Analysis of barriers in e-waste management in developing economy: An integrated MCDM approach

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“Analysis of barriers in e-waste management in developing economy: An integrated MCDM approach”

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Abstract:

An increasing quantity of electronic waste (e-waste) is not a new cause of concern, and it has been causing trouble throughout the world. This waste comprises of valuable metals along with harmful compounds that leads to harmful environmental consequences. Managing this kind of waste in developing economies is difficult due to presence of lot of hindrance in the process. Therefore, the goal of this research work is to determine the barriers while taking expert opinions and through available literature, and subsequently prioritize them to address the challenges in e-waste management. Moreover, this study reflects a hybrid Fuzzy DEcision-MAking Trail and Evaluation Laboratory (F-DEMATEL) and Fuzzy Interpretive Structural Modeling (F-ISM) approaches applied for determining the interrelationship between the barriers. The F-DEMATEL technique facilitates in identifying influential and influenced barriers and categorizes them into causal or effect groups. Performance data obtained from this combined approach is applied to determine an overall rank for 15 identified barriers. In addition, a fuzzy Matrice d'impacts Croisés Multiplication Appliquée an un Classeement (F-MICMAC) analysis is exercised to sort them into dependent or driving factor. The findings suggest that the underlying cause barriers include ‘lack of customer awareness about return’, ‘less policies addressing e-waste problem’, ‘lack of long-term planning’, and ‘insensitiveness of public towards environmental issues. The methodology is integrated with fuzzy logic to take uncertainty in the data gathered into consideration. This approach aids policymakers and decision-makers in determining the barriers' mutual relationships and interconnections.

Keywords: F-DEMATEL, F-ISM, MCDM, e-waste management, Barriers

1. Introduction

The electronic sector is currently one of the fastest expanding markets in developing countries. Rapid economic expansion is driving up demand for and usage of electronic devices. Increased e-waste is caused by urbanization, rapid technical progress, lowering pricing, and the replacement of electronic gadgets with new ones based on user behaviors. As a result, the manufacturing of electronics items has become more difficult, resulting in a significant increase in harmful e-waste (Dwivedy and Mittal, 2010). This e-waste comprises toxic metals and harmful compounds which have a detrimental effect both on humans and environment. Inappropriate waste treatment results in resource depletion and significant loss to the environment and economic (Menikpura et al., 2014). Understanding the relevance and impact of the e-waste surge, the developed economies have created mandatory e-waste handling legislation. As a result of inadequate environmental policies, low - cost labor, and other considerations, these wastes are sent to underdeveloped countries for recycling (Garlapati, 2016; Wakolbinger et al., 2014;). Furthermore, disposed of in landfills along with lack of reliable information on the amount of e-waste recycled in every year has magnanimously created a hazardous environment for humans in underdeveloped nations. The rapid pace of e-waste generation is posing serious garbage management difficulties in developing countries.

1.1 Research motives

The current study aims to evaluate the hurdles in construction of an e-waste management system which is also sustainable. Furthermore, this project would help in understanding the need of a systemic approach for e-waste management in developing economies.

1.2 Research goals

The goal of this work is to obtain barriers in implementing e-waste management system successfully, to provide a clear view of these barriers, to aid policymakers in identifying the interrelationships between them and to study their impact on each other. Several techniques have been developed to address the inconsistency that arises as a result of failing to consider the interrelationship between the barriers in this problem-solving process. The Interpretive Structural Modeling (ISM) and Decision-Making Trail and Evaluation Laboratory (DEMATEL) appear to be acceptable approaches for providing explicit hierarchical and relational structure strategically. The suggested integrated F-DEMATEL and F-ISM based model can be applied as a reliable tool for solving this problem. By providing effective methodology for measuring the hurdles to e-waste management implementation in the emerging economy. Future research will benefit from the findings of this study. The following are the three key questions addressed in this research:

- RQ₁: What are the major barriers in efficient management of e-waste?
- RQ₂: What is the interrelationship among the identified barriers?
- RQ₃: How can these critical barriers be structured into cause-and-effect groups to ensure a long-term implementation approach?

The remaining sections of this research paper are developed as follows: Section 2. presents brief review about the previously published work in this area and gives details about the identified barriers, including strategic, organizational, technological and economic considerations. This also highlights the application of a multi-criteria decision-making (MCDM) approach for issues affecting the implementation of e-waste management. In Section 3, integrated F-DEMATEL and F-ISM methods are employed to develop an efficient e-waste management approach. Subsequently, on the note of their driving and dependance power, the F-MICMAC analysis could be performed to group these barriers. Finally, a detailed outcomes and discussion on the research work's key findings and managerial implications is represented in Section 4. In the final section, conclusions, limitations of the study, and future scope for the research possibilities is mentioned.

2. Literature review

Here the whole relevant literature is broadly classified into two parts. Initial part comprises determining relevant criteria for e-waste management implementation through a comprehensive review of the previously published research works. These evaluation criteria are based on strategic, organizational, technological, economic aspects that have a significant impact on e-waste management. The later part of the literature review covers application of MCDM techniques for managing e-waste. Total 15 barriers (A to O) have been identified through extensive literature study and collective survey conducted with the experts from academic, industry and government sector. All the barriers considered in the study are displayed in Table 1.

