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Modelling the Barriers to Circular Economy Practices in the Indian State of Tamil Nadu in Managing E-Wastes to Achieve Green Environment

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Abstract: Owing to a heightened necessity, the consumption rate of electronic items has increased exponentially in recent decades, resulting in huge quantities of electronic waste (e-waste). Though increasing e-waste has many adverse impacts, it also provides an ample opportunity of recover value from the waste through circular economy (CE) practices. However, the adoption to CE practices is jeopardised by myriad barriers. This paper wishes to identify and evaluate the barriers that hamper CE practices in e-waste management. First, 30 barriers to the adoption of CE practices in India e-waste management are identified by reviewing the existing literature and conformed using experts' inputs. Furthermore, based on the experts' opinion, the thirty barriers are categorised into social, economic, and environmental categories. An integrated multi-criteria decision-making (MCDM) framework of fuzzy decision-making trial and evaluation laboratories (FDEMATEL) and fuzzy analytic network processes (FANP) is employed to understand the causal interrelationship and also to rank the barriers. Uncertainty about the profitability of the circular economy (E9), insufficient market demand (E6), lack of successful circular business model (E5), shortage of high-quality recycling materials (E4), and lack of adequate technology (EN6) have been identified as the top five barriers to the incorporation of CE practice in e-waste management. Out of these 30 barriers, 12 come under the cause group and 18 come under the effect group. Understanding the causal interrelationship and prioritization of barriers provide better insight into the barriers. This study offers some managerial implications that could assist industrial practitioners and policymakers.

Keywords: circular economy; e-waste management; FDEMATEL; FANP; barriers

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1. Introduction

Reasons such as necessity and cheaper prices, coupled with technological innovations, have increased the consumption of electronic items. However, the shorter lifetime and introductions of new products into the market at a low price make the existing electronic products obsolete quickly and are discarded as waste. Such an unprecedented quantity of electrical and electronic equipment waste is collectively termed, e-waste, and it has turned out to be a major concern for the global community as it possesses a severe risk to humans and the environment [1]. E-waste is a rapidly expanding waste stream with an annual growth rate of 3–5% and is expected to increase by 2045 [2,3]. According to the Global E-waste Monitor 2017 report, at present, approximately 50 million tonnes of e-waste is generated annually, and from this, only 20% is formally recycled. Currently, "take-make-use-disposal" methods, i.e., the linear economy, are practiced world-wide, yet are also more unsustainable. Although the menace of e-waste is a global issue, developing nations are affected badly, owing to the illegal export/import of e-waste from developed nations [4]. India, a highly populated country with illegal imports, is facing the adverse impacts of e-waste.

Being a highly populated country, leading electronic companies are seeing India as an opportunity for market expansion [5]. A study [6] highlights that India annually produces 2 million metric tonnes of e-waste. These numbers are expected to increase in the coming years, and presently, India is ranked fifth in the e-waste generation. Many developed nations are viewing India as an e-waste dump yard for reasons such as cheap labour [7]. Imported e-waste and domestic e-waste makes e-waste management a critical problem for India. Furthermore, nearly 95% of the e-waste in India is handled and recycled by informal sectors by following unrecognised recovery activities [8]. Though the informal sector is illegal, it is generally considered a source of employment opportunity for semi-skilled and economically marginalised people. As a result, informal sectors are continuously booming and remain a challenge for India in e-waste management. Compared to formal sectors, the informal sectors are easily accessible to the common people, and hence, most of the discarded e-waste reaches informal sectors than formal sectors [9].

Because of a continuous insistence on the possibility of recovering value from e-waste, the incorporation of circular economy (CE) practices has received wide attention. CE practice is a model that intends to maximise the usefulness of discarded materials by keeping them in the economic cycle [5]. Furthermore, CE practice may reduce the demand for raw materials while improving job opportunities. Thus, CE practice will assist in bringing sustainability to recycling business activities. Hence, CE practice has become a niche topic among academicians and research communities. Murthy and Ramakrishna (2022) [10] advocate that despite various environmental legislations, informal practices such as open incineration and dumping by informal sectors question the efficiency of CE practice. Xavier et al. (2021) [11] view CE practice as an extension of urban mining, where the e-waste can be upcycled, and value recovery from the e-waste can be achieved. In the study by Koshta et al. (2022) [12], the authors indicate that sharing economic responsibility among the various stakeholders involved in the manufacturing of electronics and electrical components will help in ensuring CE practice in e-waste management. Shahabuddin et al. (2022) [13] highlight that besides offering many benefits, the incorporation of CE practice in e-waste management remains a tedious task for reasons such as difficulty in sorting, heterogeneity, and the need for the technological infrastructure. It has also been indicated that developing nations which need CE practice in e-waste management are facing many challenges.

