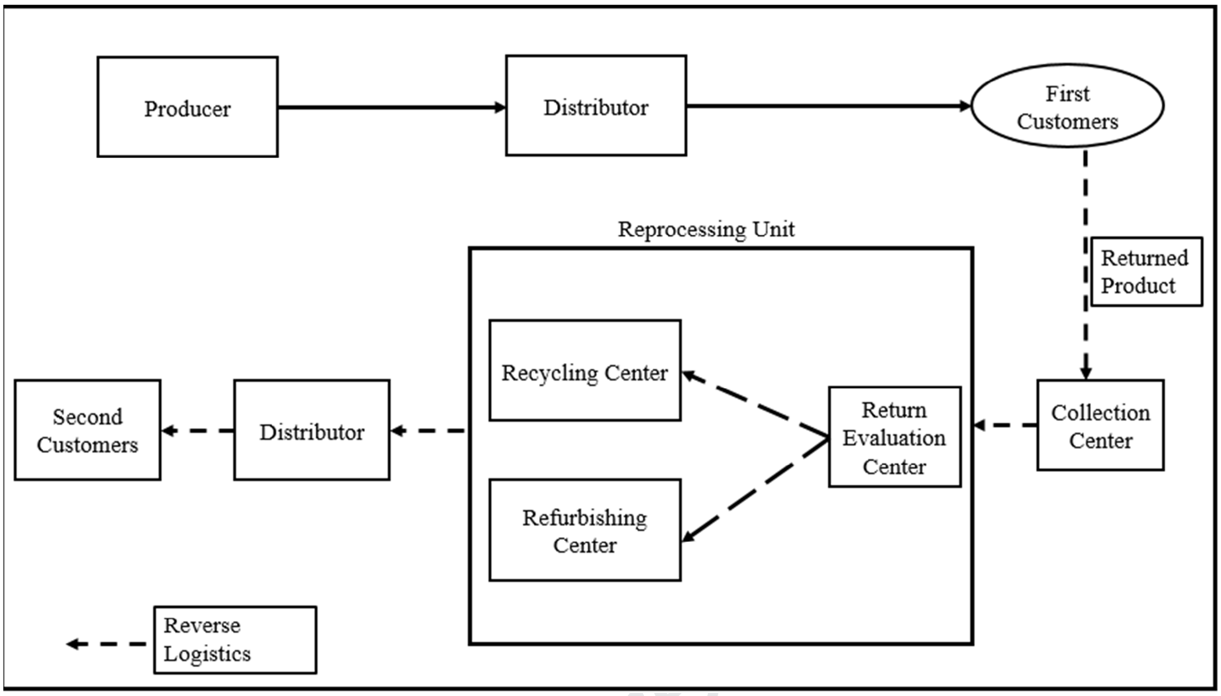


Fig. 2. Network structure for reverse logistics of returned electrical products.

Four out of the seven layers are considered as a single unit named the reprocessing unit, which are the return evaluation centers, recycling centers, and refurbishing centers. Due to the presence of these three centers within a reprocessing unit, the overall transportation cost is minimized. Similarly, the concept of having a single and separate return evaluation center is introduced to enhance the ease of assessment and facilitate the grading and categorization of the returned products against some pre-defined standards. The assumptions for the defined problem are presented in Section 3.2.

3.2 Model Assumptions

1. The location of collection centers, reprocessing unit (return evaluation, recycling and refurbishing centers) and distribution centers are known and fixed.
2. The parameter values are deterministic.
3. The proposed model is a single-period and single-product.
4. The grading and categorization of the product will be done separately at the return evaluation center.
5. The return evaluation, recycling and refurbishing centers are considered as a single entity in the form of a reprocessing unit. Due to this consideration, the transportation cost and carbon emission will be minimized.
6. The location of the first customers and second customers are known due to the presence of regional collection centers and distribution centers.

7. The returned products can be recycled or recovered at different rates based on their grading and categorization at the return evaluation center.
8. The recycled and recovered products can only be sold as second-hand products in a secondary market.
9. The reprocessing unit consisting of return evaluation, recycling, and refurbishing centers is assumed to be one.

3.3 Notations

Sets

F	first customer; indexed by f
S	second customers; indexed by s
C	collection centers; indexed by c
E	return evaluation centers; indexed by e
R	recycling centers; indexed by r
X	reprocessing centers; indexed by x
V	refurbishing centers; indexed by v
D	distribution centers; indexed by d
P	product; indexed by p

Decision Variables

Q_{pfc}	amount of returned product sent by the first customer to the collection center
Q_{pce}	amount of returned product sent from the collection center to the return evaluation center
Q_{per}	amount of returned product sent from the return evaluation center to the recycling center
Q_{pev}	amount of returned product sent from the return evaluation center to the refurbishing center
Q_{prd}	amount of recycled product sent from the recycling center to the distribution center
Q_{pvd}	amount of recovered product sent from the refurbishing center to the distribution center
Q_{pds}	amount of reprocessed product sent from the distribution center to the second customer

Parameters

Z	fuel rate
L_{pce}	per-unit labor cost incurred during transportation from the collection center to return evaluation center
L_{pxd}	per-unit labor cost incurred during transportation from the reprocessing center to distribution center
t_{cx}	transportation distance between the collection center and return evaluation center
t_{xd}	transportation distance between the reprocessing center and distribution center
I_p	capacity of vehicle
U_{pc}	per-unit collection cost of the returned product at the collection center
U_{pe}	per-unit return evaluation cost of the returned product at the return evaluation center
U_{pr}	per-unit recycling cost of the returned product at the recycling center
U_{pv}	per-unit refurbishing cost of the returned product at the refurbishing center
U_{pd}	per-unit distribution cost of the reprocessed product at the distribution center
C_{pce}	carbon emission indicator for transportation of the returned product from the collection center to the return evaluation center
C_{pxd}	carbon emission indicator for transportation of the reprocessed product from reprocessing center to the distribution center
K_{pe}	carbon emission indicator of the return evaluation center
K_{pr}	carbon emission indicator of the recycling center
K_{pv}	carbon emission indicator of the refurbishing center
a_{pc}	average number of units processed by one worker at the collection center
a_{pe}	average number of units processed by one worker at the return evaluation center
a_{pr}	average number of units processed by one worker at the recycling center
a_{pv}	average number of units processed by one worker at the refurbishing center
a_{pd}	average number of units processed by one worker at the distribution center

g_{ce}	number of operators required for each truck moving from the collection center to the return evaluation center
g_{xd}	number of operators required for each truck moving from the reprocessing center to the distribution center
B_{pc}	capacity of storing returned product at the collection center
B_{pe}	capacity of evaluating returned product at the return evaluation center
B_{pr}	capacity of recycling returned product at the recycling center
B_{pv}	capacity of refurbishing returned product at the refurbishing center
B_{pd}	capacity of handling reprocessed product at the distribution center
Ed_{ps}	expected demand for the reprocessed product at the end of the second customer
VC	variable processing cost
CT	transportation cost
TP	total profit
EI	environmental impact
EP	carbon emission from the processing of used products
ET	carbon emission from transportation
EC	employment creation
H_{pc}	per-unit handling cost of product at the collection center
H_{pe}	per-unit handling cost of product at the return evaluation center
H_{pr}	per-unit handling cost of product at the recycling center
H_{pv}	per-unit handling cost of product at the refurbishing center
H_{pd}	per-unit handling cost of product at the distribution center
W_{pr}	per-unit material cost to process product at the recycling center
W_{pv}	per-unit material cost to process product at refurbishing center
S_{pc}	per-unit storage cost of product at the collection center
S_{pe}	per-unit storage cost of product at the return evaluation center

S_{pd}	per-unit storage cost of product at the distribution center
L_{pc}	per-unit labor cost at the collection center
L_{pe}	per-unit labor cost at the return evaluation center
L_{pr}	per-unit labor cost at the recycling center
L_{pv}	per-unit labor cost at the refurbishing center
L_{pd}	per-unit labor cost at the distribution center
T	carbon trading market price
M	maximum carbon emissions limit
RC	revenue generated from selling extra allowable emissions in the trading market
RP	revenue generated from selling the reprocessed products to second customers

4 Formulation of a mathematical model

The mathematical model formulation of the proposed model is described in this section. The model comprises of three objectives are (1) maximization of total profit, (2) minimization of environmental impact and (3) maximization of social impact.

4.1 Economic objective

The first objective of the proposed multi-objective reverse logistic network is profit maximization. The profit function consists of the revenue earned from selling reprocessed products and selling extra allowable emissions in the trading market and the cost is divided into two parts; variable processing cost (VC) and transportation cost (CT) .

The variable processing cost is based on the costs incurred at the five centers; collection centers, return evaluation centers, recycling centers, refurbishing centers, and distribution centers. At each of these centers, different types of variable processing costs are incurred based on the operations performed in them. The composition of variable processing cost at each center is discussed as follows:

Equation (1) shows that the unit processing cost at each collection center consists of the per-unit storage cost $\left(S_{pc}\right)$, per-unit handling cost $\left(H_{pc}\right)$ and per-unit labor cost $\left(L_{pc}\right)$ incurred during collection operations.

$$U_{pc} = \sum_{p\in P}\sum_{c\in C}(S_{pc} + H_{pc} + L_{pc}) \tag{1}$$

Equation (2) shows that the unit processing cost at each return evaluation center consists of the per-unit storage cost$\left(S_{pe}\right)$, per-unit handling cost $\left(H_{pe}\right)$ and per-unit labor cost $\left(L_{pe}\right)$ incurred during return evaluation operations.

$$U_{pe} = \sum_{p\in P}\sum_{e\in E}(S_{pe} + H_{pe} + L_{pe}) \tag{2}$$

Equation (3) shows that the unit processing cost at each recycling center consists of the per-unit handling cost$\left(H_{pr}\right)$, per-unit labor cost $\left(L_{pr}\right)$ and per-unit material cost$\left(W_{pr}\right)$ incurred during recycling operations.

$$U_{pr} = \sum_{p\in P}\sum_{r\in R}(H_{pr} + L_{pr} + W_{pr}) \tag{3}$$

Equation (4) shows that the unit processing cost at each refurbishing center consists of the per-unit handling cost$\left(H_{pv}\right)$, per-unit labor cost $\left(L_{pv}\right)$ and per-unit material cost$\left(W_{pv}\right)$ incurred during refurbishing operations.

$$U_{pv} = \sum_{p\in P}\sum_{v\in V}(H_{pv} + L_{pv} + W_{pv}) \tag{4}$$

Equation (5) shows that the unit processing cost at each distribution center consists of the per-unit storage cost$\left(S_{pd}\right)$, per-unit handling cost $\left(H_{pd}\right)$ and per-unit labor cost $\left(L_{pd}\right)$ incurred during distribution operations.

$$U_{pd} = \sum_{p\in P}\sum_{d\in D}(S_{pd} + H_{pd} + L_{pd}) \tag{5}$$

The total variable processing cost incurred at the five centers is expressed in Equation (6) as follows:

$$\begin{aligned} VC = {} & (\sum_{p\in P}\sum_{c\in C}\sum_{e\in E}U_{pc}Q_{pce}) + (\sum_{p\in P}\sum_{e\in E}\sum_{r\in R}\sum_{m\in M}\sum_{v\in V}U_{pe}(Q_{per} + Q_{pev})) + (\sum_{p\in P}\sum_{r\in R}\sum_{d\in D}U_{pr}Q_{prd}) + \\ & (\sum_{p\in P}\sum_{v\in V}\sum_{d\in D}U_{pv}Q_{pvd}) + (\sum_{p\in P}\sum_{d\in D}\sum_{s\in S}U_{pd}Q_{pds}) \end{aligned} \tag{5}$$

The second part of the total cost is the transportation cost that is incurred at only two points as shown in Equation (7). Firstly, transportation cost is incurred when the returned product is being sent from the collection center to the return evaluation center. Secondly, when the reprocessed product is sent from the recycling and refurbishing centers to the distribution centers for selling purposes. No cost is incurred for transportation when the evaluated products are sent from the return evaluation center to recycling and refurbishing centers because all the three centers are present at the same location. Similarly, a one-time transportation cost is incurred for sending reprocessed products from recycling and refurbishing centers to the distribution center because all these centers are located inside a reprocessing unit.

$$CT = \sum_{p\in P}\sum_{c\in C}\sum_{e\in E} L_{pce} Zt_{cx} \frac{Q_{pce}}{I_p} + \sum_{p\in P}\sum_{x\in X}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D} ZL_{pxd} t_{xd} \frac{(Q_{prd} + Q_{pvd})}{I_p} \tag{6}$$