2.1 Identifying major barriers to e-waste management implementation in developing economies

Table 1: Barriers to implementing long-term e-waste management

Sub Barriers Criteria with code	Barrier's description	References
Lack of long-term planning (A)	Unfortunately, the majority of e-waste ends up in landfills, posing substantial environmental risks. One of India's biggest drawbacks in managing e-waste is the failure to establish long-term planning.	(Prakash and Barua 2016)
Less policies addressing e-waste problem (B)	It is known that company policies are one of the most effective tools managing any problem.	(Balon et al.2016; Luthra, et al., 2011;
Lack of customer awareness about return (C)	Majority of the population is unaware of return policies and rules for recycling electronic items.	Rahman and Subramanian (2012), Chung and Zhang (2011);
Insensitiveness of public towards environmental issues (D)	E-waste is recycled informally due to public insensitiveness towards environmental issues, which has serious harmful effects.	Abdulrahman et al. (2014)
Lack of corporate social responsibility (CSR) initiatives (E)	By recycling their garbage in an environmentally sustainable manner, organizations can spend minimal revenues while working toward sustainability.	Mudgal et al., 2010; Mulliner et al., 2013
Insufficient organizational structure and support (F)	The informal sector has a distinct advantage in accessing e-waste from both enterprises and households while keeping their overheads low due to the type of organizational structure and the wide network built across the country.	Turaga et. al 2019
Limited human resources (G)	It is increased in developing countries by totally adopting or imitating developed-country e-waste management, as well as numerous related issues such as a lack of investment and technically qualified human resources.	Suggested by the experts
Underdeveloped recycling technologies (H)	There is a communication gap between the industries which recycle waste due to which it is difficult to develop technologies that can serve the purpose of waste management.	Jindal and Sangwan (2011), Wong et al. (2011)
Lack of technological infrastructure (I)	The managing methods are limited owing inefficient of technological infrastructure for recycling, collection and storage facilities, and sufficient transportation facilities for the waste generated.	Patil & kant (2014)
Low safety and security of information system (J)	Less advanced technology, as well as the safety and security of information systems, are major barriers in adopting these practices.	(Gunasekaran & Nagai, 2004)
Less investment in warehouses (K)	Due to a lack of funding, there is no suitable warehouse training or testing for hazardous substance restrictions or e-waste recycling enterprises.	Abdulrahman et al. (2014)
Huge investment initially and high operating cost (L)	To establish e-waste management practices, a large initial financial expenditure would be required for recycling plants, collecting centers, training, and awareness programmes.	Presley et al. (2007)
High cost of technology (M)	Processing the waste and creating a recycled product would require a cutting-edge technology which will be costly.	Scheinberg et al, 2011
Inadequate funds to recycle e-waste (N)	A lot of money is needed for recycling the waste.	Kumar and Dixit (2018b)
Lack of subsidy from government (O)	The government's financial aid to encourage industrialists to establish garbage recycling facilities.	Shih et al, 2013

2.2 Application of MCDM techniques:

Managing e-waste is a complex problem which requires an in-depth analysis of the various factors involved, prompting the development of many MCDM models in the past two decades. Srivastava and Sharma (2015) employed ISM technique to formulate the relationship between the identified factors for e-waste management. Ravi (2015) applied the ISM approach to investigate the barriers for Eco efficiency interact in the electronic packaging industry. Prakash and Barua (2016) applied fuzzy analytic hierarchy process technique for prioritization of reverse logistics adoption barriers under fuzzy environment in Indian electronics industry. Garlapati (2016) examined at the most important factor in attaining successful e-waste management. Welfens et al. (2016) investigated the key enablers and barriers that affect the return and recycling of mobile phones by applying Interpretive Structural Modeling (ISM) approach. Satapathy (2017) employed ISM technique to analyse the interrelationships between the barriers, which identifies the difficulties. Yukalang et al. (2017) examined barriers through SWOT (strength, weakness, opportunity, and threat) analysis which associated with municipal solid waste management based on social, technical, financial, and legal political aspects incorporated in Thailand. Kumar and Dixit (2018a) applied ISM-DEMATEL approach to analysis of barriers affecting the implementation of e-waste management practices in India. Vieira et al. (2020) applied MCDM approach to identified barriers in the implementation of reverse logistics of e-waste. Chen et al. (2021) employed DEMATEL methodology to analyze the barriers for textile sector. Unlike traditional MCDM techniques, F-DEMATEL can grasp the interconnectedness of the barriers and display the causal–effect link between those barriers criteria.

Fuzzy DEMATEL and Fuzzy ISM approaches applied in different sector like biofuel sector (Chin et al. (2014), Zhang & Jiang (2017), Demirbas (2017), Saravanan et al. (2018)), sustainable manufacturing (Jadhav et al. (2014), Zhang et al. (2020), Singh & Sarkar (2020)), sustainable human resources management (Tooranloo et al. (2017)), supply chain management (Raut et al. (2017), Guarnieri and Trojan (2019)), Ahmadi et al. (2017)), sustainable project management in construction (Mavi and Standing (2018), Shakeri and Khalilzadeh (2020)), sustainable development in adaptive reuse of urban industrial buildings (Awan et al. (2018), Chen et al. (2019)), sustainable lean six sigma in Indian manufacturing sector (Parmar and Desai (2020)).