The existing literature on CE practice in e-waste management highlights the potential impacts while also cautioning against the challenges. Proper e-waste material collection, technological infrastructure, and skilled labours are some of the main challenges in the incorporation of CE practice in e-waste management. The necessity of CE practice in e-waste management is more compelling for developing nations than developed nations. However, developing nations are faced with many challenges. India, one of the leading generators of e-waste, needs to adopt CE practices for effective e-waste management.

In this connection, this study pursues to identify and analyse the critical challenges to CE practice in e-waste management in the Indian scenario. Accordingly, the following research questions are hypothesised:

1. What are the barriers to the incorporation of CE procedures in e-waste management?
2. What is the relationship between various barriers to CE practice in e-waste management?
3. What are the most significant barriers to the incorporation of CE practices?

First, the challenges to CE practice in e-waste management in India are collected by reviewing the existing literature. Then, to confirm the challenges, interactions with the industrial experts engaged in e-waste management are made. By considering the experts' inputs, the challenges are finalised and evaluated using the integrated multi-criteria decision-making (MCDM) approach. Here, the decision-making trial and evaluation laboratory (DEMATEL), developed by Gabus and Fontela (1972) [14], has been employed to prioritise and reveal the causal interrelationship among the challenges. Likewise, analytic network process (ANP), introduced by Saaty (1980) [15], has been used to rank the challenges. Both DEMATEL and ANP techniques are used in fuzzy context to overcome the ambiguities and vagueness in the rating of the barriers.

The structure of the paper is as follows. Section 2 is a literature review. Section 3 describes the nature of the problem and application of the proposed methodology for the problem. Section 4 discusses the results obtained. Implications of the study are provided in Section 5. Finally, Section 6 summarises the study by highlighting the contributions, limitations, and suggesting the future scope of the study.

2. Literature Survey

2.1. E-Waste Management and Circular Economy

E-waste has become a worldwide problem for the past two decades, discharging approximately 50 MT of e-waste per year [16]. According to a report by the United National University, in 2019, out of 53.6 Mt of e-waste generated, only 17.4% was recycled, while 82.6% were discarded as waste in open landfills [17]. E-waste produced in developed nations are being shipped to developing nations for disposal [18]. Both the domestic and imported e-waste is handled mostly by the informal sectors. Primitive methods of e-waste recycling are often adopted by the informal sectors, which could create high environmental contamination by the release of many harmful materials [19]. According to [20], e-waste disposal mixed with household residual waste is the common e-waste recycling practice performed in developing countries. In this e-waste recycling practice, most of the e-waste, along with the household waste, is disposed in landfills or incinerated; hence, the chance of e-waste separation is very low. Furthermore, if left as such, it results in toxic leaching in the landfills and harmful gaseous emission if incinerated. Even after separation, the e-waste is cleaned using water and chemicals, which may release harmful chemicals into the environment without any treatment. Discharge of such harmful chemicals exposes humans to toxic elements such as lead, manganese, and zinc [21]. Therefore, the burden of e-waste doubles. Since developing nations account for more informal e-waste recycling facilities, these nations are facing more difficulties with e-waste. According to a study by [22], the informal recycling facility centres in India hold a lion's share of e-waste management.

On one hand, the piling up of e-waste has turned out to be a pressing issue for global nations, while on the other hand, the optimistic scientific community views e-waste as a secondary source of certain precious raw materials [23]. The scientific community urges the industrial community to transition from convenient linear production patterns to CE practices. The CE practices include keeping materials in the economic cycle for as long as possible by adopting various measures, such as reusing, repairing, refurbishing, and recycling existing materials. By CE practice, both the quantity of e-waste generated and the resources consumed are reduced. In a study, Sharma et al. (2020) [5] claim that the current increase in e-waste generation compels the industrial community to adopt CE practices. In a study, Pan et al. (2022) [1] acknowledge that following CE practices offers sustainable economic development, emphasising that CE practices are much needed in e-waste handling. Furthermore, the 10 Rs strategies for CE (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) have also been examined. Factors such as social, economic, and environmental factors have been found to influence the incorporation of CE practices in e-waste management.