The revenue generated from selling reprocessed products, shown in Equation (8), is calculated by multiplying the average unit selling price J_p with quantity supplied by distribution centers to the second customers Q_{pds}.

$$RP = \sum_{p\in P}\sum_{d\in D}\sum_{s\in S} J_p Q_{pds} \tag{7}$$

Let (M) denote the maximum carbon cap set by the regulatory authorities. If the carbon emissions do not exceed the carbon cap, reverse logistics can sell their carbon credits to the carbon trading market. In this model, the total carbon emissions should be less than and equal to the maximum carbon cap. This only allows the reverse logistics to sell the extra carbon emissions and limits it from purchasing excess carbon emissions. Revenue generated from selling extra allowable emissions in the trading market is shown in Equation (9).

$$RC = T\left(M - \left[\begin{array}{l} \left(\sum_{p\in P}\sum_{c\in C}\sum_{x\in X} C_{pcx} \sum_{p\in P}\sum_{c\in C}\sum_{e\in E} Q_{pce} + \sum_{p\in P}\sum_{x\in X}\sum_{d\in D} C_{pxd} \sum_{p\in P}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D} (Q_{prd} + Q_{pvd}) \right) + \\ \left(\begin{array}{l} \sum_{p\in P}\sum_{e\in E} K_{pe} \left(\sum_{p\in P}\sum_{e\in E}\sum_{r\in R} Q_{per} + \sum_{p\in P}\sum_{e\in E}\sum_{v\in V} Q_{pev}\right) + \sum_{p\in P}\sum_{r\in R} K_{pr} \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} Q_{prd} + \\ \sum_{p\in P}\sum_{v\in V} K_{pv} \sum_{p\in P}\sum_{v\in V}\sum_{d\in D} Q_{pvd} \end{array} \right) \end{array} \right] \right) \tag{8}$$

The total profit function is expressed in Equation (10) and (11) as follows:

$$MaxTP = RP + RC - VC - CT \tag{9}$$

$$MaxTP=\sum_{p\in P}\sum_{d\in D}\sum_{s\in S}J_pQ_{pds}+\left(T\left(M-\left[\begin{matrix}\left(\begin{matrix}\sum_{p\in P}\sum_{c\in C}\sum_{x\in X}C_{pcx}\sum_{p\in P}\sum_{c\in C}\sum_{e\in E}Q_{pce}+\\ \sum_{p\in P}\sum_{x\in X}\sum_{d\in D}C_{pxd}\sum_{p\in P}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D}(Q_{prd}+Q_{pvd})\end{matrix}\right)+\\ \left(\begin{matrix}\sum_{p\in P}\sum_{e\in E}K_{pe}(\sum_{p\in P}\sum_{e\in E}\sum_{r\in R}Q_{per}+\sum_{p\in P}\sum_{e\in E}\sum_{v\in V}Q_{pev})+\\ \sum_{p\in P}\sum_{r\in R}K_{pr}\sum_{p\in P}\sum_{r\in R}\sum_{d\in D}Q_{prd}+\\ \sum_{p\in P}\sum_{v\in V}K_{pv}\sum_{p\in P}\sum_{v\in V}\sum_{d\in D}Q_{pvd}\end{matrix}\right)\end{matrix}\right]\right)\right)-$$
$$\left(\begin{matrix}(\sum_{p\in P}\sum_{c\in C}\sum_{e\in E}U_{pc}Q_{pce})+(\sum_{p\in P}\sum_{e\in E}\sum_{r\in R}\sum_{m\in M}\sum_{v\in V}U_{pe}(Q_{per}+Q_{pem}+Q_{pev}))+(\sum_{p\in P}\sum_{r\in R}\sum_{d\in D}U_{pr}Q_{prd})+\\ (\sum_{p\in P}\sum_{v\in V}\sum_{d\in D}U_{pv}Q_{pvd})+(\sum_{p\in P}\sum_{d\in D}\sum_{s\in S}U_{pd}Q_{pds})\end{matrix}\right)-$$
$$\left(\sum_{p\in P}\sum_{c\in C}\sum_{e\in E}ZL_{pce}t_{cx}\frac{Q_{pce}}{I_p}+\sum_{p\in P}\sum_{x\in X}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D}ZL_{pxd}t_{xd}\frac{(Q_{prd}+Q_{pvd})}{I_p}\right) \tag{10}$$

4.2 Environmental Impact

The second objective of the proposed multi-objective reverse logistic network is the minimization of environmental impact. The environmental impact function (EI) is divided into two parts; Carbon emissions from transportation (ET) and Carbon emissions from the processing of used products (EP). Carbon emissions significantly contribute to environmental changes that lead to global warming and health impacts. In this model, carbon emissions related to transportation and used products are analyzed to minimize the overall environmental impact. Equation (12) shows the first part of the environmental function which evaluates the carbon emission from the transportation of used products from the collection center to return evaluation center and reprocessed products from the reprocessing unit to the distribution center. The carbon emission indicator C_{pcx} represents the carbon emissions for transporting one unit of used product and C_{pxd} represents the carbon emissions for transporting one unit of reprocessed products depending on vehicle type and vehicle load.

$$ET=\sum_{p\in P}\sum_{c\in C}\sum_{x\in X}C_{pcx}\sum_{p\in P}\sum_{c\in C}\sum_{e\in E}Q_{pce}+\sum_{p\in P}\sum_{x\in X}\sum_{d\in D}C_{pxd}\sum_{p\in P}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D}(Q_{prd}+Q_{pvd}) \tag{11}$$

Equation (13) shows the second part of the environmental impact function which evaluates the carbon emission for processing of used products at four centers including return evaluation center, recycling center, and refurbishing center. The carbon emission indicators K_{pe}, K_{pr}, K_{pv} represent the carbon emissions for processing one unit of product at each facility depending on processing time and technology usage level.

$$\begin{aligned}EP = &\sum_{p\in P}\sum_{e\in E} K_{pe}\Big(\sum_{p\in P}\sum_{e\in E}\sum_{r\in R} Q_{per} + \sum_{p\in P}\sum_{e\in E}\sum_{v\in V} Q_{pev}\Big) + \sum_{p\in P}\sum_{r\in R} K_{pr} \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} Q_{prd} + \\ &\sum_{p\in P}\sum_{v\in V} K_{pv} \sum_{p\in P}\sum_{v\in V}\sum_{d\in D} Q_{pvd}\end{aligned} \tag{12}$$

The environmental impact is expressed in Equation (14) as follows:

$$\begin{aligned}Min\, EI = &\left(\sum_{p\in P}\sum_{c\in C}\sum_{x\in X} C_{pcx} \sum_{p\in P}\sum_{c\in C}\sum_{e\in E} Q_{pce} + \sum_{p\in P}\sum_{x\in X}\sum_{d\in D} C_{pxd} \sum_{p\in P}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D} (Q_{prd} + Q_{pvd})\right) + \\ &\left(\begin{aligned}&\sum_{p\in P}\sum_{e\in E} K_{pe}\Big(\sum_{p\in P}\sum_{e\in E}\sum_{r\in R} Q_{per} + \sum_{p\in P}\sum_{e\in E}\sum_{v\in V} Q_{pev}\Big) + \sum_{p\in P}\sum_{r\in R} K_{pr} \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} Q_{prd} + \\ &\sum_{p\in P}\sum_{v\in V} K_{pv} \sum_{p\in P}\sum_{v\in V}\sum_{d\in D} Q_{pvd}\end{aligned}\right)\end{aligned} \tag{13}$$

4.3 Social Impact

For maximizing employment creation, Equation (15) shows that the model is considering job creation at two levels; one at the facility level and the other at the transportation level. At the facility level, jobs are created at the collection, return evaluation, recycling, refurbishing, and distribution centers. The number of jobs created at each center or facility is determined, based on the factors of the quantity being processed at each center and the average number of units that can be processed by one worker. However, at the transportation level, jobs are created when returned products are sent from collection to return evaluation center (reprocessing unit) and reprocessed products are sent from the reprocessing unit to the distribution centers. Here, the number of jobs created is determined, based on the factors of the quantity being sent from one center to the next, number of operators required for each truck and the average number of units that can be processed by one worker. Hence, by maximizing the employment creation at these two levels, the unemployment rate can be declined, resulting in a better lifestyle for the majority population.

$$\begin{aligned}Max\, EC = &\sum_{p\in P}\sum_{c\in C}\sum_{e\in E} \frac{Q_{pce}}{a_{pc}} + \sum_{p\in P}\sum_{e\in E}\sum_{r\in R}\sum_{v\in V} \frac{(Q_{per} + Q_{pev})}{a_{pe}} + \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} \frac{Q_{prd}}{a_{pr}} + \\ &\sum_{p\in P}\sum_{v\in V}\sum_{d\in D} \frac{Q_{pvd}}{a_{pv}} + \sum_{p\in P}\sum_{d\in D}\sum_{s\in S} \frac{Q_{prd}}{a_{pr}} + \sum_{p\in P}\sum_{c\in C}\sum_{e\in E} \frac{Q_{pce}}{I_p}(g_{cx}) + \sum_{p\in P}\sum_{x\in X}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D} \frac{(Q_{prd} + Q_{pvd})}{I_p}(g_{xd})\end{aligned} \tag{14}$$

4.4 Constraints

The constraints of the formulated model are given below.

4.4.1 Capacity Constraints

The capacity constraint in Equation (16) shows that the quantity of returned products sent from the collection center to the return evaluation center should be less than or equal to the processing capacity of the product at the collection center.

$$\sum_{p\in P}\sum_{e\in E} Q_{pce} \le B_{pc} \qquad \forall c \in C \tag{15}$$

The capacity constraint shows in Equation (17) that the sum of quantities of the evaluated product sent from the return evaluation center to the recycling center and refurbishing center should be less than or equal to the processing capacity of the product at a return evaluation center.

$$\sum_{p\in P}\sum_{r\in R} Q_{per} + \sum_{p\in P}\sum_{v\in V} Q_{pev} \le B_{pe} \qquad \forall e \in E \tag{16}$$

The capacity constraint shows in Equation (18) that the quantity of recycled products sent from the recycling center to the distribution center should be less than or equal to the processing capacity of the product at the recycling center.

$$\sum_{p\in P}\sum_{d\in D} Q_{prd} \le B_{pr} \qquad \forall r \in R \tag{17}$$

The capacity constraint in Equation (19) shows that the quantity of refurbished products sent from the refurbishing center to the distribution center should be less than or equal to the processing capacity of the product at the refurbishing center.

$$\sum_{p\in P}\sum_{d\in D} Q_{pvd} \le B_{pv} \qquad \forall v \in V \tag{18}$$

The capacity constraint in Equation (20) shows that the sum of quantities of the reprocessed product sent from the recycling center and refurbishing center to the distribution center should be less than or equal to the processing capacity of the product at the distribution center.

$$\sum_{p\in P}\sum_{r\in R} Q_{prd} + \sum_{p\in P}\sum_{v\in V} Q_{pvd} \le B_{pd} \qquad \forall d \in D \qquad (19)$$

4.4.2 Transshipment Constraints

The transshipment constraint for all collection centers in Equation (21), shows that the quantity of returned product sent from the first customer to the collection center should be equal to the quantity of returned product sent from the collection center to the return evaluation center.

$$\sum_{p\in P}\sum_{f\in F} Q_{pfc} = \sum_{p\in P}\sum_{e\in E} Q_{pce} \qquad \forall c \in C \qquad (20)$$

The transshipment constraint for all return evaluation centers in Equation (22), shows that the quantity of returned product sent from the collection center to the return evaluation center should be equal to the quantity of evaluated product sent from the return evaluation center to the recycling center and refurbishing center.

$$\sum_{p\in P}\sum_{c\in C} Q_{pce} = \sum_{p\in P}\sum_{r\in R} Q_{per} + \sum_{p\in P}\sum_{v\in V} Q_{pev} \qquad \forall e \in E \qquad (21)$$

The transshipment constraint for all recycling centers in Equation (23), shows that the quantity of evaluated product sent from the return evaluation center to the recycling center should be equal to the quantity of recycled product sent from the recycling center to the distribution center.

$$\sum_{p\in P}\sum_{e\in E} Q_{per} = \sum_{p\in P}\sum_{d\in D} Q_{prd} \qquad \forall r \in R \qquad (22)$$

The transshipment constraint for all refurbishing centers in Equation (24), shows that the quantity of evaluated product sent from the return evaluation center to the refurbishing center should be equal to the quantity of refurbished product sent from the refurbishing center to the distribution center.

$$\sum_{p\in P}\sum_{e\in E} Q_{pev} = \sum_{p\in P}\sum_{d\in D} Q_{pvd} \qquad \forall v \in V \qquad (23)$$