Although, Kumar and Dixit (2018a) combined the ISM- DEMATEL approach for an efficient e-waste management practice in India, the study does not consider the data's ambiguity. It offers the motivation for our research. The barriers in effective implementation of e-waste were evaluated using an integrated F-ISM and F-DEMATEL method in this study. This research work adds to the body of knowledge by-

- Identifying the factors responsible for inefficient e-waste management using a literature analysis and expert feedback.
- Applying F-DEMATEL and expert input, the finalized barriers were evaluated to separate them into cause-and-effect groups.
- Adopting F-ISM and expert input, the finalized barriers were evaluated to examine the contextual relationships between them and to comprehend their hierarchical relationships.
- Discussing the managerial implications of e-waste management policies in developing nations to identify the issues related to their implementation.

Therefore, in this study, a hybrid F-ISM and F-DEMATEL approach is applied to address uncertainty and inconsistency in the gathered data. Moreover, this study considers an exhaustive list of 15 barriers that have a significant character to play in implementation of e-waste management. which has not been carried out previously. Figure 1 exhibits the framework for current research work.

3. Methodology

The F-DEMATEL and F-ISM methods are combines in this study to examine causal relationships of barriers in sustainable e-waste management. The subjective nature of human assessments is addressed while integrating fuzzy logic with this methodology. In fuzzy environment, in place of crisp numbers of interval sets are utilized. The proposed methodology aids in establishing the interrelationships between barriers and consequently, ranking them based on the type of relationships and degree of impact on each barrier. The output of F-DEMATEL was ingress to F-ISM as input and obtained the final results. The F-MICMAC analysis is also applied in combination with the F-ISM technique to cluster the barriers.

Fig. 1: Proposed research methodology's framework

3.1 F-DEMATEL procedure

Step I: Development of the fuzzy direct-relation matrix

To determine the type of relationships between n criteria, a $n \times n$ matrix is initially created. The impact of row element on column component of this matrix is expressed with the use of fuzzy number. The fuzzy scale utilized in the model is shown in Table 2.

All experts must fill out the matrix if several experts' perspectives are to be considered. Moreover, a direct relation matrix z was created by calculating the arithmetic mean of all the experts' opinions, as stated in Equation 1.

$$z = \begin{bmatrix} 0 & \cdots & \tilde{z}_{n1} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{1n} & \cdots & 0 \end{bmatrix} \quad (1)$$

Table 2: Fuzzy scale

Scale	Effects presented in Linguistic terms	L	M	U
0	NIL	0	0	0.25
1	Low	0	0.25	0.5
2	Medium	0.25	0.5	0.75
3	High	0.5	0.75	1
4	Very high	0.75	1	1

Step II: Normalize the fuzzy direct-relation matrix.

Equation 2 can be introduced to get the normalized fuzzy direct-relation matrix.

$$\tilde{x}_{ab} = \frac{\tilde{z}_{ab}}{r} = \left(\frac{l_{ab}}{r}, \frac{m_{ab}}{r}, \frac{u_{ab}}{r} \right) \quad (2)$$

Equation 3 can be applied to calculate r value.

$$r = \max_{a,b} \left\{ \max_a \sum_{b=1}^n u_{ab}, \max_b \sum_{a=1}^n u_{ab} \right\} \quad a, b \in \{1, 2, 3, \dots, n\} \quad (3)$$

Step III: Calculate the total-relation matrix with fuzziness.

Equation 4 can be applied to calculate the fuzzy total-relation matrix in step 3

$$\tilde{T} = \lim_{k \rightarrow +\infty} (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \dots \oplus \tilde{x}^k) \quad (4)$$

Equation (5) (6) and (7) may be applied to calculate each factor of the fuzzy total-relation matrix, which is written as $\tilde{t}_{ab} = (l_{ab}^{\prime\prime}, m_{ab}^{\prime\prime}, u_{ab}^{\prime\prime})$.

$$[l_{ab}^{\prime\prime}] = x_l \times (I - x_l)^{-1} \quad (5)$$

$$[m_{ab}^{\prime\prime}] = x_m \times (I - x_m)^{-1} \quad (6)$$

$$[u_{ab}^{\prime\prime}] = x_u \times (I - x_u)^{-1} \quad (7)$$

Step IV: Defuzzify the values into crisp ones.

For defuzzification, converting fuzzy data into crisp scores (CFCS) process is adopted. First, the fuzzy values are converted to crisp values using a technique similar to that used for calculating the right and left scores using fuzzy max and min values respectively. Finally, the total score is obtained using the membership functions as a weighted average.

Assume that the alternatives are weighed using the fuzzy numbers f_{ab} , $b=1\dots J$ and the a th criteria (where J is the number of alternatives). The crisp value of the b^{th} criterion could be calculated using the four-step CFCS algorithm for the triangular fuzzy numbers $f_{ab} = (l_{ab}, m_{ab}, u_{ab})$, $b=1, \dots, J$

Using Equation (8) (9) and (10) the CFCS technique, the steps are as follows:

$$l_{ab}^n = \frac{(l_{ab}^t - \min l_{ab}^t)}{\Delta_{min}^{max}} \quad (8)$$

$$m_{ab}^n = \frac{(m_{ab}^t - \min l_{ab}^t)}{\Delta_{min}^{max}} \quad (9)$$

$$u_{ab}^n = \frac{(u_{ab}^t - \min l_{ab}^t)}{\Delta_{min}^{max}} \quad (10)$$

in order for

$$\Delta_{min}^{max} = \max u_{ab}^t - \min l_{ab}^t \quad (11)$$

Normalized values for lower and upper boundary conditions are calculated by utilizing Equations (12) and (13) respectively.

$$l_{ab}^s = m_{ab}^n / (1 + m_{ab}^n - l_{ab}^n) \quad (12)$$

$$u_{ab}^s = u_{ab}^n / (1 + u_{ab}^n - l_{ab}^n) \quad (13)$$

Crisp values are the result of the CFCS algorithm.

