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Evaluating the Electronic Waste Management System by Using Technique for Order Performance by Similarity to Ideal Solution

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ABSTRACT

The waste created after the useful life of electronic or electrical products is labeled as electronic waste. Introduction of better and upgraded options into market increase the rate of disposal of obsolete discarded products from the consumer side. Electronic waste contains many toxic ingredients and major toxicants are heavy metal ions that may find the way to environment matrix after improper disposal of products. In recent years due to rapid technological development and industrialization; electronic waste management has become a major challenge throughout the world and receiving an attention from researchers, governments, and public. Poor management of waste may adversely affect the environment and human health. Thus, it is necessary to segregate all e-waste materials at the point of generation, for appropriate treatment/disposal. The assessment of the most suitable and appropriate framework has been a subject of extreme research interest as it involves many conflicting factors such as cost, type of waste, energy consumption, environmental impact of waste residue, rate of waste generation, treatment efficiency, and practical feasibility, consumer awareness, occupational hazards etc. There are numerous constraints and knowledge gaps to plan a feasible strategy in realistic scenario. The exact amount of disposed of e-waste is very difficult to predict because of many reasons including the unavailability of collection units for e-waste as well lack of awareness to consumer regarding its proper way of disposal. Various approaches that have been proposed needs to be analyzed with respect to every individual factor. To address this problem, we have proposed multi-criteria decision-making(MCDM) based Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to develop framework that determine the interdependency among different factors and obtained the priority value of each e-waste treatment method for appropriate selection and successful implementation in real scenario. From the results of the given information gathered from 3 sources, it is observed that re-use method is the preferred over recycle and landfill methods. The findings of this study will support the organizations and stakeholders to take suitable steps for the disposal of electronic waste strategies.

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1. Introduction

The waste created after the functional life of electronic or electrical products is tagged as electronic waste. Electronic waste from obsolete or discarded products contains many substances such as heavy metals, plastic, glass, flame retardant materials, polycyclic aromatic hydrocarbon etc. Improper disposal of electronic waste leads to many environmental and health issues ([1], [2]). It has been observed in a study that heavy metals as well as organic contaminants reaching the Electronic wastes have also potential to induce lethal effects on the behavior, physiology, and growth of aquatic species. There is a severe concern for the contamination at the disposal sites located near to water bodies as it enhances the probability of transport of hazardous substances to water. As per recent united nation report, the world produces 50 million tonnes of electronic waste annually, but only 10 million ton is formally recycled. Rest of the waste enters the landfill, or recycled off the record in developing countries. India's contribution is approx. Various studies specified the importance of the appropriate electronic waste treatment methods but the selection of appropriate method in real scenario is considered to be a complex decision problem, which can be efficiently handled by the methods of multi criteria decision making. There are many challenges for researchers due to the vagueness of available data and information.

Zadeh [3], proposed the concept of fuzzy set theory to tackle with the situations of uncertainty or vagueness. Atanassov [4], proposed the concept of intuitionistic fuzzy set (IFS)theory, which is the generalized version of fuzzy set theory. Moreover, IFS is an instrumental in solving Multi-Criteria Decision-Making (MCDM) problems. Gupta[5], used the concept of intuitionistic fuzzy information theory for the selection of courses among the available ones. Kumar [6], proposed the procedure under intuitionistic fuzzy environment for the diagnosis of malaria. Kumar [7-8] proposed algorithms based on intuitionistic fuzzy aggregation operators for the decision making of suitable treatment for lung cancer. Researchers [9-12] developed certain aggregation operators under intuitionistic fuzzy environment, which addresses the problems of decision making when attribute weights are completely known. Hussian [13] proposed IF based aggregation operator to develop sustainable system for curriculum design. The objectives of sustainable development goal (SDG) no. 9, 11 and 17 were covered by Badi[14] in their research work. The authors used MCDM based MARCOS method to propose decision support system for logistics. A novel fuzzy MCDM model with Z-fuzzy numbers has been proposed by Moslem[15] to evaluate travel mode choices and investigated that cars are the most preferred travel mode. Khan[16] used IF averaging and geometric aggregation operators to develop decision support system that evaluate safety improvements in urban bike sharing systems. A new decision support system using fuzzy graph theory has been developed by Khan[17] that used to evaluate network resilience and optimization.
Badi[18] used MCDM based Best-Worst Method (BWM) and Analytic Hierarchy Process (AHP) techniques to address the problem of inflation analysis, which leads to support economic policymaking. On the same tune, [19-23] proposed various methods for solving MCDM problems. Hwang[24] developed the Technique for order performance by similarity to ideal solution (TOPSIS) technique to deal with the MCDM problems and is considered as classical approach. The proposed technique is elaborative, simple, and computationally efficient and provides hand held support to the decision makers for the improvement of electronic waste recycling strategies.