The transshipment constraint for all distribution centers in Equation (25), shows that the quantity of reprocessed product sent from the recycling center and refurbishing center to the distribution center should be equal to the quantity of reprocessed product sent from the distribution center to the second customer.

$$\sum_{p\in P}\sum_{r\in R} Q_{prd} + \sum_{p\in P}\sum_{v\in V} Q_{pvd} = \sum_{p\in P}\sum_{s\in S} Q_{pds} \qquad \forall d \in D \qquad (24)$$

4.4.3 Demand Constraint

The demand constraint in Equation (26) shows that the quantity of reprocessed products sent from the recycling center and refurbishing center to the distribution center should be equal to the expected demand of second-hand reprocessed products generated from all the second customers.

$$\sum_{p\in P}\sum_{r\in R}\sum_{d\in D} Q_{prd} + \sum_{p\in P}\sum_{v\in V}\sum_{d\in D} Q_{pvd} = Ed_{ps} \qquad \forall s\in S \tag{25}$$

4.4.4 Carbon Cap Constraint

Equation (27) shows that the carbon cap constraint is the sum of the carbon emitted from transportation from collection center to reprocessing center and from reprocessing center to distribution center and the carbon emitted from the processing of used products at return evaluation, recycling and refurbishing center.

$$\left(\begin{array}{l}\left(\sum_{p\in P}\sum_{c\in C}\sum_{x\in X} C_{pcx}\sum_{p\in P}\sum_{c\in C}\sum_{e\in E} Q_{pce} + \sum_{p\in P}\sum_{x\in X}\sum_{d\in D} C_{pxd}\sum_{p\in P}\sum_{r\in R}\sum_{v\in V}\sum_{d\in D}(Q_{prd}+Q_{pvd})\right)+\\ \left(\begin{array}{l}\sum_{p\in P}\sum_{e\in E} K_{pe}(\sum_{p\in P}\sum_{e\in E}\sum_{r\in R} Q_{per} + \sum_{p\in P}\sum_{e\in E}\sum_{v\in V} Q_{pev}) + \sum_{p\in P}\sum_{r\in R} K_{pr}\sum_{p\in P}\sum_{r\in R}\sum_{d\in D} Q_{prd} + \\ \sum_{p\in P}\sum_{v\in V} K_{pv}\sum_{p\in P}\sum_{v\in V}\sum_{d\in D} Q_{pvd}\end{array}\right)\end{array}\right) \le M \tag{26}$$

Equation (28) shows that all the quantities taken as decision variables should be greater than or equal to zero and integer.

$$Q_{pfc}, Q_{pce}, Q_{per}, Q_{pev}, Q_{prd}, Q_{pvd}, Q_{pds} \ge 0 \textit{ and integer} \tag{27}$$

5 Solution methodology

The neutrosophic set approach has been applied to deal with the inconsistent, uncertain and imprecise parameters in the proposed multi-objective linear programming problem for a reverse logistics network. A neutrosophic set is an approach in which each object $x \in X$ to a Z set that consists of a truth membership function R, indeterminacy membership function I, falsity membership function A, considering R, I, A as real standard. Uncertain programming has extensively been applied to different design and management problems. But previously used methods to deal with uncertain information did not account for the indeterminate solutions. Indeterminacy provides latitude in the decision making process as the objective function and decision variable acquire optimized indeterminate solutions. When optimization is done through the neutrosophic approach then the objective functions are converted to neutrosophic fuzzy constraints. This refined and developed neutrosophic model efficiently addresses the uncertainty. The presented neutrosophic multi-objective linear programming model is capable of treating uncertain data that allows preventing impractical modeling. The flowchart for Neutrosophic optimization is shown in Fig. 3. A computational algorithm for the neutrosophic approach of optimization is shown in Table 2.

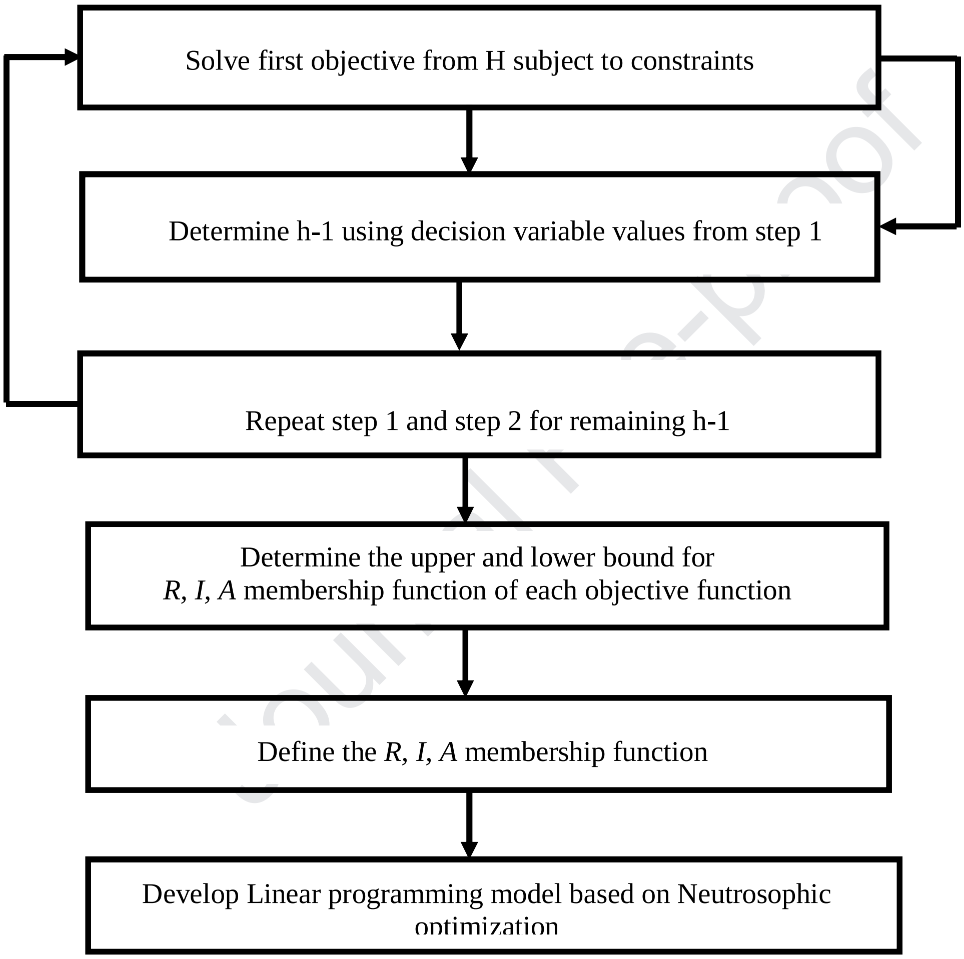


Fig. 3. Flowchart for Neutrosophic optimization

Table 2

Computational framework for neutrosophic approach

Step 1	Select the first objective function from objectives set H and solve it as a single objective function. For computation of objective functions and decision variables values will be subjected to constraints.
Step 2	Determine the values of the remaining objective functions $(h-1)$ based on the decision variable

	values from step 1.
Step 3	Repeat step 1 and step 2 to determine the values of the remaining objective functions. $\begin{bmatrix} f_1^*(x^1) & f_2(x^1) & f_3(x^1) & \dots\dots\dots & f_z(x^1) \\ f_1(x^2) & f_2^*(x^2) & f_3(x^2) & \dots\dots\dots & f_z(x^2) \\ f_1(x^3) & f_2(x^3) & f_3^*(x^3) & \dots\dots\dots & f_z(x^3) \\ \vdots & \vdots & \vdots & & \vdots \\ f_1^*(x^d) & f_2(x^d) & f_3(x^d) & \dots\dots\dots & f_z^*(x^d) \end{bmatrix}$
Step 4	Determine the upper and lower bound for truth R, falsity A and indeterminacy I membership of each objective function $u_z^R = \max\{f_z(x^b)\}, \quad l_z^R = \min\{f_z(x^b)\}, \quad where \quad d = 1,2,3,\dots,z$ $u_z^A = u_z^T, \quad l_z^A = l_z^R + t(u_z^R - l_z^R), \quad u_z^I = l_z^R + s(u_z^R - l_z^R), \quad l_z^I = l_z^R$
Step 5	Define the truth R, falsity A and indeterminacy I membership functions: $R_z(f_z(x)) = \left\{\begin{matrix} 1 & f_z(x) \le l_z^R \\ \dfrac{u_z^R - f_z(x)}{u_z^R - l_z^R} & l_z^R \le f_z(x) \le u_z^R \\ 0 & f_z(x) \ge u_z^R \end{matrix}\right\}$ $I_z(f_z(x)) = \left\{\begin{matrix} 1 & f_z(x) \le l_z^I \\ \dfrac{u_z^I - f_z(x)}{u_z^I - l_z^I} & l_z^I \le f_z(x) \le u_z^I \\ 0 & f_z(x) \ge u_z^I \end{matrix}\right\}$ $A_z(f_z(x)) = \left\{\begin{matrix} 1 & f_z(x) \le l_z^A \\ \dfrac{f_z(x) - l_z^A}{u_z^A - l_z^A} & l_z^A \le f_z(x) \le u_z^A \\ 0 & f_z(x) \ge u_z^A \end{matrix}\right\}$
Step 6	Now develop a linear programming model based on the neutrosophic optimization model $Max \quad \alpha - \beta + \gamma \qquad such\,that, \quad R_z(f_z(x)) \ge \alpha, \quad I_z(f_z(x)) \ge \gamma, \quad A_z(f_z(x)) \le \beta$ $with \;\; \alpha + \beta + \gamma \le 3 \;\; and \;\; \alpha \ge \beta, \quad \alpha \ge \gamma, \quad where \;\; \alpha, \beta, \gamma \in [0,1]$ $g_j(x) = b_j, \quad x \ge 0, \quad j = 1,2,3,\dots,q$ $Max \quad \alpha - \beta + \gamma \quad such\,that \;\; f_z(x) + (u_z^R - l_z^R).\alpha \le u_z^R, \; f_z(x) + (u_z^I - l_z^I).\gamma \le u_z^I,$ $and \quad f_z(x) - (u_z^A - l_z^A).\beta \le l_z^A, \quad for \quad z = 1,2,3,\dots,k$

	$with\ \alpha+\beta+\gamma\le 3\ \ and\ \ \alpha\ge\beta,\quad \alpha\ge\gamma,\quad where\ \ \alpha,\beta,\gamma\in[0,1]$ $g_j(x)=b_j,\quad x\ge 0,\quad j=1,2,3,...,q$

5.1 Numerical Example

For analyzing the proposed model with the help of the suggested methodology, a numerical example is considered in which some of the parameter values are taken from existing literature related to reverse logistics and electrical products. However, other parameters are assumed based on some standard values and the general understanding of them. The numerical example is based on reverse logistics of electrical products. To conduct the study at a comparatively medium scale, the model consisted of ten first customers in the form of either the original consumers or the retailers for returning products, four regional collection centers for collecting returned products, one return evaluation center for grading and categorizing the returned products, one recycling center, one refurbishing center, four distribution centers, and ten second customers in the form of either retailers or original consumers to fulfill demand. The reprocessing unit in this model consists of one return evaluation, one recycling center and one refurbishing center located at the same location to minimize total transportation cost. The quantity flowing from one center to another is taken in terms of units and one average unit of electrical products is equal to 0.07 tons. However, the average selling price for electrical products is considered as $258.40 for calculating the revenue term. The demand from ten first customers is assumed to be 30, 16, 16, 24, 14, 12, 11, 29, 24 and 22 units respectively, making a total demand of 198 units or 13.86 tons. Similarly, the capacities of the collection centers, return evaluation center, recycling center, refurbishing center and distribution centers are assumed to of 250, 300, 100, 100 and 300 units respectively.