Total normalized crisp values derived using Equation 14 are shown in Table 3.

$$x_{ab} = \frac{[l_{ab}^s(1-l_{ab}^s)+u_{ab}^s \times u_{ab}^s]}{[1-l_{ab}^s+u_{ab}^s]} \quad (14)$$

Step V: Decide on a value for the threshold.

A threshold value is required to compute the internal relationships matrix. This value is calculated by taking average values of the matrix T. Once the threshold value is determined, the entries in matrix T that are less relative to the threshold value are set to zero. As a result, a network relationship map (NRM) is constructed in which only the relationships with scores in matrix T greater than the threshold value are illustrated and incomplete relationships are not considered. The threshold value in this research is 0.2382. The defuzzied total-relation matrix (T) is depicted in Table 4 below.

Step VI: Create a causal relationship diagram using the final output.

The following step is performed to get the values in rows and columns of the total-relation matrix (T) (in step 4). Equations (15) and (16) can be used to get the sum of rows (D) and columns (R):

$$D = \sum_{b=1}^n T_{ab} \quad (15)$$

$$R = \sum_{a=1}^n T_{ab} \quad (16)$$

Step VII: Analyze the outcomes

As illustrated in Figure 3 and Table 8, each element can be assessed using the following criteria.:

- The horizontal vector (D + R) indicates both the impact of factor on the entire system and the influence of other components on that factor.
- The degree of a factor's influence on the system is presented by the vertical vector (D-R). A positive value for D-R shows causative nature of the variable, whereas a negative D-R value represents its effect.

214 The ISM methodology was proposed by Warfield in the year 1973. It is an effective tool for determining the
 215 direction and order of interrelationships between variables. It is a method to be carried out individually or in a
 216 group environment to display domain knowledge in a model with interrelationships to comprehend its complexity
 217 better. The following are the many steps in the fuzzy ISM methodology:

218 *Integrated F-DEMATEL and F-ISM*

219 Create the initial reachability matrix, as well as the threshold limit and influence matrix. The threshold value
 220 (0.2382) is determined by expert opinion or by using the Equation 14 to calculate the average of the numbers in
 221 the total relationship matrix (T).

222 Identifying the barrier's level: For each barrier, the intersection of the input and output sets is calculated once the
 223 input and output sets have been determined. Barriers with identical output set and joint set are placed at the top of
 224 the ISM's hierarchy, as indicated in Table 6 and Figure 2. After the first iteration the highest actions are removed
 225 from the other set of barriers. This process is continued till all of the barriers' levels have been determined.

226 **Table 3. Total normalized crisp value**

	Di			Ri			Di+Ri			Di-Ri		
	l	m	u	l	m	u	l	m	u	l	m	u
A	0.9145	2.6953	11.1498	0.9840	2.8272	11.33985	1.8985	5.5225	22.4897	-10.4254	-0.1319	10.1658
B	0.8009	2.4792	10.5811	0.9342	2.7322	11.37823	1.7351	5.2114	21.9594	-10.5773	-0.2529	9.6469
C	0.6198	2.1361	9.5106	0.9622	2.7854	11.385	1.5820	4.9215	20.8956	-10.7652	-0.6492	8.5484
D	0.7969	2.4718	10.9679	1.1343	3.1117	11.80091	1.9313	5.5835	22.7688	-11.0040	-0.6399	9.8335
E	0.8334	2.5408	10.5634	0.8387	2.5518	10.92558	1.6720	5.0926	21.4889	-10.0922	-0.0110	9.7247
F	0.7794	2.4391	10.7263	0.9787	2.8172	11.34551	1.7581	5.2563	22.0718	-10.5661	-0.3781	9.7476
G	0.8795	2.6291	10.7185	0.7982	2.4743	10.7945	1.6778	5.1033	21.5130	-9.9150	0.1548	9.9202
H	0.9213	2.7080	11.3658	1.0247	2.9040	11.38301	1.9460	5.6120	22.7488	-10.4617	-0.1960	10.3411
I	0.7961	2.4702	10.5845	0.8500	2.5730	10.73682	1.6461	5.0432	21.3213	-9.9408	-0.1028	9.7345
J	0.8540	2.5804	10.9572	1.0363	2.9257	11.60881	1.8904	5.5062	22.5660	-10.7548	-0.3453	9.9209
K	0.7487	2.3808	10.5192	0.6960	2.2803	10.13793	1.4447	4.6612	20.6571	-9.3892	0.1005	9.8232
L	0.9001	2.6674	10.7699	0.6468	2.1877	9.895871	1.5469	4.8550	20.6657	-8.9958	0.4797	10.1230
M	0.9511	2.7646	11.1396	0.7040	2.2963	10.09026	1.6550	5.0609	21.2299	-9.1392	0.4683	10.4357
N	1.0592	2.9695	11.5747	0.7268	2.3389	10.36849	1.7861	5.3084	21.9432	-9.3093	0.6306	10.8478
O	1.0262	2.9069	11.5872	0.5660	2.0336	9.524848	1.5922	4.9405	21.1121	-8.4986	0.8733	11.0213

227 **Step VIII:** On a reachability matrix, level partitioning is used to acquire information about the arrangement of
 228 barriers in a degree-clever manner (Warfield, 1973). For all the barriers produced from the final reachability
 229 matrix shown in Table 5, reachability sets, antecedent sets, and intersection sets are determined. A element is
 230 assigned to the ISM hierarchy at the first level if it has a reachability set that is similar to the intersection set
 231 (Mathiyazhagan and Haq 2013). The previous levelled barrier is erased from the entire matrix in the following
 232 stage for level partitioning. The method is repeated until all barriers are levelled from Ist to IVth, as exhibited in
 233 Table 6.