To deal with this problem, MCDM framework has been proposed to analyze the significant factors and assign weights for appropriate selection and successful implementation in real scenario. We have selected three disposal methods for the disposal of electronic waste as alternatives and factors include population, socio-economic context, awareness), environmental implications, human health hazards, Regulatory aspects, non-regulatory aspects for further assignment.

2. Preliminaries

In this section, some basic concepts related to the intuitionistic fuzzy sets, TOPSIS method have been present, which will be required in the following analysis.

2.1 Fuzzy Set

Zadeh[3], For a set A, fuzzy set is defined as a finite discourse of universe $X = \{x_1, x_2, ..., x_n\}$ as: $A = \{< x, \mu_A(x) >| x \in X\}$, where $\mu_A : X \to [0,1]$ is the membership function of A and $\mu_A(x)$ describes the degree of membership of $x \in X$ to A

2.2 Intuitionistic Fuzzy Set(IFS)

Atanassov [4], A fuzzy set A is defined as a finite discourse of universe $X = \{x_1, x_2, ..., x_n\}$ as: $A = \{< x, \mu_A(x), \nu_A(x) >| x \in X\}$, where $\mu_A, \nu_A : X \to [0,1]$ is the membership and non-membership function of A. Also, $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ is the intuitionistic/hesitation index of $x \in X$ to A

2.3 Intuitionistic fuzzy number (IFN)

IFN is designated as $\alpha = (\mu_\alpha, \nu_\alpha)$ a, where $\mu_\alpha, \nu_\alpha \in [0,1]$ and $0 \le \mu_\alpha(x) + \nu_\alpha(x) < 1, x \in X$

In 1972, Luca and Termini proposed the non-probabilistic entropy version of shannon measure of entropy in intuitionistic fuzzy set form and is defined as:

$$E_{LT}(A) = -k \sum_{i=1}^{n} \left[\mu_A(x_i) \log_e(\mu_A(x_i)) + \nu_A(x_i) \log_e(\nu_A(x_i)) + \pi_A(x_i) \log_e(\pi_A(x_i)) \right], k > 0$$

2.4 Intuitionistic Entropy Measure:

Szmidt [25] extended the axioms proposed by De Luca[26] with regard to Intuitionistic entropy measure. Sharma[27] proposed the exponential measure of intuitionistic fuzzy entropy as:

$$E_{VS}(A) = \frac{1}{n\sqrt{e-1}} \sum_{i=1}^{n} \left[\begin{array}{l} \left(\frac{\mu_A(x_i) + 1 - \nu_A(x_i)}{2} \right) \exp\left(\frac{\nu_A(x_i) + 1 - \mu_A(x_i)}{2} \right) + \\ \left(\frac{\nu_A(x_i) + 1 - \mu_A(x_i)}{2} \right) \exp\left(\frac{\mu_A(x_i) + 1 - \nu_A(x_i)}{2} \right) - 1 \end{array} \right]$$

For the purpose of decision making, intuitionistic fuzzy based TOPSIS method has been proposed in the next section as:

3. Algorithm for the TOPSIS Decision Making method

Following are the steps follows under as:

Step 1: Construction of decision matrix of MCDM problem in intuitionistic fuzzy environment and assign the weights of each criteria as:

$$D=\begin{array}{c} \quad C_1 \quad C_2 \quad ..... \quad C_n \\ \begin{bmatrix} x_{11} & x_{12} & .... & x_{1n} \\ x_{21} & x_{22} & .... & x_{2n} \\ ... & .... & .... & ..... \\ x_{m1} & x_{m2} & .... & x_{mn} \end{bmatrix}\end{array} \quad \text{and} \quad W=(w_1, w_2, ..., w_n)$$