2.2. Barriers to CE in E-Waste Management

Although CE practices render many benefits, its adoption is inhibited by many factors. One common factor that limits the incorporation of CE practice in any activity is the technological infrastructure. While developing nations are in the infant stage of CE practice, with essential technological infrastructure, developed nations are spearheading CE practices [24]. Consumers have become habitualised to live a use-and-throw lifestyle rather than a use-and-reuse mentality [2]. They prefer to buy a new product over products made of secondary raw materials from e-waste [25,26]. Since the success of any practice largely depends on societal reception, such a dismal response from society makes the industrial community rethink about the continuation of CE practices. The unavailability of an active sustainable take-back programme limits public participation in the e-waste management practice [10,27]. Taking advantage of the non-existence of a proper reverse supply chain for e-waste collection, many informal sectors ventured into the business of collecting discarded e-wastes directly from consumers. Thus, the informal sectors continue to boom, which remains a crucial problem. Challenges such as a lack of vision in the long run and a divergence of views between officials in the corporate office, hinders e-waste management practices [25]. Lack of capital and weak economic benefits make the setting up of e-waste management sites a tough process. Due to the uncertainty regarding the profitability and lack of successful CE business models, the stakeholders are reluctant to invest [28]. Non-availability of high-quality recycling materials poses the biggest challenge to implementing CE in e-waste management [29]. Stakeholders are also reluctant to invest since virgin materials cost lower than the secondary raw materials obtained from e-wastes [30]. Most e-waste management sites are facing space inadequacy due to the high volume of e-waste produced [31]. The barriers are collected by conducting a literature review and survey from experts in the segment of e-waste management. Thorough literature reviews uncovered 30 important barriers, which are briefly explained and given in Table 1.

Table 1. Barriers to the incorporation of CE practices in e-waste management.

Barrier	Description	Reference(s)
Consumer habits	Brining change in the consumers preference remains a difficult task.	[2,32,33]
Divergence of views	Stakeholders involved in e-waste management have different views.	[25]
Problem in finding qualified personnel and expertise	People are less skilled in terms of e-waste management.	[34]
Lack of societal participation	Lack of participation on proper sorting and returning e-waste reduces the efficiency of e-waste management.	[35,36]
Involvement of informal recyclers	Informal sectors are well-established in comparison with formal sectors.	[23,35]
Lack of collaborative efforts	Consensus among the stakeholders involved is very critical.	[37]
Buy-new mentality	People are choosing new instead of recycled products.	[26]
Lack of vision	Stakeholders with short-term goals find it hard to continue CE practices.	[24]
Unsustainable take-back programmes	Most of the take-back programmes initiated have not been carried out in the long run.	[10,27]
Lack of supply chain integration	Transitioning to CE will require redesigning the existing supply chain model.	[38,39]
Lack of capital	Changing from a linear to CE necessitates significant upfront investment in practically all value chain operations.	[40]
Slow rate of return	Industrial community expects quick rate of return which is not possible in CE practice.	[39]
Short-term goals	As the rate of return in CE practices takes time, stakeholders are reluctant towards embracing CE practices.	[41]
Shortage of high-quality recycling materials	Inability to produce high-quality goods from recycled materials poses a great recycling challenge.	[29]
Less availability of successful circular business models	There are not many successful circular models.	[30,34]
Insufficient market demand	The market demand for green products is insufficient due to their higher processing and production costs.	[42]
Weak economic incentives	Incentives are less and this does not motivate them to support CE.	[23]
Uncertainty about the profitability of circular business	Since there is a much less successful circular business model, there is uncertainty in the profitability in the long run.	[28]