Table 4: Defuzzified total-relation matrix T

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	0.2172	0.2602	0.2734	0.2858	0.2353	0.2733	0.2472	0.2639	0.2493	0.2793	0.2205	0.2288	0.2195	0.2244	0.2070
B	0.2629	0.2022	0.2357	0.2622	0.2244	0.2507	0.2208	0.2385	0.2387	0.2677	0.2105	0.1900	0.2094	0.2416	0.2121
C	0.1991	0.2399	0.1828	0.2523	0.2184	0.2119	0.2021	0.2432	0.1865	0.2346	0.1904	0.1697	0.1739	0.2108	0.1646
D	0.2390	0.2518	0.2543	0.2220	0.2286	0.2393	0.2394	0.2561	0.2265	0.2593	0.2288	0.2079	0.2136	0.2332	0.2285
E	0.2638	0.2617	0.2523	0.2644	0.1955	0.2213	0.2510	0.2644	0.2095	0.2586	0.1943	0.2217	0.2114	0.2303	0.1996
F	0.2503	0.2492	0.2493	0.2616	0.2236	0.2060	0.2220	0.2536	0.2509	0.2552	0.2385	0.2035	0.2084	0.2138	0.1814
G	0.2402	0.2392	0.2671	0.2792	0.2447	0.2552	0.1957	0.2301	0.2549	0.2723	0.2296	0.2085	0.2410	0.2182	0.2005
H	0.2644	0.2746	0.2645	0.2885	0.2378	0.2643	0.2496	0.2223	0.2371	0.2821	0.2374	0.2312	0.2226	0.2272	0.2249
I	0.2512	0.2483	0.2197	0.2465	0.2381	0.2626	0.2216	0.2648	0.1933	0.2404	0.2383	0.2047	0.2088	0.2282	0.1963
J	0.2677	0.2410	0.2689	0.2811	0.2454	0.2559	0.2426	0.2594	0.2434	0.2189	0.2007	0.2109	0.2298	0.2196	0.2028
K	0.2458	0.2456	0.2462	0.2584	0.2195	0.2588	0.2330	0.2611	0.2350	0.2377	0.1769	0.1852	0.2048	0.2103	0.1782
L	0.2698	0.2556	0.2420	0.2544	0.2587	0.2575	0.2548	0.2447	0.2573	0.2488	0.2008	0.1809	0.2439	0.2198	0.2180
M	0.2639	0.2630	0.2628	0.2872	0.2515	0.2750	0.2346	0.2778	0.2505	0.2811	0.2211	0.2433	0.1904	0.2106	0.2090
N	0.2853	0.2432	0.2729	0.2977	0.2736	0.2731	0.2595	0.2886	0.2720	0.2787	0.2454	0.2531	0.2451	0.2038	0.2165
O	0.2727	0.2705	0.2835	0.2849	0.2723	0.2832	0.2275	0.2763	0.2435	0.2777	0.2434	0.2396	0.2553	0.2605	0.1837

Step IX: The digraph is developed by arranging all of the barriers graphically in levels and drawing directed links to demonstrate relationships in the reachability matrix. By deleting the transitive relationships grade by grade and analyzing their interpretation from the expert's perspective, a simpler version of the preliminary digraph can be obtained. The most effective association with the most crucial interpretation is kept.

Step X: Interaction matrix: The final digraph yields a binary interplay matrix that depicts all interactions with a single access.

Step XI: Digraph formation and conversion: The digraph is converted to an ISM, and the miles are examined for conceptual conflicts. By replacing element nodes with charges, the resulting digraph from step X is turned into an ISM. Finally, we evaluate the ISM version to look for inconsistencies.

Step XII: The F-MICMAC analysis is applied to identify the different types of dependencies. The criteria are classified as dependent, independent, linkage, or drivers based on the standard's dependence energy. It is carried out to determine the driving and dependent powers of the factors.

As shown in Figure 4, F-MICMAC analysis is utilized to classify barriers based in four different categories i.e. autonomous, dependent, linkage and independent (Mousavizade and Shakibazad,2019).

- Autonomous: having a low driving and dependent power.
- Dependent: having a low driving but a high dependence power.
- Linkage: having a lot of driving and depending on power.
- Independent: having a high driving but a low dependence power.

The driving and dependency powers are traditionally calculated using the final reachability matrix. In this matrix, the vertical sum gives the dependent power and the horizontal sum of individual barriers gives the driving power.

The steps in F-MICMAC analysis are as follows:

Step I: Binary direct reachability matrix: Due to the fact that a factor has no reachability, the diagonal components of the initial reachability matrix are replaced by zero.

Step II: Fuzzy direct relationships matrix: Traditional MICMAC analysis appears to be less sensitive because it is based on a binary relationship between the variables. Furthermore, many factors distribute unevenly and randomly, causing all factors in a given area to appear to have different driving and dependency powers. This necessitates a distinct explanation for each aspect. Therefore, fuzzy set theory is used in this study to improve the sensitivity of the analysis. Based on of the expert's view, the F-MICMAC analysis presents the possibility of interaction among the factors. The case of an interaction is assessed using a Likert scale ranging from 0 to 1, as shown in table 7. The opinions on how all of the factors interact have been gathered from the same experts who have already been discussed.