The per-unit processing costs at the collection centers, recycling center, and refurbishing center are taken from the paper of Yu, H. and Solvang, W.D. (2016). The per-unit processing costs at the four collection centers, one recycling center, one refurbishing center, one return evaluation center and four distribution centers are shown in Table 1A of Appendix A. The transportation cost is incurred at two ends; first when returned products are sent from four collection centers to one reprocessing unit and second when reprocessed products are sent from one reprocessing unit to the four distribution centers. Both of these transportation costs are calculated by including parameters like fuel rate for a heavy-duty truck, the distance between the centers, capacity of a truck and per-unit labor cost being incurred. The values of all these parameters are also shown in Table 2A of Appendix A. The carbon emission indicators for recycling and refurbishing center are taken as 4 and 2 respectively (Yu, H. and Solvang, W.D., 2016) while the carbon emission indicator for a return evaluation center is assumed to be 2. The maximum allowable emissions are taken as 100,943 tons while the per-unit carbon trading market price is taken as

$22 (Bing et al., 2015). In the proposed model, jobs are being created at collection centers, return evaluation center, recycling center, refurbishing center, distribution centers, transportation between collection centers and reprocessing unit and between reprocessing unit and distribution centers. Jobs created at various centers and for transportation are calculated by including parameters like the average number of units processed by one worker at any center, number of operators required for each truck during transportation and capacity of a truck used during transportation. The average number of units processed by one worker at four collection centers, one return evaluation center, one recycling center with respect to four distribution centers, and one refurbishing center with respect to four distribution centers are also shown in Table 3A of Appendix A. The average number of units processed by one worker at four distribution centers with respect to ten second customers are taken as 12, 7, 10, 8, 12, 4, 6, 9, 8, 4, 5, 6, 2, 7, 14, 11, 9, 6, 5, 3, 5, 7, 5, 9, 4, 7, 9, 8, 5, 8, 5, 7, 5, 8, 4, 9, 5, 3, 7 and 9 units. The number of operators required for each truck during transportation between collection centers and the reprocessing unit, transportation between the reprocessing unit and the distribution centers, and capacity of a heavy-duty truck are also shown in Table 2A of Appendix A.

6 Results and Discussion

The designed multi-objective reverse logistic model for electrical products with social, economic and environmental considerations of the triple bottom line was solved using MATLAB Coding Tool and was then optimized using Neutrosophic optimization technique. When the model was solved, the optimal value for total profit earned from reprocessing and reselling of the returned electrical products to the second customers was $2063738.78. The environmental objective in the model results in the optimal value of total emissions was 989.90 tons, considering the carbon emitted during both reprocessing and transportation of the returned electrical products. The social objective in the model was based on the number of jobs created at various processing centers and during the transportation of returned electrical products and resulted in an optimal value of a total of 139 jobs.

In the model, the first customers in the form of either retailers or consumers are supposed to return the electrical products to the collection centers operating in various areas. Here, the first customers are denoted by “FC” while the collection centers are denoted by “CC”. The optimal quantities of the returned electrical product that are being sent from FC 1 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of returned electrical products that are being sent from FC 2 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 3 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 4 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 5 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 6 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 7 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 8 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 5 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 9 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 4 units respectively. The optimal quantities of the returned electrical product that are being sent from FC 1 to CC 1, CC 2, CC 3 and CC 4 are 5, 5, 5 and 4 units respectively. The optimal values for the quantity of returned electrical products that are being sent from ten first customers that can either be retailers or consumers, to four collection centers are shown in Table 3.

Table 3

Optimal quantities flowing from first customers to collection centers

	Collection Center 1	**Collection Center 2**	**Collection Center 3**	**Collection Center 4**
First Customer 1	5	5	5	5
First Customer 2	5	5	5	5
First Customer 3	5	5	5	5
First Customer 4	5	5	5	5
First Customer 5	5	5	5	5
First Customer 6	5	5	5	5
First Customer 7	5	5	5	5
First Customer 8	5	5	5	5
First Customer 9	5	5	5	4
First Customer 10	5	5	5	4

In the model, the returned electrical products collected at the collection centers are then sent to the return evaluation center for grading and categorization purposes. Here, the collection centers are denoted by “CC” and the return evaluation center is denoted by “EC”. The optimal quantity of returned electrical product that is being sent from CC 1 to EC 1 is 52 units. The optimal quantity of returned electrical product that is being sent from CC 2 to EC 1 is 46 units. The optimal quantity of returned electrical product that is being sent from CC 3 to EC 1 is 52 units. The optimal quantity of returned electrical product that is being sent from CC 4 to EC 1 is 48 units. The optimal values for the quantity of returned product that is being transported from four collection centers to one return evaluation center are shown in Table 4.

Table 4

Optimal quantities flowing from collection centers to return evaluation center

	Return Evaluation Center 1
Collection Center 1	52
Collection Center 2	46
Collection Center 3	52
Collection Center 4	48

In the model, some of the returned electrical products that were being evaluated at the return evaluation center are then sent to the recycling center for recycling purposes. Here, the return evaluation center is denoted by “EC” while the recycling center is denoted by “RC”. The optimal value for the quantity of evaluated product that is being sent from EC 1 to RC 1 for recycling purposes is 99 units. However, some of the evaluated products are also sent for refurbishing purposes to the refurbishing center in the reprocessing unit. Here, the return evaluation center is denoted by “EC” while the refurbishing center is denoted by “VC”. The optimal value for the quantity of evaluated product that is being transported from one return evaluation center to one refurbishing center is 99 units.

In the model, the returned electrical products that are being recycled at the recycling center are then sent to the distribution centers for distributing them to the second customers. Here, the recycling center is denoted by “RC” while the distribution centers are denoted by “DC”. The optimal quantities of recycled products that are being sent from RC 1 to DC 1, DC 2, DC 3 and DC 4 are 38, 26, 25 and 10 units respectively. In the model, the returned electrical products that are being refurbished at the refurbishing center are then sent to the distribution centers for distributing them to the second customers. Here, the refurbishing center is denoted by “VC” while the distribution centers are denoted by “DC”. The optimal quantities of refurbished products that are being sent from VC 1 to DC 1, DC 2, DC 3 and DC 4 are 41, 22, 13 and 23 units respectively.

In the end, the recycled and refurbished products sent to the distribution centers are sold to the second customers that can either be retailers or consumers of electrical products. Here, the distribution centers are denoted by “DC” while the second customers are denoted by “SC”. The optimal quantities of reprocessed product that are being purchased from DC 1 by SC 1, SC 2, SC 3, SC 4, SC 5, SC 6, SC 7, SC 8, SC 9 and SC 10 are 22, 5, 16, 6, 5, 0, 0, 13, 13 and 0 units respectively. The optimal quantities of reprocessed product that are being purchased from DC 2 by SC 1, SC 2, SC 3, SC 4, SC 5, SC 6, SC 7, SC 8, SC 9 and SC 10 are 5, 3, 0, 5, 9, 9, 7, 6, 2 and 0 units respectively. The optimal quantities of reprocessed product that are being purchased from DC 3 by SC 1, SC 2, SC 3, SC 4, SC 5, SC 6, SC 7, SC 8, SC 9 and SC 10 are 2, 4, 0, 8, 0, 0, 4, 10, 0 and 10 respectively. The optimal quantities of reprocessed product that are being purchased from DC 4 by SC 1, SC 2, SC 3, SC 4, SC 5, SC 6, SC 7, SC 8, SC 9 and SC 10 are 1, 4, 0, 5, 0, 3, 0, 0, 9 and 12 units respectively. The optimal values for the quantity of reprocessed product that is being purchased from four distribution centers by ten second customers are shown in Table 5.

Table 5

Optimal quantities flowing from distribution centers to second customers

	SC 1	**SC 2**	**SC 3**	**SC 4**	**SC 5**	**SC 6**	**SC 7**	**SC 8**	**SC 9**	**SC 10**
DC 1	22	5	16	6	5	0	0	13	13	0
DC 2	5	3	0	5	9	9	7	6	2	0
DC 3	2	4	0	8	0	0	4	10	0	10
DC 4	1	4	0	5	0	3	0	0	9	12

"DC" denotes distribution centers

"SC" denotes second customers

Based on the results of Table 5, it is important to highlight that SC 3 is only purchasing the reprocessed product from DC 1 and DC 2, which depicts that the other two distribution centers are located away from the vicinity of SC 3. So, SC 3 is fulfilling its demand from DC 1 and DC 2. Similarly, SC 5 is fulfilling its demand by purchasing the reprocessed product from only DC 1 and DC 2, SC 6 is fulfilling its demand by purchasing the reprocessed product from only DC 2 and DC 4, SC 7 is fulfilling its demand by purchasing the reprocessed product from only DC 2 and DC 3, SC 8 is fulfilling its demand by purchasing the reprocessed product from only DC 1, DC 2 and DC 3, SC 9 is fulfilling its demand by purchasing the reprocessed product from only DC 1, DC 2 and DC 4, and SC 10 is fulfilling its demand by purchasing the reprocessed product from only DC 3 and DC 4; based on the criteria of nearest possible market available for purchase

The total profit function consists of the revenue generated from selling the reprocessed products and from selling extra allowable emissions to the trading market and all the costs incurred at all the centers. The costs include processing costs at four collection centers, one return evaluation, one recycling center, one refurbishing center, and four distribution centers, and the transportation costs incurred between four collection centers and one reprocessing unit and between one reprocessing unit to four distribution centers. The total incurred cost is $83,813.02 and the total revenue earned from selling the reprocessed product and extra allowable emissions are $2,147,551.80. The total incurred cost of $83,813.02 consists of a major chunk of transportation cost incurred for transporting reprocessed products from one reprocessing unit to four distribution centers, which valued to $34,771.36 i.e. 41% of total cost value. This huge chunk of cost needs to be minimized by adopting measures like proper route and capacity planning and allocation. However, the processing at the four distribution centers has made the least contribution to the total incurred cost, which valued to $2,138.37 i.e. 3% of total cost value. A summarized detail about the costs incurred at various processing centers and during transportation is shown in Fig. 4.

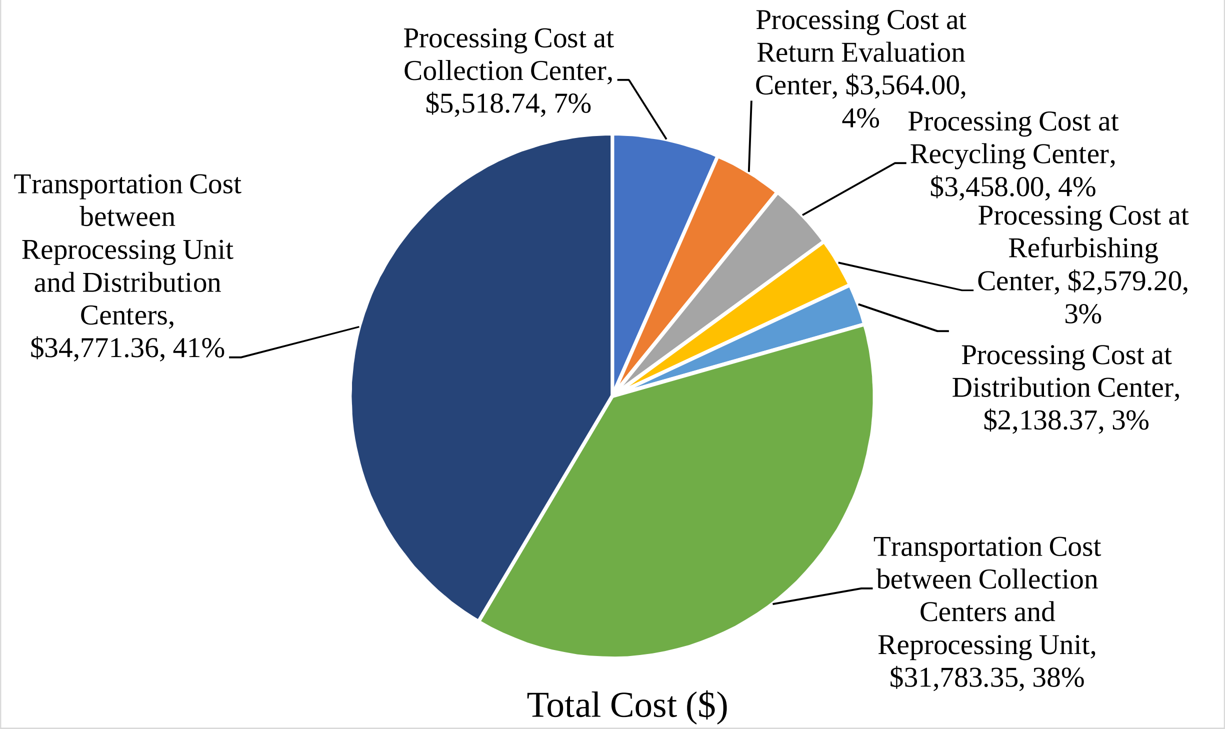


Fig. 4. Cost incurred at various processing centers and during transportation

The social objective in the model is focused on how social benefits are provided due to the creation of jobs at various processing centers and in the transportation sector. The processing centers where jobs are being created in the reverse logistics network for electrical products include the four collection centers, one return evaluation center, one recycling center, one refurbishing center, and the four distribution centers. In the transportation sector, jobs are being created at two different transportation nodes in the reverse logistics network. The first transportation jobs are created when the returned electrical products are sent from the collection center to the reprocessing unit. While the second transportation jobs are created after the reprocessed electrical products are sent to the distribution centers for selling them to the second customers. An in-depth analysis of the numerical example showed that the maximum number of 33 jobs each with an individual share of 24% are being created during the transportation of returned products; (1) from four collection centers to one reprocessing unit and (2) from one reprocessing unit to four distribution centers. While the least number of only 11 jobs (8%) are being created during the reprocessing of returned products at the refurbishing center, which can be maximized in the future if the demand from second customers is increased. A summarized detail about the jobs created at various processing centers and during transportation is shown in Fig. 5.