Table 1. *Cont.*

Barrier	Description	Reference(s)
Illegal shipment of e-waste	Due to weak government policies, the informal sector conducts illegal shipments of e-waste to and from the country.	[24]
Ineffective environmental laws and industrial regulations	Existing environmental norms and industrial regulations are insufficient to enforce CE practice for industrial community.	[21]
Environmental contamination	E-waste management in developing nations has sparked global concern because of the primitive techniques that cause environmental pollution.	[21]
Human health consequences	Following primitive approaches in e-waste handling has serious health impacts on humans.	[38]
Unfriendly disposal methods	Until now, huge quantities of e-waste is incinerated by the informal sectors.	[39]
Low reuse value	The value of goods recovered from the waste stream is frequently low or non-existent.	
Absence of awareness programme	Sufficient awareness initiatives have not been taken by government and private sectors	[41]
Lack of adequate technology	As the facilities required for CE practices are costly, most recycling facilities are reluctant to adopt it.	[43]
Lack of environmental education	Society is not sufficiently educated regarding sustainable development and significance of CE practices.	[44]
Logistical barriers	Reverse logistics is not well-established	[31]
Lack of space	Since most of the informal sectors engaged in e-waste management are micro-level industries, they are facing space shortage	[38]
Low prices of many virgin materials	Raw materials cost very less than the ones that are recycled and hence it is not economical to use recycled materials and these are disposed of instead of recycling.	[30]

3. Problem Description and Methodology

E-waste contains substances that are toxic to the environment and human health. On a positive note, this e-waste can also be viewed as a huge source of secondary raw materials. Many studies state that more than 95% of e-waste is dealt with by the informal sector and is finally disposed of in open dump yards [22,43]. The improper treatment of e-waste by the informal sector leads to a loss of non-renewable resources and increased carbon footprint [21]. Annually, around 50 MT of e-waste is created around the world, most of which end up in developing nations located in the Asian continent through illegal shipments [16,18]. These shipped e-wastes are handled by the informal sector using primitive methods that often pollute the surrounding area. To overcome these problems and achieve sustainability, new methods such as CE are needed. Implementing CE has a lot of barriers in today's world [24]. The Ministry of Electronics and Information Technology (MeitY), Government of India encourages CE to aim for zero to minimal wastage in the use of electronics and within the electrical sector and has formulated a policy paper that deals with these issues. The percentage of extraction of raw materials from the e-waste for manufacturing electrical products is much higher than the rate of extraction from natural resources. Hence, CE approach will be beneficial to a large extent. CE practices will greatly enhance the efficiency of the electrical and electronics industry by reducing resource consumption and waste generation, thus providing a great stimulus for sustainable development via 'Make in India' policy [45]. This paper intends to find the most influential barriers to incorporating CE in the e-waste sector by gathering the most critical barriers from the existing literature and expert opinions.

In general, a problem turns out to be difficult if it is influenced by numerous factors. Under such a situation, the MCDM techniques become handy and have offered many benefits. MCDM techniques have been used in solving or analysing many real-time problems. For instance, to evaluate factors that induce occupational accidents in leather garments, Karuppiah et al. (2020) [46] utilised an integrated DEMATEL-ANP approach.

MCDM techniques have also been used in problems related to e-waste management. For instance, Jangre et al. (2022) [47] used fuzzy DEMATEL (FDEMATEL) and fuzzy interpretive structural modeling (FISM) to establish the relationship between the barriers to e-waste management from a developing nation's background. Likewise, in a study by Keshavarz-Ghorabaee et al. (2022) [37], the authors used fuzzy simultaneous evaluation of criteria and alternatives (SECA) to analyse the different e-waste management practices. Jain et al. (2022) [38] employed the best worst method (BWM) to examine the robustness of the reverse supply chain in e-waste management. From this, it is clear that MCDM techniques are suitable for analysing the problems related to e-waste management.

Here, integrated FDEMATEL and fuzzy ANP (FANP) methods are employed over the collected barriers and the most influential barriers are ranked. The potentiality of using the integrated FDEMATEL and FANP lies in the fact that, with this combination, the interrelationship among the barriers to the incorporation of CE practices in e-waste management can be revealed, and the barriers can be ranked on the basis of weightage. The limitation of the integrated method is that only the causal relationship can be understood; however, it is equally important to understand structural relationship. This method is more suitable for a case study as it allows the respondents to rate the barriers with a linguistic scale. The framework of the paper is illustrated in Figure 1.