Table 5: Final reachability matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Driving factor
A	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	13
B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
C	1	1	1	1	0	1	1	1	1	1	0	0	0	1	0	10
D	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	13
E	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	12
F	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	12
G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
H	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	13
I	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	12
J	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	13
K	1	1	1	1	0	1	1	1	1	1	1	0	0	1	0	11
L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
M	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
O	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
Dependence factor	15	15	15	15	13	15	15	15	15	15	13	6	11	15	1	

Table 6: Level Partitioning

Barrier	Reachability	Antecedents	Intersection	Level
A	ABCDEFGHIJKMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKMN	I
B	ABCDEFGHIJKLMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKLMN	I
C	ABCDFGHIJ N	ABCDEFGHIJKLMNO	ABCDFGHIJ N	I
D	ABCDEFGHIJKMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKMN	I
E	ABCDEFGHIJMN	ABDEFGHIJLMNO	ABDEFGHIJMN	II
F	ABCDEFGHIIJKN	ABCDEFGHIJKLMNO	ABCDEFGHIIJKN	I
G	ABCDEFGHIJKLMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKLMN	I
H	ABCDEFGHIJKMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKMN	I
I	ABCDEFGHIIJKN	ABCDEFGHIJKLMNO	ABCDEFGHIIJKN	I
J	ABCDEFGHIJKMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKMN	I
K	ABCDFGHIJ K N	ABDFGHIJLMNO	ABDFGHIJKN	II
L	ABCDEFGHIJKLMN	BGLMNO	BGLMN	III
M	ABCDEFGHIJKLMN	ABDEGHJLMNO	ABDEGHJLMN	III
N	ABCDEFGHIJKLMN	ABCDEFGHIJKLMNO	ABCDEFGHIJKLMN	I
O	ABCDEFGHIJKLMNO	O	O	IV

Fig. 2: Final output of ISM

Step III: F-MICMAC stabilized matrix: The study's main determinants can be appropriately acted upon by observing at their direct and indirect interrelationships. By multiplying the fuzzy direct relationship matrix until the variables' driving and dependent orders stabilize, these indirect linkages can be constructed.

Table 7: Fuzzy- Likert scale

Effects presented in Linguistic terms	NIL	Very low	Low	Medium	High	Very high	Complete
Values	0	0.1	0.3	0.5	0.7	0.9	1.0

Fuzzy matrix multiplication is essentially an extension of Boolean matrix multiplication shown in equation (17).

$$M = P, Q = \text{Max } k [\min (a_{ik}, b_{kj})] \text{ where } P = [a_{ik}] \text{ and } Q = [b_{kj}] \quad (17)$$

In the eighth stage of multiplication, the driving and dependency powers alternately repeat, resulting in the fuzzy stabilized matrix are shown in Table 9.

4. Results and discussion

The obtained results from application of the integrated MCDM methodology for implementation of e-waste management are presented and evaluated in detail in this section. F-DEMATEL approach following pair-wise comparison was used for determining the cause-and-effect relationship among the related factors. The final output as exhibited in Table 8 is also graphically represented in the form of a causal diagram as shown in Figure 3. The degree of prominence ($D + R$) on the X-axis denotes the degree of deciding role played by a barrier, or the influence (prominence) given or received by the barriers. The causal degree ($D - R$) on the Y-axis represents the net effect created by a barrier, i.e., the degree to which one barrier is influenced (causal influence) by other barriers. As a result, barriers with positive ($D - R$) values belong to the cause group, implying that they have a net influence on others. barriers with negative ($D - R$) values belong to the effect group, which means they are influenced by other barriers. barriers G and K-O; belong to the cause group, whereas barriers A-F, H; I; and J belong to the effect group, as can be seen from Table 8 and Figure 3. Taking an overall average of total relation matrix yielded a final threshold value of 0.2382.

The F-ISM approach was employed in the current study to exploit conceptual and computational leverage to explain the complicated pattern of contextual relationships among the barriers. Then the initial reachability matrix prepared by considering threshold limit and introduced in the matrix to concoct influence matrix. The initial reachability matrix was converted into a final reachability matrix. The final reachability matrix was used to create the reachability and antecedent sets of barriers. The “reachability set” for a given barrier consists of the barrier itself and barriers that it may impact, whereas the “antecedent set” consists of the barrier itself and barriers that affect it. The intersection of both sets is then determined for all barriers and levels of each barrier. The first level is occupied by barriers with similar reachability and intersection sets. For the next level-iteration, the first level barriers were isolated from the other components in order to analyze the next level barriers. The method was continued until each barrier's level was determined (Figure 2). The level partitioning of elements to be placed in the ISM model is shown in Table 6. The number in the sets table (i.e., Reachability Set, Antecedent Set, and Intersection Set) represent the relevant barriers. The numbers in the row relating to the levels, on the other hand, represented the barrier's rank. A hierarchical ISM model was created using the levels assigned to various barriers. The barriers are further linked by arrows based on the relationships found in the initial reachability matrix. The ISM model shows that barrier O is the most significant barrier for implementation of e-waste management. As a result, barriers evaluating environmental concerns for implementation of e-waste were found to have a considerable impact on other barriers. Subsequently, F-MICMAC was applied to check the intensity of the correlation between dependency and driving powers of barriers. Figure 5 shows a fuzzy MICMAC analysis. The barriers' driving and dependent powers are calculated by adding the row and column entries, respectively. Their driving powers determine the hierarchies of the barriers. The main barrier for effective e-waste management is the barrier with the highest driving power, such as A-D, J, L-O. In addition, the F barrier is a major dependent barrier shown in Table 9.