Let $A=(A_1, A_2, ..., A_m)$ be a set of alternatives which consists of *m* non-inferior decision-making alternatives. Each alternative is assessed on n criteria, and the set of all criteria is denoted $C=(c_1, c_2, ..., c_n)$ $\mathrm{C}=\{\mathrm{C}_1, \mathrm{C}_2, ..., \mathrm{C}_\mathrm{n}\}$. Let $W=(w_1, w_2, ..., w_n)$ be the weighting vector of criteria, where $w_j \geq 0$ and $\sum_{j=1}^{n} w_j = 1$

The characteristics of the alternatives A_i are represented by the IFS as:

$$A_i = \{\langle c_j, \mu_{A_i}(c_j), \nu_{A_i}(c_j)\rangle \mid c_j \in C\}, i = 1,2,......,m$$

In order to get collective opinion, find the average of individual opinion collected through various sources. Suppose $\mathrm{r}_{\mathrm{ij}}^{\mathrm{k}}$ = ($\mu_{\mathrm{ij}}^{\mathrm{k}}$, $\nu_{\mathrm{ij}}^{\mathrm{k}}$) be the IFN specified by the decision makers and the aggregated IF rating (r_{ij}) of methods corresponding each criteria can be evaluated with the help of Symmetric Intuitionistic Fuzzy Weighted Averaging (SIFWA) operator as:

$$r_{ij} = SIFWA(r_{ij}^1, r_{ij}^2, ...r_{ij}^l) = \sum_{k=1}^{l} \eta_k r_{ij}^k, = \left(\frac{\prod_{k=1}^{l} (\mu_{ij}^k)^{\eta_k}}{\prod_{k=1}^{l} (\mu_{ij}^k)^{\eta_k} + \prod_{k=1}^{l} (1-\mu_{ij}^k)^{\eta_k}}, \frac{\prod_{k=1}^{l} (\nu_{ij}^k)^{\eta_k}}{\prod_{k=1}^{l} (\nu_{ij}^k)^{\eta_k} + (1-\nu_{ij}^k)^{\eta_k}} \right)$$

Step 2: Using entropy method to determine the criteria weights.

Objective weights have been obtained from entropy weights by using entropy method (Zeleny [28]). Smaller entropy values of each alternative with respect to the set of criteria are obtained.

Step 3: Construction of weighted intuitionistic fuzzy decision matrix.

The weighted intuitionistic fuzzy decision matrix $Z = w^T \otimes D = [x_{ij}]_{m \times n}$

Step 4 Determine intuitionistic fuzzy positive (A^{+}) and negative (A^{-}) ideal solution.

The evaluation criteria can be categorized as: benefit criteria(G) and cost criteria(B).

Using the principle of classical TOPSIS method under IF environment, positive (A^{+}) and negative (A^{-}) ideal solutions can be defined as:

$$A^{+} = \left\{ \left\langle c_j, \left((\max_i \mu_{ij}(c_j) \mid j \in G), (\min_i \mu_{ij}(c_j) \mid j \in B) \right), \left((\min_i \nu_{ij}(c_j) \mid j \in G), (\max_i \nu_{ij}(c_j) \mid j \in B) \right) \right\rangle \mid i \in m \right\}$$

$$A^{-} = \left\{ \left\langle c_j, \left((\min_i \mu_{ij}(c_j) \mid j \in G), (\max_i \mu_{ij}(c_j) \mid j \in B) \right), \left((\max_i \nu_{ij}(c_j) \mid j \in G), (\min_i \nu_{ij}(c_j) \mid j \in B) \right) \right\rangle \mid i \in m \right\}$$

Step 5. Calculation of distance between each alternative A_i from positive (A^{+}) and negative (A^{-}) ideal solutions.