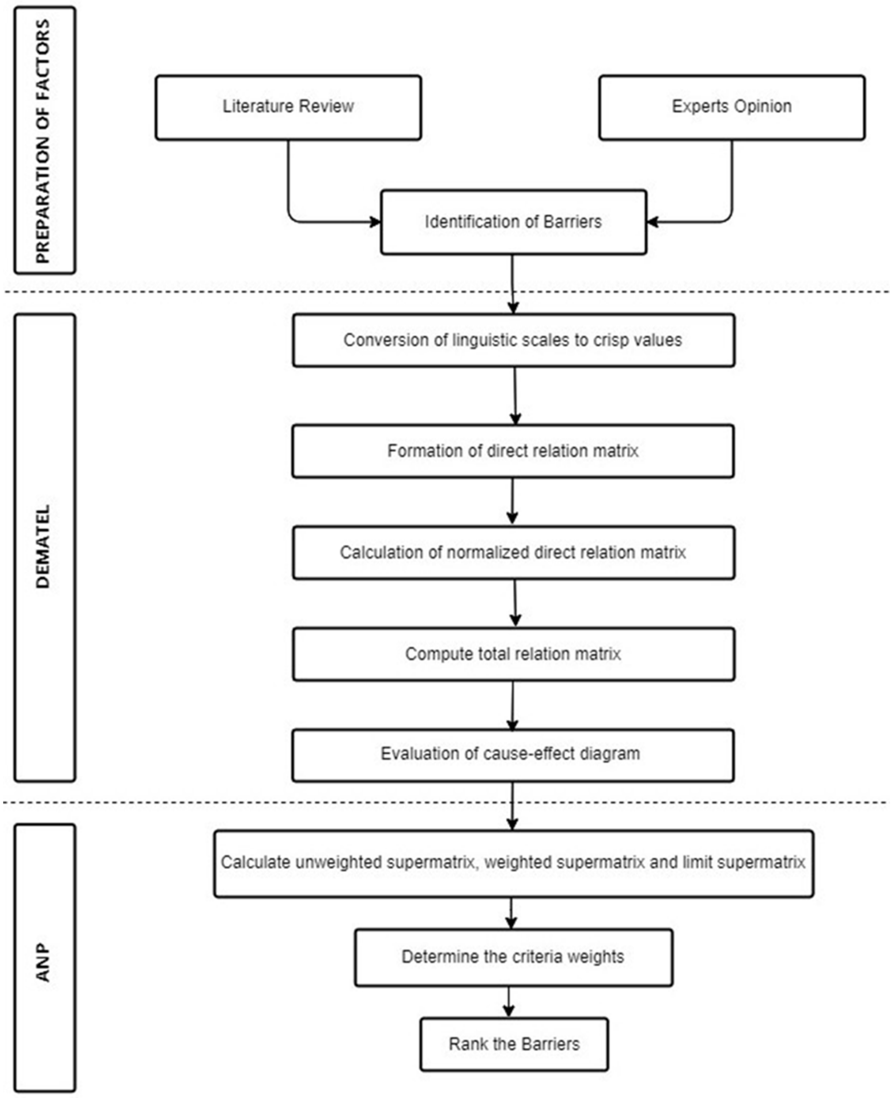

Figure 1. Research Framework.

3.1. Preparation of Factors

The paper first defines the research problem, based on which the research questions are framed. To begin with, first, the critical barriers to CE implementation in the e-waste were identified by reviewing the existing literature. Here, the barriers from the earlier literature were selected based on the frequency of mentions. However, to assess the conformity of the barriers in real case scenarios, experts with sufficient knowledge on e-waste management and CE practice were approached. On a five-point Likert scale, a questionnaire was made with the collected barriers, and experts were requested to rate them. From the experts' response, it has been found that the barriers collected from the existing literature is relevant, and hence, the barriers are considered for further evaluation.

3.2. Evaluation of Factors

After confirmation, the collected barriers are evaluated using an integrated MCDM method comprising FDEMATEL and FANP. Using FDEMATEL, the causal interrelationship among the barriers is explored. FANP helps in the integration of statistical data and experts' opinions about various barriers. The steps followed in the integrated MCDM method are given below [48].

3.2.1. Establishing Causal Interrelationship

Step 1: Pair-wise comparison is performed to obtain an initial fuzzy direct-relationship matrix (K). The matrix K consisting of $n \times n$ factors is set up and each element is represented as $a_{ij} = (l_{ij}, m_{ij}, n_{ij})$ which is used to represent the degree of influence of factor i over factor j for experts. Pair-wise comparisons are used depending on the influence of one barrier over another barrier.