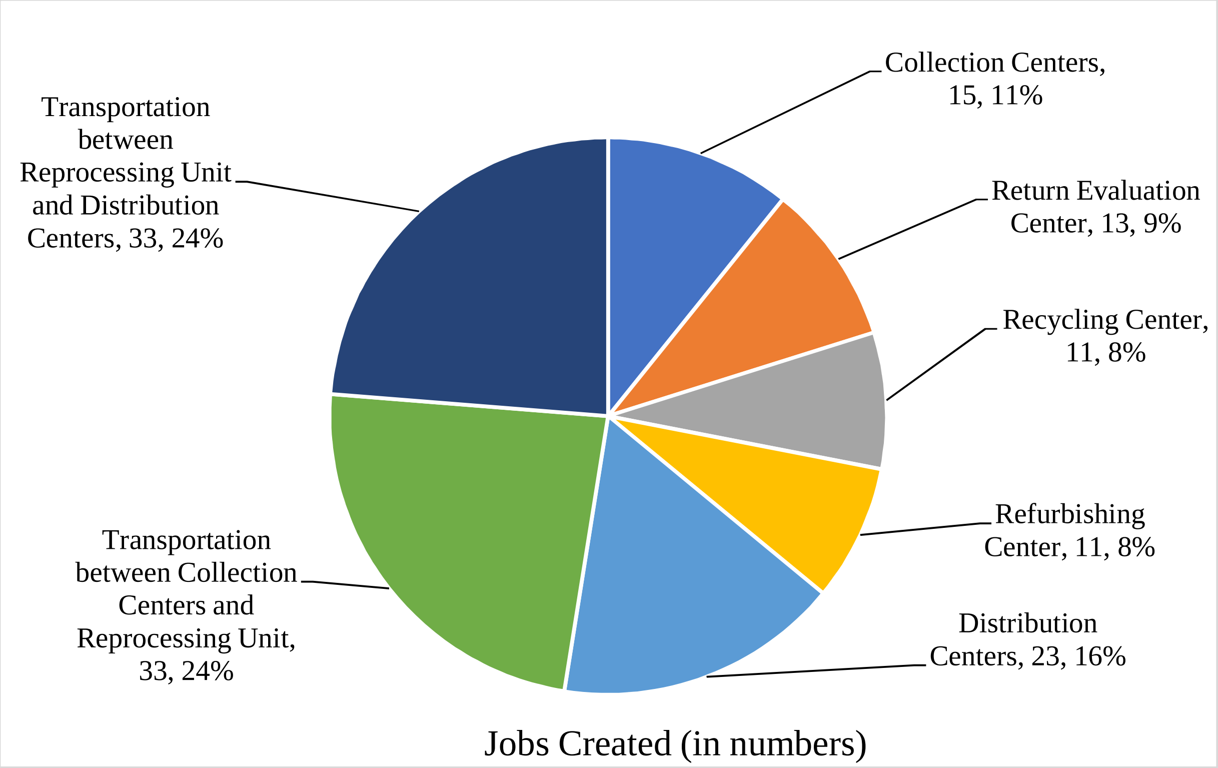


Fig. 5. Number of jobs created at various processing centers and during transportation

The environmental objective consists of carbon emitted during the reprocessing of the returned electrical product at the return evaluation, recycling and refurbishing centers. Also, when the transportation sector is considered in the designed reverse logistics network, transportation cost is incurred at two ends. The first transportation cost is incurred when the returned electrical products are sent from the collection center to the reprocessing unit. While the second transportation cost is incurred after the reprocessed electrical products are sent to the distribution centers for selling them to the second customers. The reverse logistics network considered in the numerical example has emitted a total of 989.90 tons of carbon. An in-depth analysis shows that processing at the return evaluation center emits 396.00 tons of carbon and processing at the recycling center emits 395.20 tons of carbon, which are the maximum amounts of carbon emitted in the considered numerical example. The reprocessing of the returned electrical products at the refurbishing center emits 198.40 tons of carbon. While transportation between collection centers and reprocessing unit and between reprocessing unit and distribution centers emit 0.15 tons of carbon each, which is the minimum amount of carbon emitted in the considered numerical example. This shows that the transportation sector has comparatively good control over the carbon emissions which can be due to the use of better vehicles, improved infrastructure, good quality roads, and optimized route allocation. However, the large amount of carbon emitted during the evaluation and reprocessing of the returned electrical products needs to be minimized in the future for both the economic and environmental growth of the reverse logistics network. A summarized detail about the carbon emitted at various processing centers and during transportation is shown in Fig. 6.

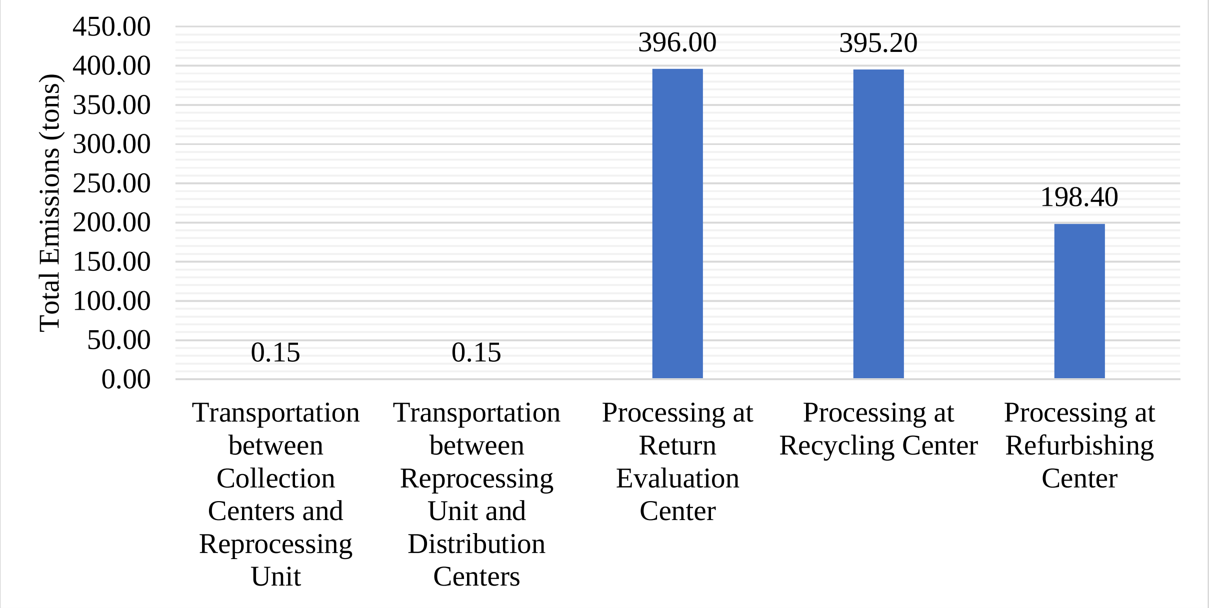


Fig. 6. Amount of carbon emitted in the reverse logistics of electrical products

6.1 Sensitivity Analysis

A sensitivity analysis is performed on some major parameters used in the proposed multi-objective model for reverse logistics network design. By changing the values of parameters by a certain percentage, then the effect of that change on profit maximization function, environmental impact minimization in the form of carbon emission reduction and on social impact maximization in the form of number jobs created. The percentage changes considered in the sensitivity analysis are +20%, -20%, +40%, and -40% while the parameters on which these changes are individually analyzed are unit processing cost at return evaluation center, unit processing cost at recycling center, unit processing cost at refurbishing center, per-unit carbon trading price, carbon emissions at the recycling center and the average number of units processed by one worker at a return evaluation center. Table 6 shows the sensitivity analysis of the key parameters.

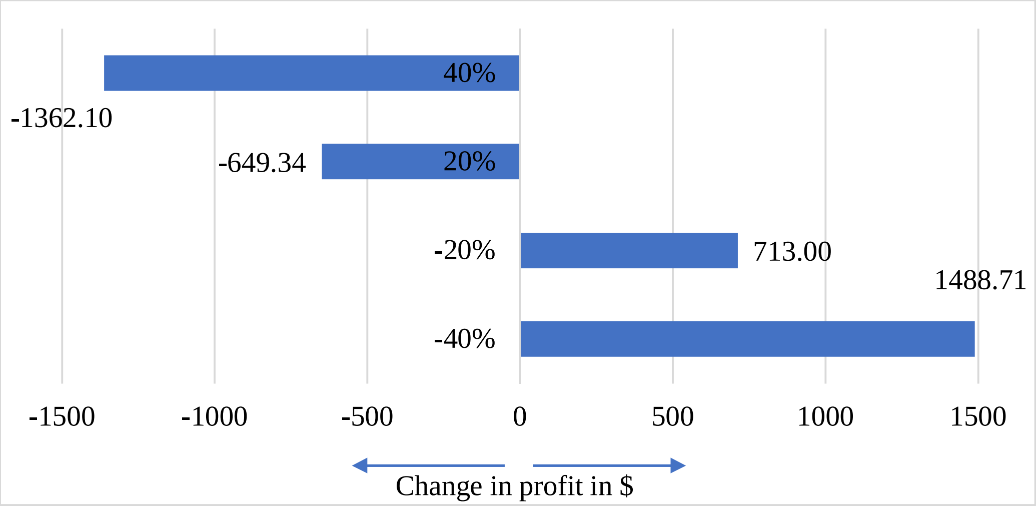
Table 6

Sensitivity analysis of key parameters.

Parameter	**Percentage Change**	**Percentage Change in Profit ($)**	**Percentage Change in Emissions (tons)**	**Percentage Change in Jobs (number)**
Unit processing cost at return evaluation center	20%	-0.031%	0.000%	0.000%
	-20%	0.035%	0.000%	0.000%
	40%	-0.066%	0.000%	0.000%
	-40%	0.072%	0.000%	0.000%
Unit processing cost at recycling center	20%	-0.030%	0.000%	0.000%
	-20%	0.008%	0.000%	0.000%
	40%	-0.093%	0.000%	0.000%
	-40%	0.070%	0.000%	0.000%
Unit processing cost at refurbishing center	20%	-0.022%	0.000%	0.000%
	-20%	0.028%	0.000%	0.000%
	40%	-0.047%	0.000%	0.000%
	-40%	0.053%	0.000%	0.000%
Per-unit carbon trading price	20%	21.283%	0.000%	0.000%
	-20%	-21.306%	0.000%	0.000%
	40%	42.620%	0.000%	0.000%
	-40%	-42.617%	0.000%	0.000%
Carbon emission at recycling center	20%	-0.084%	7.985%	0.000%
	-20%	0.087%	-7.985%	0.000%
	40%	-0.165%	15.969%	0.000%
	-40%	0.171%	-15.969%	0.000%
Average number of units processed by each worker at return	20%	0.000%	0.000%	-5.818%
	-20%	0.000%	0.000%	8.968%
	40%	0.000%	0.000%	-10.043%

evaluation center	-40%	0.000%	0.000%	23.755%

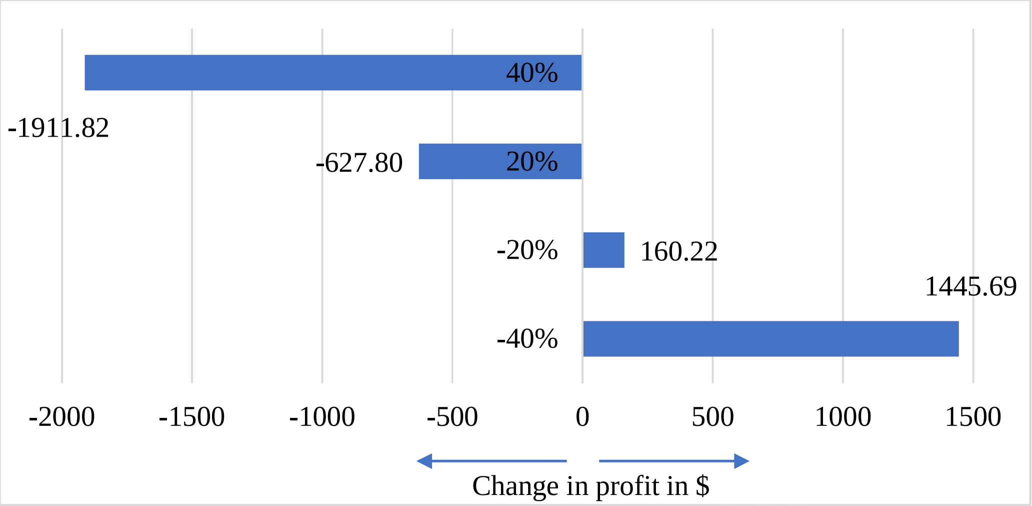
The positive change of 20% in the value of unit processing cost at return evaluation center parameter shows a decrease in profit value by 0.031%. The negative change of 20% in the value of unit processing cost at return evaluation center parameter shows an increase in profit value by 0.035%. The positive change of 40% in the value of unit processing cost at return evaluation center parameter shows a decrease in profit value by 0.066%. The negative change of 40% in the value of unit processing cost at return evaluation center parameter shows an increase in profit value by 0.031%. The graphical representation is shown in Fig. 7.