$$d(A_i, A^{+}) = \left[\sum_{i=1}^{n} \left[\left(\mu_{A_i}(c_j) - \mu_{A^{+}}(c_j) \right)^2 + \left(\nu_{A_i}(c_j) - \nu_{A^{+}}(c_j) \right)^2 + \left(\pi_{A_i}(c_j) - \pi_{A^{+}}(c_j) \right)^2 \right] \right]^{\frac{1}{2}}$$

$$d(A_i, A^{-}) = \left[\sum_{i=1}^{n} \left[\left(\mu_{A_i}(c_j) - \mu_{A^{-}}(c_j) \right)^2 + \left(\nu_{A_i}(c_j) - \nu_{A^{-}}(c_j) \right)^2 + \left(\pi_{A_i}(c_j) - \pi_{A^{-}}(c_j) \right)^2 \right] \right]^{\frac{1}{2}}$$

Step 6. To calculate the order of preference of each alternative, relative closeness coefficient (cc_i) has been calculated as:

$$cc_i = \frac{d(A_i, A^{-})}{\left(d(A_i, A^{+}) + d(A_i, A^{-}) \right)}, \quad 0 \le cc_i \le 1, \; i = 1, 2, ,...m$$

The larger value of closeness coefficient (cc_i) indicates that an alternative is closer to positive ideal solution than negative ideal solution. Therefore, the ranking of all the alternatives can be done in descending order (cc_i). The methodology of the proposed algorithm is given in the figure 1.

4. Case Study

Let us consider three methods such as, Recycle, Re-use, Landfill for the disposal of e-waste as alternatives with seven criteria, which include S_1(Population), S_2 (socio-economic context), S_3(Awareness), S_4(Environmental implications), S_5 (Human health hazards), S_6 (Regulatory aspects), S_7 (Non-regulatory aspects) for further assignment (Figure 1). For the evaluation of appropriate method for the disposal of e-waste, information from three sources such as I, II and III are collected. The information collected through various sources are in the form of linguistic term as listed in Table 1. Criteria weights of all the given criteria against each method are presented in Table 2 and the weightage according to the criteria of particular place as shown in Table 3. In selection procedure of particular method for some specified place, accompanying weights are allocated to sources of information collected as: λ_1=0.20, λ_2=0.35 and λ_3=0.45, which is based on the kind of information source.