Step 2: Using Equation (1), the fuzzy numbers are defuzzified to get crisp values.

$$u_{ij} = \frac{l_{ij} + m_{ij} + n_{ij}}{3} \tag{1}$$

Step 3: The defuzzified direct-relationship matrix K determined in the previous step is transformed to a normalised direct-relationship matrix X using Equation (2).

$$X = s \times K \tag{2}$$

where s is obtained using Equation (3).

$$s = \frac{1}{\max\sum_{i}^{n} u_{ij}} \tag{3}$$

Step 4: The total-relation matrix (T) is obtained using Equation (4).

$$T = X(I - X)^{-1} \tag{4}$$

where T = total relation matrix; X = normal matrix; I = identity matrix.

Step 5: The summation of rows and columns, referred as R and C in the total-relation matrix (T) is determined using Equations (5)–(7).

$$T = t_{ij}, i, j = 1, 2, \ldots, n \tag{5}$$

where T = total-relation matrix; t_{ij} = elements of the total-relation matrix.

$$R = \sum_{i=1}^{n} t_{ij} \tag{6}$$

where R = summation of rows.

$$C = \sum_{i=1}^{n} t_{ji} \tag{7}$$

where C = sum of columns.

Step 6: A cause-effect diagram is set up from the data.

3.2.2. Ranking of Barriers

Step 1: The unweighted supermatrix 'W' is calculated using Equation (8).

$$W = T.w \tag{8}$$

Step 2: The weighted supermatrix 'W^{α}' is calculated.

$$W^{\alpha} = T^{\alpha} \times W \tag{9}$$

where W^{α}—normalisedtotal-influence matrix.

Step 3: The weighted supermatrix is limited. To obtain a stable supermatrix, the power of the weighted supermatrix is raised to a certain power $\lim_{h\to\infty} (W^{\alpha})^{h}$ where h represents any number of powers.

Step 4: The limit supermatrix is normalised and the column sum is calculated using Equation (10) to determine the weights.

$$C = \sum_{i=1}^{n} t_{ij} \tag{10}$$

where C = the summation of columns; t_{ij} = elements of the total-relation matrix.

Step 5: Rank the preference order.

3.3. Application of the Integrated MCDM Approach in Evaluating the Barriers to CE Practice in E-Waste Management

The finalised barriers are circulated among the experts and were asked to categorise them based on the related areas. As a result, the 30 barriers are classified under three categories as shown in Table 2. Furthermore, the barriers are coded with notations.

Table 2. Classification of barriers.

Barrier	Description
Social Barriers	Consumer habits (S1) Divergence of views (S2) A problem in finding qualified personnel and expertise (S3) Lack of societal participation (S4) Involvement of informal recyclers (S5) Lack of collaborative efforts (S6) Buy-new mentality (S7) Lack of vision (S8) Unsustainable take back programmes (S9) Lack of supply chain integration (S10)
Economic Barriers	Lack of capital (E1) The slow rate of return (E2) Short-term goals (E3) Shortage of high-quality recycling materials (E4) Lack of successful circular business models (E5) Insufficient market demand (E6) Weak economic incentives (E7) Uncertainty about profitability of circular business (E8) Illegal shipments of e-waste (E9) Ineffective environmental laws and industrial regulations (E10)

Table 2. *Cont.*

Barrier	Description
Environmental Barriers	Environmental contamination (EN1) Human health consequences (EN2) Unfriendly disposal methods (EN3) Low reuse value (EN4) Absence of awareness programme (EN5) Lack of adequate technology (EN6) Lack of environmental education (EN7) Logistical barriers (EN8) Lack of space (EN9) Low prices of many virgin materials (EN10)

Then, the barriers are evaluated using the steps mentioned in the proposed methodology. The steps are explained as follows:

Establish Initial Direct Relation Matrix 'K'

The experts were sought to rate the selected barriers and the categories of barriers to the incorporation of CE in e-waste management through a questionnaire using the fuzzy five-point scale as shown in Table 3. Both the questionnaire surveys were carried out simultaneously. A fuzzy five-point scale is used to enable rapid and precise evaluation of barriers and categories. From the expert's responses, the initial direct relation matrix was set up for the barriers and the categories.

Table 3. Barriers to the incorporation of CE practices in e-waste management.

Linguistic Terms	Five-Point Scale	Corresponding Triangular Fuzzy Numbers (TFNs)
No influence	0	(0, 0, 0.25)
Low influence	1	(0, 0.25, 0.5)
Medium influence	2	(0.25, 0.5, 0.75)
High influence	3	(0.5, 0.75, 1)
Very high influence	4	(0.75, 1, 1)

Using Equation (1), TFNs are defuzzified to obtain the crisp value. Then, the normalised direct relation matrix is established using Equation (2). Total relation matrix 'T' is established through Equation (4). Summation of rows and columns is calculated using Equations (6) and (7), as shown in Table 4. The summation of rows and columns are marked as R_i and C_i, respectively. Finally, a cause-effect diagram is constructed (Figure 2). From Figure 2, the causal interrelationship among the barriers can be understood.