Further barriers could be classified into four prominent regions based on their dependency and driving powers respectively. Autonomous or independent barriers are those that have a low driving power as well as a low dependence power. Barriers E and F are present in this region. The dependent region includes barriers with low driving power but significant dependence power. This is where barrier K appears. When there exists high driving, as well as high dependence power among the barriers, they are known as linkage barriers. Therefore, this region includes barriers A, B, D, G-J, L-N and. The driving part contains independent barriers with high driving power and low dependence power, such as barriers C, and O.

4.1 Discussion on significant barriers

Lack of customer awareness about return (C) barrier have significant effect on eight barriers that emphasizes on A; B; D; J; L; M; N; O. Lack of customer awareness about return (C) is the furthestmost influential barriers with high driving and low dependence power respectively; as a result, this barrier is crucial for e-waste management implementation in the developing economy context. Previous research has found that Lack of customer awareness about return play a substantial role in e-waste management (Kumar and Dixit (2018a).

Less policies addressing e-waste problem (B) barrier e-waste management regulations and policies should be amended to reflect developed-country policies. As a result, consumer awareness of e-waste must be enhanced, and policies must be effectively implemented to monitor and regulate the future growth of e-waste (Verma and Agrawal, 2014).

Lack of long-term planning (A) has a significant impact on e-waste disposal policies as public awareness of the necessity of e-waste disposal increases. More indispensably, sharing information to promote green recycling processes helps ecosystem conservation and development (Kumar and Dixit, 2018).

Insensitiveness of public towards environmental issues (D) have a significant impact on lack of corporate social responsibility (CSR) initiatives (E). Inadequate information and inadequate consumer awareness of environmental conscience have an impact on the e-waste management in developing economy, according to the report (Garlapati, 2016).

Insufficient organizational structure and support (F) is significantly affected by barriers E; G; H; I; and J apart from the barriers discussed earlier in this section. As a result of the kind of organizational structure and the extensive network created across the country, the informal sector has a significant advantage in accessing e-waste from both business and individuals while keeping their overheads low (Turaga et. al 2019).

From the above discussion, it is clear ‘lack of customer awareness about return’(C), ‘less policies addressing e-waste problem’ (B), ‘lack of long-term planning (A) and ‘insensitiveness of public towards environmental issues’ (D) will all play a significant role in successful implementation of e-waste management; thus, these barriers will have a significant impact on other barriers. Researchers and business professionals have acknowledged the additional cause and effect correlations mentioned here in various studies (Boyden et al., 2016; Park & Kremer, 2017; Zarte et al., 2018).

It is evident form Table 8 that there are six influential barriers that lie in the causal group as obtained from F-DEMATEL. After applying the F-ISM method, it can be concluded that out of nine barriers, four barriers are common. The macro technique is used in the F-ISM method, whereas the micro approach is used in the F-

DEMATEL method. Further, it is observed that the outcomes of both integrated MCDM approaches for the four barriers are most influence e-waste management implementation.

The goal of this study is to examine into the numerous barriers that come up when implementing e-waste management. Few studies have been established on e-waste management barriers, and no study has been done to establish a structured relationship between the barriers for e-waste management in fuzzy environment with integrated MCDM approach. F-ISM and F-DEMATEL analyses are also applied to examine the interrelation of these barriers. However, e-waste management is a critical matter that requires the decision- maker's full attention. Determining which barrier is the most/least essential in terms of sustainability-oriented barrier is difficult because each barrier has its value as a whole. In such circumstances, understanding both, contextual as well as the cause-and-effect relationships would prove to be beneficial. In this regard, it is advised that decision-makers analyze barriers in terms of their contextual and causal relationships. Subsequently, a hierarchical and cause-and-effect diagram is used for putting them in practice in a logical manner, which would aid in evaluating barriers for e-waste management. The findings of this study will have a significant impact on the acceptance of e-waste in underdeveloped nations. Because the discourse is concentrated on e-waste management, which is a major problem in many developing countries. The findings of this study will make a substantial contribution to the research on this. Governments may take these effects into consideration and make important policy changes to address these concerns.

The current work is significant since it is the first to integrate e-waste management for emerging economies in a new hierarchical cause-effect model, as well as because it focuses on cognitive barriers that yield environmental, social, and economic problems. The objectives outlined in the introduction part of this work are addressed in this study. Firstly, identifying the barriers for e-waste management in developing economy, yielded 15 barriers. Then these barriers are prioritized applying integrated F-DEMATEL and F-ISM methodologies, which establish interrelationships and provide details about the severity of interrelationships between identified barriers. Furthermore, barriers with comparable properties are clustered. Lastly, assess the interrelationships between the barriers that have been discovered.

4.2 Managerial implications

The findings in this research have significant management and practical consequences. First, the study provides a foundation for furthering our understanding of crucial characteristics that affect the sustainable e-waste management. Second, the findings provide decision-makers with a more attentive approach to segregating essential aspects to undertake e-waste management implementation and maximize their limited improvement resources. The barriers identified in this study can be used as a checklist to cover all of the probable critical barriers connected with the e-waste management. This will also help policymakers assess every component and its impact, allowing them to make strategic decisions to meet the requirements of long-term e-waste management. Barriers with lesser dependence power and higher driving power have a tactical orientation, whereas higher dependence power and lesser driving power barriers have a performance orientation. The fuzzy based proposed structural decision model aids in the discovery of causal relationships between distinct barriers. This can help policymakers focus on barriers by taking into account the causal effect of other barriers and offer ways to increase the efficiency of successful biodiesel sustainability development.