“→” shows a profit increasing trend and “←” shows a profit decreasing trend

Fig. 7. Profit change in $ due to a change in unit processing cost incurred at the return evaluation center

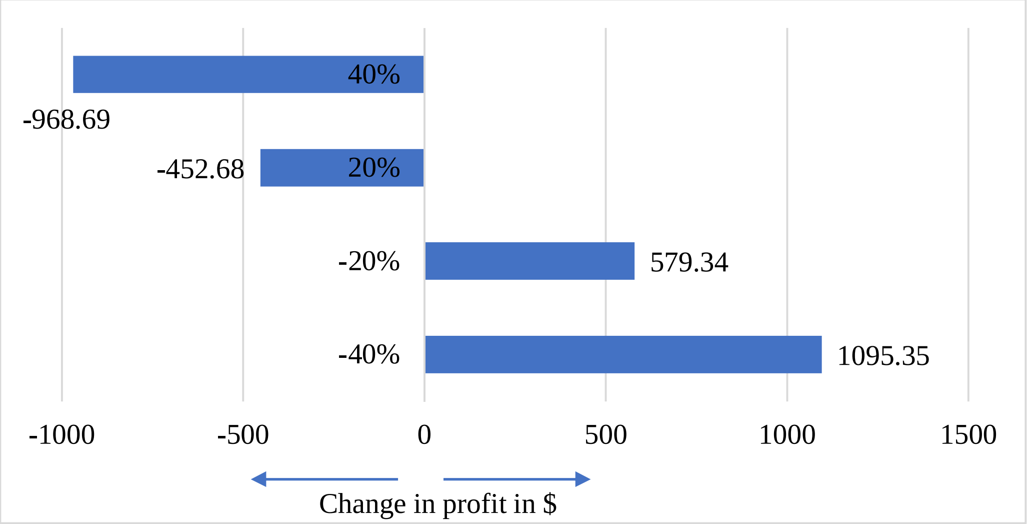
The positive change of 20% in the value of unit processing cost at the recycling center parameter shows a decrease in profit value by 0.030%. The negative change of 20% in the value of unit processing cost at the recycling center parameter shows an increase in profit value by 0.008%. The positive change of 40% in the value of unit processing cost at the recycling center parameter shows a decrease in profit value by 0.093%. The negative change of 40% in the value of unit processing cost at the recycling center parameter shows an increase in profit value by 0.070% as shown in Fig. 8.



"→" shows a profit increasing trend and "←" shows a profit decreasing trend

Fig. 8. Profit change in $ due to a change in unit processing cost incurred at the recycling center

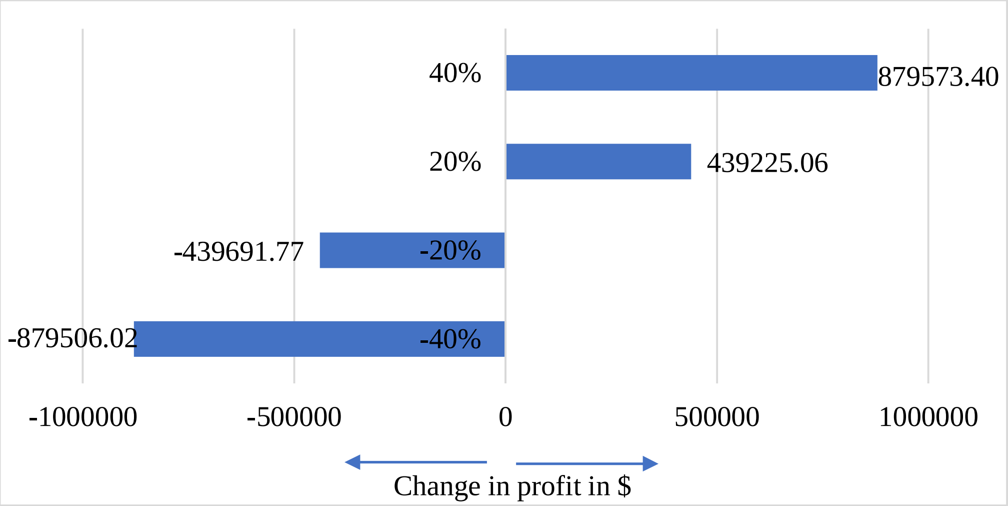
The positive change of 20% in the value of unit processing cost at the refurbishing center parameter shows a decrease in profit value by 0.022%. The negative change of 20% in the value of unit processing cost at the refurbishing center parameter shows an increase in profit value by 0.028%. The positive change of 40% in the value of unit processing cost at the refurbishing center parameter shows a decrease in profit value by 0.047%. The negative change of 40% in the value of unit processing cost at the refurbishing center parameter shows an increase in profit value by 0.053% as shown in Fig. 9.



"→" shows a profit increasing trend and "←" shows a profit decreasing trend

Fig. 9. Profit change in $ due to a change in unit processing cost incurred at the refurbishing center

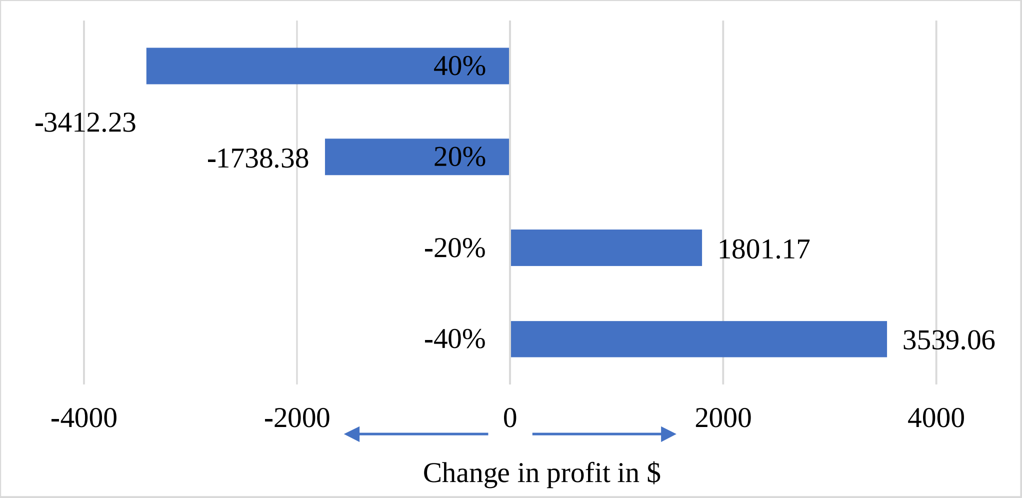
The positive change of 20% in the value of the per-unit carbon trading price parameter shows an increase in profit value by 21.283%. The negative change of 20% in the value of the per-unit carbon trading price parameter shows a decrease in profit value by 21.306% as shown in Fig 10. The positive change of 40% in the value of the per-unit carbon trading price parameter shows an increase in profit value by 42.620%. The negative change of 40% in the value of the per-unit carbon trading price parameter shows a decrease in profit value by 42.617%.



"→" shows a profit increasing trend and "←" shows a profit decreasing trend

Fig. 10. Profit change in $ due to a change in per-unit carbon trading price

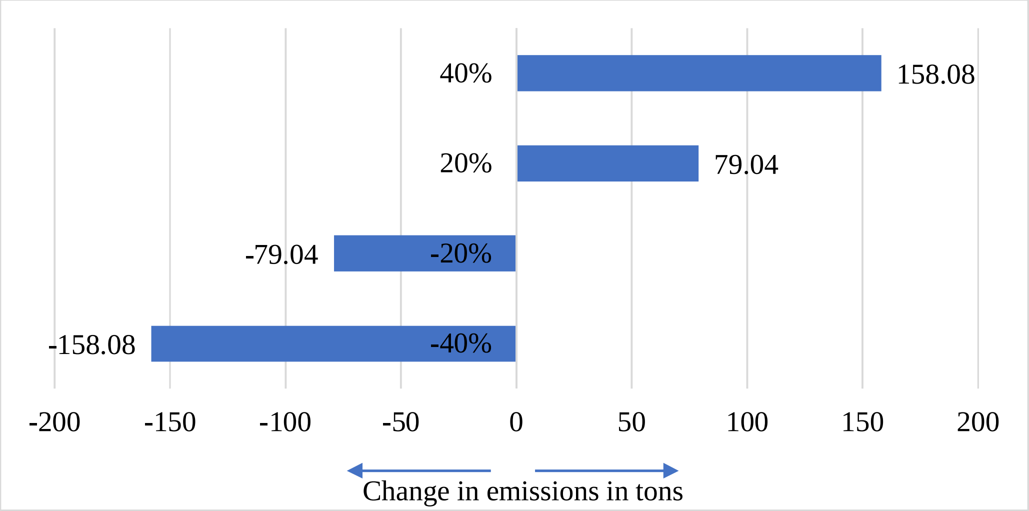
The positive change of 20% in the value of carbon emissions at the recycling center parameter shows a decrease in profit value by 0.084% as shown in Fig.11. The negative change of 20% in the value of carbon emissions at the recycling center parameter shows an increase in profit value by 0.087%. The positive change of 40% in the value of carbon emissions at the recycling center parameter shows a decrease in profit value by 0.165%. The negative change of 40% in the value of carbon emissions at the recycling center parameter shows an increase in profit value by 0.171%.



"→" shows a profit increasing trend and "←" shows a profit decreasing trend

Fig.11. Profit change in $ due to a change in the amount of carbon emitted at the recycling center

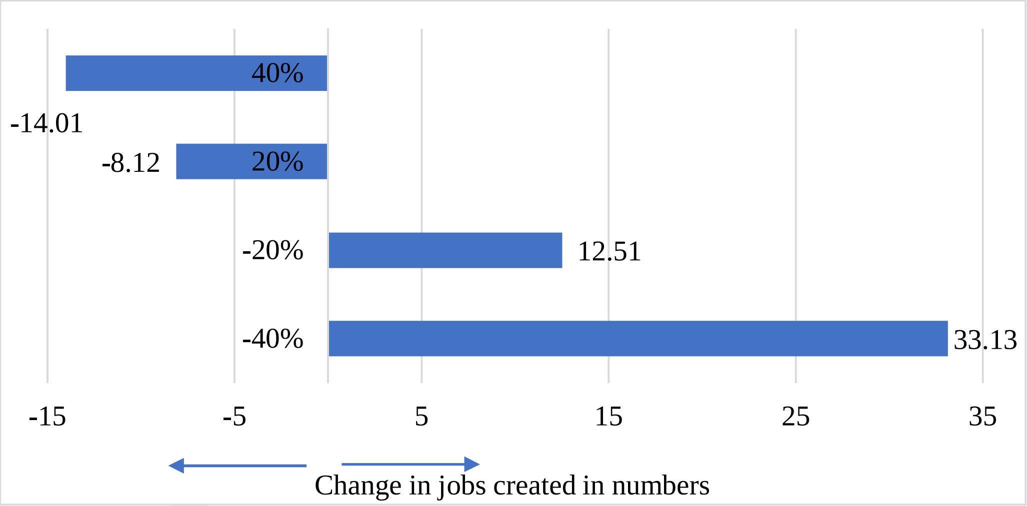
The positive change of 20% in the value of carbon emissions at the recycling center parameter shows an increase in total emissions value by 7.985%. The negative change of 20% in the value of carbon emissions at the recycling center parameter shows a decrease in total emissions value by 7.985%. The positive change of 40% in the value of carbon emissions at the recycling center parameter shows an increase in total emissions value by 15.969%. The negative change of 40% in the value of carbon emissions at the recycling center parameter shows a decrease in total emissions value by 15.969% as shown in Fig. 12.