An unweighted supermatrix 'W' is constructed using Equation (8). A weighted supermatrix W^{α} is constructed using Equation (9). Weighted supermatrix is limited and normalised. Column sum is calculated to find the weights and is ranked in descending order. Table 4 shows the barriers and their corresponding ranks.

Table 4. Summation of rows and columns of barriers.

	R	*C*	*R* + *C*	Rank	*R* − *C*	Cause/Effect
S1	2.198	1.4715	3.6700	21	0.7268	Cause
S2	0.6248	1.2040	1.8288	25	−0.5792	Effect
S3	1.3628	0.7645	2.1274	17	0.5982	Cause
S4	1.0376	1.2229	2.2606	18	−0.1853	Effect
S5	0.7581	1.3399	2.0980	16	−0.5817	Effect
S6	1.3469	1.8766	3.2236	26	−0.5297	Effect
S7	1.2878	1.3903	2.6781	13	−0.1024	Effect
S8	1.7575	1.1371	2.8946	24	0.6203	Cause
S9	1.2961	1.5468	2.8429	23	−0.2506	Effect
S10	1.0277	1.4607	2.4885	29	−0.4329	Effect
E1	1.0809	1.0998	2.1807	8	−0.0189	Effect
E2	1.4673	1.0328	2.5002	11	0.4344	Cause
E3	0.6794	1.0781	1.7576	14	−0.3986	Effect
E4	1.7893	0.7424	2.5318	4	1.0469	Cause
E5	0.9176	2.2461	3.1637	3	−1.3284	Effect
E6	1.6989	1.2805	2.9795	2	0.4183	Cause
E7	1.1997	1.4156	2.6154	9	−0.2159	Effect
E8	1.0997	1.5211	2.6208	1	−0.4214	Effect
E9	1.0562	1.1051	2.1613	10	−0.0488	Effect
E10	1.8830	0.5667	2.4498	6	1.3162	Cause
EN1	0.4705	1.4115	1.8821	28	−0.9409	Effect
EN2	0.4204	1.5762	1.9966	30	−1.1557	Effect
EN3	0.5564	1.4088	1.9653	27	−0.8524	Effect
EN4	1.2983	0.5939	1.8923	22	0.7044	Cause
EN5	1.5165	0.6754	2.1919	19	0.8410	Cause
EN6	1.3111	0.6697	1.9808	5	0.6413	Cause
EN7	1.7199	0.7444	2.4644	12	0.9754	Cause
EN8	0.4927	0.8589	1.3516	7	−0.3661	Effect
EN9	0.4455	0.7116	1.1572	15	−0.2660	Effect
EN10	0.7757	0.4237	1.1995	20	0.3519	Cause