Table 8: The final output of F-DEMATEL

	D	R	D+R	D-R	Rank	Rank	Cause/Effect
A	3.6854	3.7933	7.4787	-0.1079	4	9	Effect
B	3.4673	3.7462	7.2135	-0.2788	7	11	Effect
C	3.0803	3.7753	6.8556	-0.6951	13	15	Effect
D	3.5285	4.0264	7.5549	-0.4979	2	14	Effect
E	3.4997	3.5674	7.0671	-0.0678	9	7	Effect
F	3.4673	3.7881	7.2554	-0.3207	6	13	Effect
G	3.5765	3.5015	7.0780	0.0750	8	6	Cause
H	3.7285	3.8448	7.5732	-0.1163	1	10	Effect
I	3.4627	3.5486	7.0112	-0.0859	10	8	Effect
J	3.5881	3.8924	7.4805	-0.3044	3	12	Effect
K	3.3966	3.2766	6.6732	0.1199	15	5	Cause
L	3.6071	3.1790	6.7861	0.4281	14	4	Cause
M	3.721643	3.277815	6.9995	0.4438	11	3	Cause
N	3.908681	3.352248	7.2609	0.5564	5	2	Cause
O	3.874776	3.023263	6.8980	0.8515	12	1	Cause

Table 9: M⁸ fuzzy multiplication matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	SUM	Rank
A	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
B	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
C	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
D	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
E	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0	9.8	2 nd
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	7	3 rd
G	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0	9.8	2 nd
H	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0	9.8	2 nd
I	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0	9.8	2 nd
J	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
K	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0	9.8	2 nd
L	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
M	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
N	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
O	0.9	0.9	0.7	0.9	0.7	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0	12	1 st
SUM	12.1	12.1	10.3	12.1	10.3	10.3	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	0		
Rank	1 st	1 st	2 nd	1 st	2 nd	2 nd	1 st	1 st	1 st	1 st	1 st	1 st	1 st	1 st			

In addition, the current study has various specific suggestions for decision-makers and policymakers in the implementation of e-waste management, as follows:

- Government policies and frameworks' importance: In defining long term successful e-waste management implementation within an economy, the government plays a critical role. Dealing with infrastructure (e.g., reliable energy) and political limits requires government backing and a regulatory framework.
- Distribution of resources and provision of funds: An organization must have the cash and resources to create a sustainability focus in e-waste management. To improve e-waste management sustainability,

- 399 policymakers must ensure that more money and resources are available to embrace current technology,
 400 equipment, instruments and new machines.
- 401 • Formation of an effective information technology network: Information that is effectively shared and
 402 disseminated promptly can significantly reduce used e- waste. Policymakers are also encouraged to
 403 employ *Global Positioning System (GPS)* technology to reduce used e-waste and increase efficiency.

Fig. 3: Cause-effect diagr

Fig. 4: F-MICMAC diagram

- 408 • Public policies: Policymakers should strive to manner education and training events in order to improve
 409 people's knowledge and awareness. This will help people rethink their minds about implementation of e-
 410 waste management.

5. Conclusions, limits, and future research possibilities:

In developing economies, such as India's large cities, e-waste management is currently one of the most difficult challenges. In order to comply with global environmental regulations, e-waste management is in high demand. As a result, we identified twelve significant barriers that needed to be assessed; these barriers were assessed using F-DEMATEL methodologies to frame long-term flexible decision-making strategies. The development of value functions is the proposed methodology for solving MCDM challenges. Because of the aforementioned causes, it

is evident that the current study aims to overcome these barriers. As a result, for successful e-waste management implementation, this study applied an integrated F-DEMATEL and F-ISM-based approach to a real-world MCDM problems.

The implementation of e-waste management is exceedingly complex, with an inter structure. According to the findings of the study, the most causal and influential barriers in integrated F-DEMATEL and F-ISM methods are "lack of customer awareness about return," "less policies addressing e-waste problem," "lack of long-term planning," and "insensitiveness of public towards environmental issues." As a result, a greater emphasis on the successful implementation of e-waste management in developing economies is required. The establishment of a cause or prominent group barriers is essential, as these have the ability to influence the entire structure.

Furthermore, the results obtained from this research are important for the e-waste management system in developing countries with similar circumstances. Given the relevance of these findings, the current research has few limitations also. The F-DEMATEL and F-ISM methodologies have been established as an interrelationship approach with only 15 barriers to e-waste management implementation in the context of the present study. Furthermore, by introducing and comparing hybrid fuzzy grey model and type-2 fuzzy sets concept into the framework, the study may examine more barriers and statistically validate this model.

Declarations:

The authors certify that the submission is original work and is not under review at any other publication.

Ethical Approval - Not applicable.

Consent to Participate - Informed consent was obtained from all individual participants included in the study.

Consent to Publish - The authors declare that there is no conflict of interest. All the co-authors have seen and agree with the contents of the manuscript and give their consent to publish.

Authors Contributions - Study conception and design: KP;

Data collection: JJ;

Analysis and interpretation of results: JJ, KP, DP;

Draft manuscript preparation: JJ, KP.

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