"→" shows an emission increasing trend and "←" shows an emission decreasing trend

Fig. 12. Emissions change in tons due to a change in the amount of carbon emitted at the recycling center

The positive change of 20% in the value of the average number of units processed by one worker at the return evaluation center parameter shows a decrease in the number of jobs creation value by 5.818%. The negative change of 20% in the value of the average number of units processed by one worker at the return evaluation center parameter shows an increase in the number of jobs creation value by 8.968%. The positive change of 40% in the value of the average number of units processed by one worker at the return evaluation center parameter shows a decrease in the number of jobs creation value by 10.043%. The negative change of 40% in the value of the average number of units processed by one worker at the return evaluation center parameter shows an increase in the number of jobs creation value by 23.755%. The graphical representation is shown in Fig. 13.



"→" shows a job increasing trend and "←" shows a job decreasing trend

Fig. 13. Jobs change in numbers due to a change in the average number of units processed by each worker at the return evaluation center

6.2 Managerial insights

This research provides significant insights for practitioners to implement a triple bottom line approach in a reverse logistics network for e-waste management. The optimized model indicates that triple bottom line targets can be achieved by providing a sustainable trade-off between the economic, environmental and social objectives. The analysis of multiple parameters presents useful guidelines for the industrial managers pertaining to the reverse logistics system. The model outcomes suggest that economic and environmental benefits can be achieved by minimizing carbon emissions. This study provides outlines for policymakers to analyze multiple aspects of reverse logistics system considering carbon cap-and-trade policy. The model also creates job opportunities that will improve the social image of the organization. Therefore, the results of this model can help in providing critical insights for designing a sustainable reverse logistics network. The implementation of this study will be beneficial for the decision-makers dealing with the development of a reverse logistics system while maximizing economic and social impact as well as minimizing environmental impact.

7 Conclusion

This research develops a multi-objective mathematical model for optimizing of a reverse logistics network for electronic waste management based on the triple bottom line approach. The model consists of three objective functions including profit maximization, environmental effect minimization and social effect maximization. The economic objective is comprised of variable processing cost, transportation cost, and revenue from selling carbon emission credits and reprocessed products. The environmental objective represents the carbon emissions generated from the reprocessing of returned products at the return evaluation, recycling center and refurbishing center. Furthermore, the carbon emissions generated during transporting products between collection centers to reprocessing unit and between reprocessing unit to distribution centers were also included. In addition, a carbon constraint is also set to limit carbon emissions. The social objective consists of the jobs created at each facility including collection enter, return evaluation center, recycling center, refurbishing center, and distribution center. Moreover, job opportunities created at the transportation level were also incorporated. Additionally, a reprocessing center is also introduced into a reverse logistic system to accurately grade and categorize the returned products. The multi-objective linear programming problem was solved through the neutrosophic approach to acquire optimized results. The results represent a trade-off between the three conflicting objectives. The proposed model analysis provides insights to decision-makers for designing a reverse logistics network design under the availability of vague and imprecise information. The analysis determines the optimal flow of quantities between different nodes, resource allocation and identifies main contributors of carbon emission in a reverse logistics network. A related numerical example and sensitivity analysis were conducted to evaluate the validity of the proposed model.

The results shows that 41% of the total cost was incurred during transporting reprocessed products from the reprocessing unit to the distribution centers. This cost needs to be minimized by adopting measures like proper route and capacity planning and allocation. The environmental function in the model showed a total optimal value of 989.90 tons of carbon emitted in the reverse logistics network for returned electrical products. Out of which emits 396.00 tons of carbon is emitted during processing at a return evaluation center while 395.20 tons of carbon is emitted during processing at the recycling center, which needs to be minimized in the future. The social objective in the model shows that new jobs are also arecreated in the various processing centers and two transportation nodes. The sensitivity analysis shows that comparatively larger changes are shown in the parameters like per-unit carbon trading price with the change in profit value, carbon emission at recycling centers with the change in total emissions value and the average number of units processed by one worker at return evaluation center with the change in the number of job creation value.

The research has various impacts on business finances as well as environmental and social responsibility. The carbon cap-and-trade policy is a significant decision that should be taken into consideration based on specified decision variables. The results reveal that integrating carbon cap-and-trade policy with economic aspect will improve the profitability along with environmental performance. The managers should consider the carbon emissions minimization to trade extra carbon credits in the market to reduce the overall cost of a reverse logistics system. The industry managers should take reverse logistics decisions based on the storage cost, handling cost, labor cost, and carbon emissions. The adjustment in these factors should result in a win-win situation economically and environmentally. The savings generated from selling extra carbon emission credits in the market can be utilized to increase the reverse logistics performance by capitalizing it in environmental friendly technology to improve social performance. Thus, the results of this study will facilitate the decision-makers by providing guidelines for a reverse logistics system considering the triple bottom line approach.

This research can be extended in the future to overcome the current limitations of the study and to add more value to the research by using real time data. Also researchers can extend the model by incorporating the multi-period and multi-product as a future extension. The comparison of results obtained by using the neutrosophic approach, with any other optimization methodology can also be a valuable work for future.

References

Abdel-Basset, M., Gunasekaran, M., Mohamed, M., Smarandache, F., 2019. A novel method for solving the fully neutrosophic linear programming problems. Neural Computing and Applications 31(5), 1595-1605 DOI: https://doi.org/10.1007/s00521-018-3404-6.

Ahmed, W., Sarkar, B., 2018. Impact of carbon emissions in a sustainable supply chain management for a second generation biofuel. Journal of Cleaner Production 186, 807-820 DOI: https://doi.org/10.1016/j.jclepro.2018.02.289.

Ahmed, W., Sarkar, B., 2019. Management of next-generation energy using a triple bottom line approach under a supply chain framework. Resources, Conservation and Recycling 150, 104431 DOI: https://doi.org/10.1016/j.resconrec.2019.104431.

Alshamsi, A., Diabat, A., 2017. A Genetic Algorithm for Reverse Logistics network design: A case study from the GCC. Journal of Cleaner Production 151, 652-669 DOI: https://doi.org/10.1016/j.jclepro.2017.02.096.

Arampantzi, C., Minis, I., 2017. A new model for designing sustainable supply chain networks and its application to a global manufacturer. Journal of Cleaner Production 156, 276-292 DOI: https://doi.org/10.1016/j.jclepro.2017.03.164.

Atanassov, K., 1986. Intuitionistic fuzzy sets. Fuzzy Sets and Systems 20(1), 87-96 DOI: https://doi.org/10.1016/S0165-0114(86)80034-3.

Ayvaz, B., Bolat, B., Aydın, N., 2015. Stochastic reverse logistics network design for waste of electrical and electronic equipment. Resources, conservation and recycling 104, 391-404 DOI: https://doi.org/10.1016/j.resconrec.2015.07.006.

Bal, A., Satoglu, S.I., 2018. A goal programming model for sustainable reverse logistics operations planning and an application. Journal of cleaner production 201, 1081-1091 DOI: https://doi.org/10.1016/j.jclepro.2018.08.104.

Baldé, C.P., Forti, V., Gray, V., Kuehr, R., Stegmann, P., 2017. The global e-waste monitor 2017: Quantities, flows and resources. United Nations University, International Telecommunication Union, and ….

Bing, X., Bloemhof-Ruwaard, J., Chaabane, A., van der Vorst, J., 2015. Global reverse supply chain redesign for household plastic waste under the emission trading scheme. Journal of cleaner production 103, 28-39 DOI: https://doi.org/10.1016/j.jclepro.2015.02.019.

Bing, X., Bloemhof-Ruwaard, J.M., van der Vorst, J.G., 2014. Sustainable reverse logistics network design for household plastic waste. Flexible Services and Manufacturing Journal 26(1-2), 119-142 DOI: https://doi.org/10.1007/s10696-012-9149-0.

Darbari, J.D., Agarwal, V., Yadavalli, V.S., Galar, D., Jha, P.C., 2017. A multi-objective fuzzy mathematical approach for sustainable reverse supply chain configuration. Journal of Transport and Supply Chain Management 11(1), 1-12 DOI: https://dx.doi.org/10.4102/jtscm.v11i0.267.

Das, P., Roy, T.K., 2015. Multi-objective non-linear programming problem based on neutrosophic optimization technique and its application in riser design problem. Neutrosophic Sets and Systems 9, 88-95.

Dat, L.Q., Linh, D.T.T., Chou, S.-Y., Vincent, F.Y., 2012. Optimizing reverse logistic costs for recycling end-of-life electrical and electronic products. Expert Systems with Applications 39(7), 6380-6387 DOI: https://doi.org/10.1016/j.eswa.2011.12.031.

Deli, I., 2017. Interval-valued neutrosophic soft sets and its decision making. International Journal of Machine Learning and Cybernetics 8(2), 665-676 DOI: https://doi.org/10.1007/s13042-015-0461-3.

Deli, I., Şubaş, Y., 2017. A ranking method of single valued neutrosophic numbers and its applications to multi-attribute decision making problems. International Journal of Machine Learning and Cybernetics 8(4), 1309-1322 DOI: https://doi.org/10.1007/s13042-016-0505-3.

Devika, K., Jafarian, A., Nourbakhsh, V., 2014. Designing a sustainable closed-loop supply chain network based on triple bottom line approach: A comparison of metaheuristics hybridization techniques. European Journal of Operational Research 235(3), 594-615 DOI: https://doi.org/10.1016/j.ejor.2013.12.032.

Drake, D.F., Kleindorfer, P.R., Van Wassenhove, L.N., 2016. Technology choice and capacity portfolios under emissions regulation. Production and Operations Management 25(6), 1006-1025 DOI: https://doi.org/10.1111/poms.12523.

Elkington, J., 1997. Cannibals with forks: the triple bottom line of twenty-first century business. Capstone. Oxford, p. 73. DOI: https://doi.org/10.1023/A:1006129603978.

Galvez, D., Rakotondranaivo, A., Morel, L., Camargo, M., Fick, M., 2015. Reverse logistics network design for a biogas plant: An approach based on MILP optimization and Analytical Hierarchical Process (AHP). Journal of Manufacturing Systems 37, 616-623 DOI: https://doi.org/10.1016/j.jmsy.2014.12.005.

Gao, X., 2019. A Novel Reverse Logistics Network Design Considering Multi-Level Investments for Facility Reconstruction with Environmental Considerations. Sustainability 11(9), 2710 DOI: https://doi.org/10.3390/su11092710.

Garg, D., Luthra, S., Haleem, A., 2016. An evaluation of barriers to implement reverse logistics: A case study of Indian fastener industry. International Journal of Industrial and Manufacturing Engineering 10(8), 1498-1503 DOI: https://doi.org/10.5281/zenodo.1126057.

Govindan, K., Paam, P., Abtahi, A.-R., 2016. A fuzzy multi-objective optimization model for sustainable reverse logistics network design. Ecological indicators 67, 753-768 DOI: https://doi.org/10.1016/j.ecolind.2016.03.017.

Isernia, R., Passaro, R., Quinto, I., Thomas, A., 2019. The Reverse Supply Chain of the E-Waste Management Processes in a Circular Economy Framework: Evidence from Italy. Sustainability 11(8), 2430 DOI: https://doi.org/10.3390/su11082430.

John, S.T., Sridharan, R., Kumar, P.R., 2017. Multi-period reverse logistics network design with emission cost. The International Journal of Logistics Management 28(1), 127-149 DOI: https://doi.org/10.1108/IJLM-08-2015-0143.

Khademikia, S., Haghizadeh, A., Godini, H., Khorramabadi, G.S., 2016. Artificial Neural Network-Cuckoo Optimization Algorithm (ANN-COA) for Optimal Control of Khorramabad Wastewater Treatment Plant, Iran. Civil Engineering Journal 2(11), 555-567 DOI: https://doi.org/10.28991/cej-2016-00000058.

Khor, K.S., Udin, Z.M., Ramayah, T., Hazen, B.T., 2016. Reverse logistics in Malaysia: The contingent role of institutional pressure. International Journal of Production Economics 175, 96-108 DOI: https://doi.org/10.1016/j.ijpe.2016.01.020.

Kilic, H.S., Cebeci, U., Ayhan, M.B., 2015. Reverse logistics system design for the waste of electrical and electronic equipment (WEEE) in Turkey. Resources, Conservation and Recycling 95, 120-132 DOI: http://doi.org/10.1016/j.resconrec.2014.12.010.

Kühn, S., 2019. Global employment and social trends. World Employment and Social Outlook 2019(1), 5-24 DOI: https://doi.org/10.1002/wow3.150.

Kumar, A., Holuszko, M., Espinosa, D.C.R., 2017. E-waste: an overview on generation, collection, legislation and recycling practices. Resources, Conservation and Recycling 122, 32-42 DOI: https://doi.org/10.1016/j.resconrec.2017.01.018.