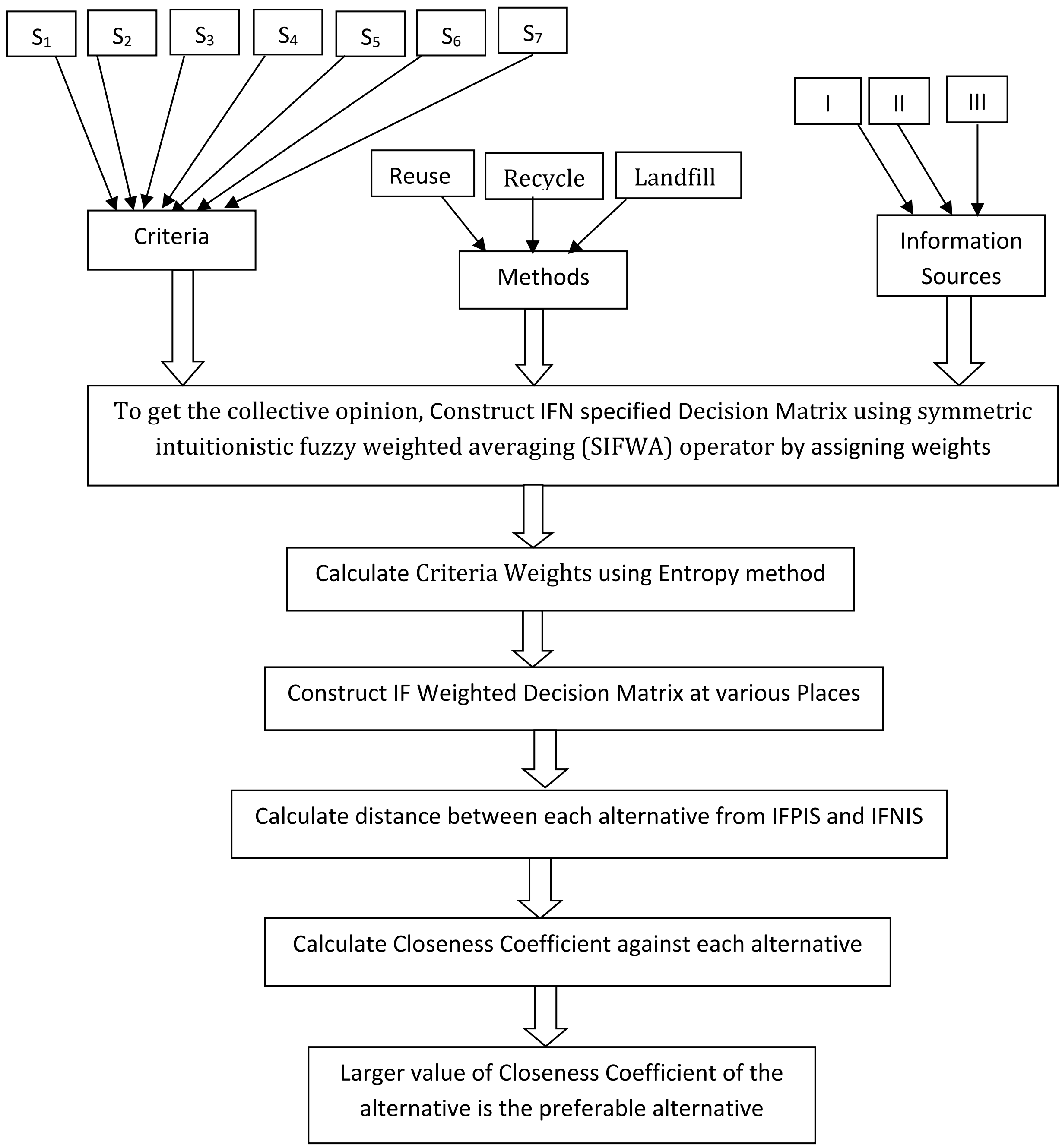

Table 1. Verbal (Linguistic) terms for alternative's and criteria's rating

Low (L)	(0.05, 0.90)
Moderate (M)	(0.50, 0.50)

High (H)	(0.80, 0.10)
Very High (VH)	(0.90, 0.05)

Step 1. The decision matrix (opinion of different information sources) as:

Table 2. Criteria weight by three information sources for each method

Criteria	Recycle			Reuse			Landfill		
	I	II	III	I	II	III	I	II	III
S_1	VH	VH	VH	H	H	H	H	H	H
S_2	H	H	H	VH	VH	VH	L	L	L
S_3	L	L	L	L	L	L	VH	VH	VH
S_4	H	H	H	H	F	H	L	L	L
S_5	VH	VH	VH	L	L	L	L	L	L
S_6	H	H	H	L	L	L	M	L	M
S_7	L	L	L	L	L	M	L	F	H

Table 3. The individual information source opinion in the decision matrix form on three methods

criteria	Information Sources	Methods of e-waste disposal		
		Recycle	Reuse	Landfill
S_1	I	VH	M	L
	II	H	M	L
	III	H	H	M
S_2	I	VH	M	H
	II	VH	M	H
	III	M	H	F
S_3	I	H	M	L
	II	H	M	H
	III	H	H	M
S_4	I	VH	M	L
	II	VH	M	L
	III	VH	H	L
S_5	I	L	M	L
	II	L	M	M
	III	L	H	L
S_6	I	H	M	L
	II	H	M	L
	III	H	M	M
S_7	I	M	H	L
	II	M	H	L
	III	M	H	L

Step 2. To calculate the criteria weights, the entropy values $E_{VS}(c_j)$ and degree of divergence d_j for criteria is defined as:

Table 4. Calculation of Entropy , Degree of Divergence and Entropy Weight of each criteria

	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Entropy $E_{VS}(s_j)$	0.6993	0.6366	0.7554	0.6756	0.6390	0.6285	0.6803
Degree of divergence d_j	0.3007	0.3634	0.2446	0.3224	0.3610	0.3715	0.3197
Entropy weights w_j	0.1316	0.1590	0.1070	0.1419	0.1580	0.1626	0.1399

Step 3. The weighted intuitionistic fuzzy decision matrix R of each criteria against different places is defined as:

Table 5. IF weights of each criteria at various places

	S_1	S_2	S_3	S_4	S_5	S_6	S_7
P1	(.9742, 0.7285)	(.9763, 0.6551)	(.7728, 0.9828)	(.9852, 0.6536)	(.6230, 0.9835)	(.9644,0.6878)	(.9076,0.9076)
P2	(.9449, 0.8417)	(.7802, 0.9512)	(.8462, 0.9669)	(.9407, 0.8304)	(.9342,0.8131)	(.8934,0.8934)	(.9693,0.7246)
P3	(.7920,0.9662)	(.7544,0.9593)	(.9066,0.9181)	(.7105,0.8929)	(.7558,0.9596)	(.6145,0.9830)	(.7140,0.9775)

Step 4. The IFPIS $\left(\mathrm{A}^{+}\right)$ and IFNIS $\left(\mathrm{A}^{-}\right)$ of each alternative with respect to criteria as:

$$A^{+}=\left\{\begin{array}{l}(0.9742,\,0.7285),(0.9763,\,0.6551),(0.9066,\,0.9181),(0.9852,\,0.6536),\\ (0.9342,\,0.8131),(0.9644,\,0.6878),(0.7140,\,0.9775)\end{array}\right\}$$

$$A^{-}=\left\{\begin{array}{l}(0.7920,\,0.9662),(0.7544,\,0.9593),(0.7728,\,0.9828),(0.7105,\,0.8929),\\ (0.6230,\,0.9835),(0.6145,\,0.9830),(0.9693,\,0.7246)\end{array}\right\}$$

Step 5. The distance between each alternatives and (IFPIS and IFNIS) is given in table 5.

Table 6. IFPIS and IFNIS of each method of e-waste

Methods	$d(A_i, A^{+})$	$d(A_i, A^{-})$
Reuse	2.7062	2.8364
Recycle	2.6868	2.5871
Landfill	3.0708	2.7969

The value of the closeness coefficients cc_i against each method is given in figure 2. Greater the closeness coefficients cc_i, more the alternative near to IFPIS $\left(A^{+}\right)$ and far from IFNIS $\left(A^{-}\right)$. Most favourable alternative is the one which has highest cc_i.

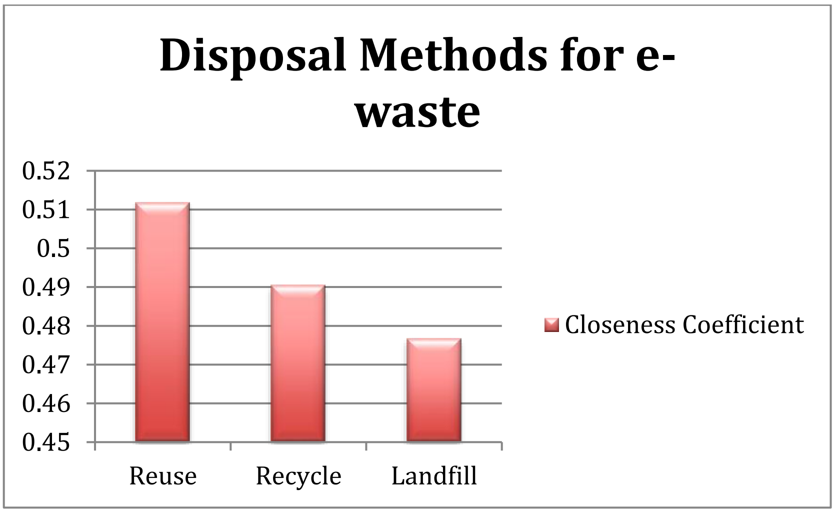

Figure 2. Methods of Disposal for E-waste and Closeness coefficient CC_i

5. Result and Discussion

From Figure 1, the highest value of the closeness coefficient revealed that reuse method is the most suitable method to manage e-waste than recycling and landfilling.

6. Conclusion

The extent of pollution caused due to electronic waste underscores the need for MCDM approach for proper electronic waste management**.** Notwithstanding the fact that every constituent of electronic waste needs special attention, it is clear from present case study that re-use of waste in original form after required repair and customization is the best available option in real scenarios. Therefore, the need for actions to be taken to compensate the effect on environment is immediate. This framework can further support the organizations and stakeholders to take suitable steps for the improvement of electronic waste recycling strategies.

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Conflicts of Interest
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.

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