Kyere, V.N., Greve, K., Atiemo, S.M., Amoako, D., Aboh, I.K., Cheabu, B.S., 2018. Contamination and health risk assessment of exposure to heavy metals in soils from informal e-waste recycling site in Ghana. Emerging Science Journal 2(6), 428-436 DOI: http://doi.org/10.28991/esj-2018-01162.

Laner, D., Rechberger, H., 2007. Treatment of cooling appliances: Interrelations between environmental protection, resource conservation, and recovery rates. Resources, Conservation and Recycling 52(1), 136-155 DOI: https://doi.org/10.1016/j.resconrec.2007.03.004.

Lee, J.-E., Chung, K.-Y., Lee, K.-D., Gen, M., 2015. A multi-objective hybrid genetic algorithm to minimize the total cost and delivery tardiness in a reverse logistics. Multimedia Tools and Applications 74(20), 9067-9085 DOI: https://doi.org/10.1007/s11042-013-1594-6.

Morgan, T.R., Tokman, M., Richey, R.G., Defee, C., 2018. Resource commitment and sustainability: a reverse logistics performance process model. International Journal of Physical Distribution & Logistics Management 48(2), 164-182 DOI: https://doi.org/10.1108/IJPDLM-02-2017-0068.

Mota, B., Gomes, M.I., Carvalho, A., Barbosa-Povoa, A.P., 2015. Towards supply chain sustainability: economic, environmental and social design and planning. Journal of Cleaner Production 105, 14-27 DOI: https://doi.org/10.1016/j.jclepro.2014.07.052.

Nanaki, E.A., Koroneos, C.J., 2016. Climate change mitigation and deployment of electric vehicles in urban areas. Renewable energy 99, 1153-1160 DOI: https://doi.org/10.1016/j.renene.2016.08.006.

O'Reilly, S., Kumar, A., 2016. Closing the loop: An exploratory study of reverse ready-made garment supply chains in Delhi NCR. The International Journal of Logistics Management 27(2), 486-510 DOI: https://doi.org/10.1108/IJLM-03-2015-0050.

Pandian, G.R.S., Abdul-Kader, W., 2017. Performance evaluation of reverse logistics enterprise–an agent-based simulation approach. International Journal of Sustainable Engineering 10(6), 384-398 DOI: https://doi.org/10.1080/19397038.2017.1370032.

Pedram, A., Pedram, P., Yusoff, N.B., Sorooshian, S., 2017. Development of closed–loop supply chain network in terms of corporate social responsibility. PloS one 12(4), e0174951 DOI: https://doi.org/10.1371/journal.pone.0174951.

Pourjavad, E., Mayorga, R.V., 2019. An optimization model for network design of a closed-loop supply chain: a study for a glass manufacturing industry. International Journal of Management Science and Engineering Management 14(3), 169-179 DOI: https://doi.org/10.1080/17509653.2018.1512387.

Prakash, C., Barua, M.K., Pandya, K.V., 2015. Barriers analysis for reverse logistics implementation in Indian electronics industry using fuzzy analytic hierarchy process. Procedia-Social and Behavioral Sciences 189, 91-102 DOI: https://doi.org/10.1016/j.sbspro.2015.03.203.

Rahimi, M., Ghezavati, V., 2018. Sustainable multi-period reverse logistics network design and planning under uncertainty utilizing conditional value at risk (CVaR) for recycling construction and demolition waste. Journal of cleaner production 172, 1567-1581 DOI: https://doi.org/10.1016/j.jclepro.2017.10.240.

Ramos, T.R.P., Gomes, M.I., Barbosa-Póvoa, A.P., 2014. Planning a sustainable reverse logistics system: Balancing costs with environmental and social concerns. Omega 48, 60-74 DOI: https://doi.org/10.1016/j.omega.2013.11.006.

Resmi, N., Fasila, K., 2017. E-waste Management and Refurbishment Prediction (EMARP) Model for Refurbishment Industries. Journal of environmental management 201, 303-308 DOI: https://doi.org/10.1016/j.jenvman.2017.06.065.

Sarkar, B., Ahmed, W., Choi, S.-B., Tayyab, M., 2018a. Sustainable inventory management for environmental impact through partial backordering and multi-trade-credit-period. Sustainability 10(12), 4761 DOI: https://doi.org/10.3390/su10124761.

Sarkar, B., Ahmed, W., Kim, N., 2018b. Joint effects of variable carbon emission cost and multi-delay-in-payments under single-setup-multiple-delivery policy in a global sustainable supply chain. Journal of Cleaner Production 185, 421-445 DOI: https://doi.org/10.1016/j.jclepro.2018.02.215.

Sarkis, J., Helms, M.M., Hervani, A.A., 2010. Reverse logistics and social sustainability. Corporate Social Responsibility and Environmental Management 17(6), 337-354 DOI: https://doi.org/10.1002/csr.220.

Smarandache, F., 1999. A unifying field in logics. neutrosophy: Neutrosophic probability, set and logic. American Research Press, Rehoboth. DOI: http://doi.org/10.6084/M9.FIGSHARE.1014204.

Soleimani, H., Govindan, K., Saghafi, H., Jafari, H., 2017. Fuzzy multi-objective sustainable and green closed-loop supply chain network design. Computers & Industrial Engineering 109, 191-203 DOI: https://doi.org/10.1016/j.cie.2017.04.038.

Song, S., Govindan, K., Xu, L., Du, P., Qiao, X., 2017. Capacity and production planning with carbon emission constraints. Transportation Research Part E: Logistics and Transportation Review 97, 132-150 DOI: https://doi.org/10.1016/j.tre.2016.10.007.

Tiwari, S., Ahmed, W., Sarkar, B., 2018. Multi-item sustainable green production system under trade-credit and partial backordering. Journal of cleaner production 204, 82-95 DOI: https://doi.org/10.1016/j.jclepro.2018.08.181.

Tiwari, S., Ahmed, W., Sarkar, B., 2019. Sustainable ordering policies for non-instantaneous deteriorating items under carbon emission and multi-trade-credit-policies. Journal of Cleaner Production 240, 118183 DOI: https://doi.org/10.1016/j.jclepro.2019.118183.

Trochu, J., Chaabane, A., Ouhimmou, M., 2020. A carbon-constrained stochastic model for eco-efficient reverse logistics network design under environmental regulations in the CRD industry. Journal of Cleaner Production 245, 118818 DOI: https://doi.org/10.1016/j.jclepro.2019.118818.

Turksen, I.B., 1986. Interval valued fuzzy sets based on normal forms. Fuzzy sets and systems 20(2), 191-210 DOI: https://doi.org/10.1016/0165-0114%2886%2990077-1.

Uko, L.U., Lutz, R.J., Weisel, J.A., 2017. An Application of Linear Programming in Performance Evaluation. Academy of Educational Leadership Journal.

Wang, L., Radovilsky, Z., 2017. Reverse Logistics Network Design–Location of Retail Refurbishing Centers. Journal of Supply Chain and Operations Management 15(1), 1.

Wang, Y., Chen, W., Liu, B., 2017. Manufacturing/remanufacturing decisions for a capital-constrained manufacturer considering carbon emission cap and trade. Journal of Cleaner Production 140, 1118-1128 DOI: https://doi.org/10.1016/j.jclepro.2016.10.058.

WMO, W.M.O., 2019. Global Climate in 2015-2019: Climate change accelerates. https://public.wmo.int/en/media/press-release/global-climate-2015-2019-climate-change-accelerates.

Xiao, Z., Sun, J., Shu, W., Wang, T., 2019. Location-allocation problem of reverse logistics for end-of-life vehicles based on the measurement of carbon emissions. Computers & Industrial Engineering 127, 169-181 DOI: https://doi.org/10.1016/j.cie.2018.12.012.

Yu, H., Solvang, W., 2016. A stochastic programming approach with improved multi-criteria scenario-based solution method for sustainable reverse logistics design of waste electrical and electronic equipment (WEEE). Sustainability 8(12), 1331 DOI: http://doi.org/10.3390/su8121331.

Yu, H., Solvang, W.D., 2016. A general reverse logistics network design model for product reuse and recycling with environmental considerations. The International Journal of Advanced Manufacturing Technology 87(9-12), 2693-2711 DOI: https://doi.org/10.1007/s00170-016-8612-6.

Yu, H., Solvang, W.D., 2017. A carbon-constrained stochastic optimization model with augmented multi-criteria scenario-based risk-averse solution for reverse logistics network design under uncertainty. Journal of cleaner production 164, 1248-1267 DOI: https://doi.org/10.1016/j.jclepro.2017.07.066.

Zadeh, L.A., 1965. Fuzzy sets. Information and control 8(3), 338-353 DOI: https://doi.org/10.1016/S0019-9958(65)90241-X.

Zarbakhshnia, N., Soleimani, H., Goh, M., Razavi, S.S., 2019. A novel multi-objective model for green forward and reverse logistics network design. Journal of cleaner production 208, 1304-1316 DOI: https://doi.org/10.1016/j.jclepro.2018.10.138.

Zhang, Y., Alshraideh, H., Diabat, A., 2018. A stochastic reverse logistics production routing model with environmental considerations. Annals of Operations Research 271(2), 1023-1044 DOI: https://doi.org/10.1007/s10479-018-3045-2.

Appendix A:

Table 1A

Data for processing of returned electrical product collection, return evaluation, recycling, refurbishing and distribution centers

Parameter	Value
Collection cost at collection center 1	26.00 $/unit
Collection cost at collection center 2	31.00 $/unit
Collection cost at collection center 3	25.00 $/unit
Collection cost at collection center 4	30.00 $/unit
Return evaluation cost at return evaluation center 1	18.00 $/unit
Recycling cost at recycling center 1	35.00 $/unit
Refurbishing cost at refurbishing center 1	26.00 $/unit
Distribution cost at distribution center 1	10.00 $/unit
Distribution cost at distribution center 2	12.00 $/unit
Distribution cost at distribution center 3	9.00 $/unit
Distribution cost at distribution center 4	13.00 $/unit

Table 2A

Data for transportation of returned electrical products

Parameter	Value
Fuel rate for a heavy-duty diesel truck	0.82 $/liter
Distance between collection center 1 and reprocessing unit	632 km
Distance between collection center 2 and reprocessing unit	418 km
Distance between collection center 3 and reprocessing unit	469 km
Distance between collection center 4 and reprocessing unit	345.5 km
Distance between reprocessing unit and distribution center 1	645 km
Distance between reprocessing unit and distribution center 2	455 km
Distance between reprocessing unit and distribution center 3	488 km

Distance between reprocessing unit and distribution center 4	322 km
Capacity of heavy-duty truck	12 units or 0.84 tons
Labor cost for transportation	0.025 $/km
Number of operators required for each truck during transportation	2 operators/truck

Table 3A

Data for average processing capacity of a worker at each center

Average number of units processed by one worker at the collection center 1	6 units/day
Average number of units processed by one worker at the collection center 2	8 units/day
Average number of units processed by one worker at the collection center 3	10 units/day
Average number of units processed by one worker at the collection center 4	12 units/day
Average number of units processed by one worker at the return evaluation center 1	4 units/day
Average number of units processed by one worker at the recycling center 1 w.r.t distribution center 1	8 units/day
Average number of units processed by one worker at the recycling center 1 w.r.t distribution center 2	9 units/day
Average number of units processed by one worker at the recycling center 1 w.r.t distribution center 3	7 units/day
Average number of units processed by one worker at the recycling center 1 w.r.t distribution center 4	6 units/day
Average number of units processed by one worker at the refurbishing center 1 w.r.t distribution center 1	10 units/day
Average number of units processed by one worker at the refurbishing center 1 w.r.t distribution center 2	8 units/day
Average number of units processed by one worker at the refurbishing center 1 w.r.t distribution center 3	5 units/day
Average number of units processed by one worker at the refurbishing center 1 w.r.t distribution center 4	12 units/day

Highlights

- Sustainable reverse logistics management for electronic waste is considered.
- Social, economic and environmental aspects are integrated simultaneously.
- Creation of new job opportunities in processing units and transportation sector.
- Application of carbon cap-and-trade policy to minimize emissions.
- Neutrosophic optimization approach is applied to improve the network.

Declaration of interest statement

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

☒The authors declare that no financial interests/personal relationships which may be considered as potential competing interests.

Credit Author Statement

Nimra Safdar, Rabia Khalid, Waqas Ahmed: Conceptualization, Methodology, Software **Nimra Safdar, Rabia Khalid.**: Data curation, Writing- Original draft preparation. **Waqas Ahmed**: Visualization, Investigation. ***Waqas Ahmed****:* Supervision.**: Muhammad Imran**: Software,: **Waqas Ahmed, Muhammad Imran:** Writing- Reviewing and Editing,