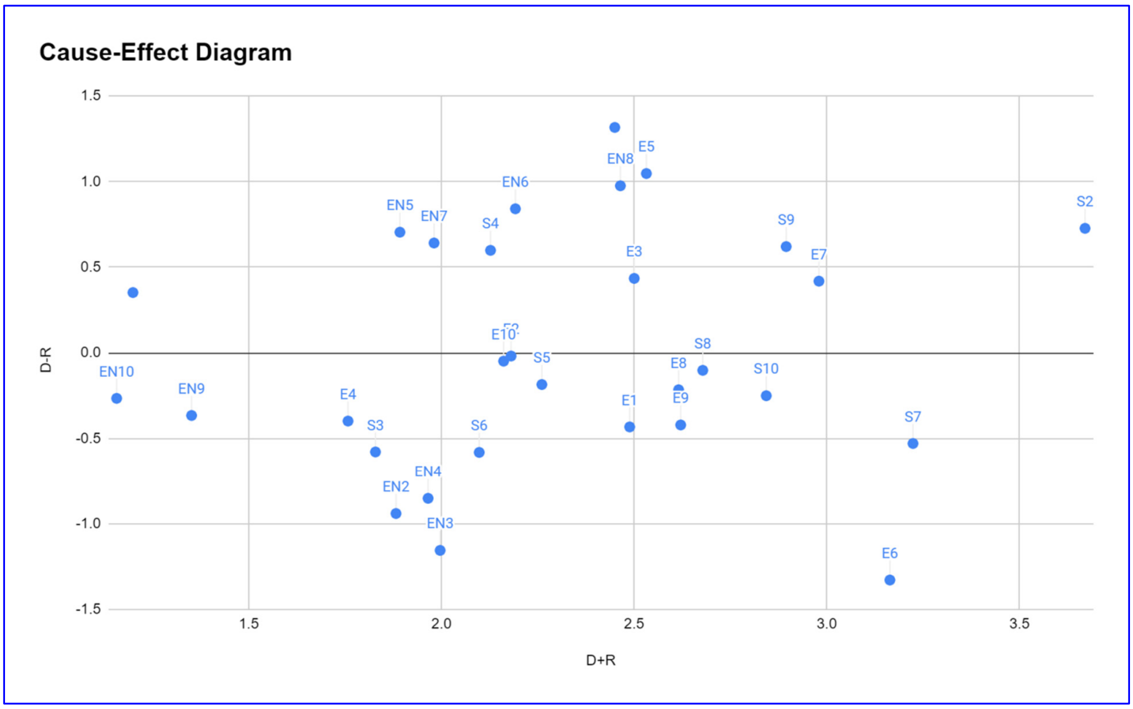

Figure 2. Cause-effect diagram.

4. Results and Discussion

Here, first, the barriers that come under the cause category are discussed as they are capable of influencing other barriers. From Table 4, it is understood that uncertainty about the profitability of the circular business (E8) is the most significant barrier to the incorporation of the CE model in e-waste management. This result clearly indicates that the industry's preference for the CE model is mainly influenced by the rate of return. As society is still not completely aware of the significance and necessity of the CE model, most of the e-waste is being discarded as waste into landfills. A study by Borthakur (2022) [8], analysing the industrial community's willingness to transition towards the CE model, indicates financial success as the crucial deciding factor. As the industries are going to invest huge capital amounts in the CE model, it is obvious that the industries are concerned about the rate of return. Hence, inclusive awareness in society regarding the CE model may help the industrial community in pursuing the CE model. The next important barrier is insufficient market demand (E6). This is one of the critical barriers that needs to be advocated for in the short run. Only the market demand for a specific product may propel the industrial community to invest more in the development of the specific product. Since the products developed using the CE model are not well received by society, the interest in CE model incorporation is reducing among the industrial sectors. Insufficient market demand may result in economic loss. This finding was supported by Karuppiah et al. (2021) [23] in a study where market demand is indicated as a prominent key performance indicator for the success of CE model practice.

The lack of successful circular business models (E5) is the third important barrier. Since the definition of the CE business model is unclear and lacks a concrete definition, there exists a problem in developing a proper globally recognised CE business model. Industries interested in the adoption of CE models are developing their own business models and, to some extent, they have witnessed some success. However, there are also some drawbacks. This finding was supported by Jain et al. (2022) [38] in a study where it has been indicated that, due to the non-existence of a universal CE business model, industrial communities are following their own CE practice models, resulting in unsustainable industrial practice. A shortage in high-quality recycling materials (E4) is another important barrier in the CE business model. For successful CE practice, sufficient quantity and quality waste materials are required. However, as reverse supply chain management is not well-established, the industrial community is facing difficulty in receiving an adequate quantity of e-waste materials with benchmark quality. The intervention of informal sectors has created a ripple effect in e-waste recycling and management [21]. By following unrecognised recycling activities, the informal sectors are leaving adverse environmental impacts. The fifth important barrier is the lack of adequate technology (EN6). The technological infrastructure needed for retrieving the value from the e-waste is quite expensive. Further, numerous activities are involved in recovering valuable material from e-waste. Hence, huge capital and technical assistance are needed for the proper deployment of the CE business model in e-waste management. Being expensive, the technological infrastructure needed for the CE business model is not affordable for many industries (Karuppiah et al. (2020) [47].

Next, the top five effect barriers are discussed. These barriers are influenced by the cause barriers. Buy-new mentality (S7) is the top most barrier in the effect category. There has been a conviction in society that the products developed through CE practice are inferior in quality to the products developed using virgin raw materials [43]. Such a conviction pressurises the customers to prefer new products rather than preferring products developed using recycled materials. As a result, the products introduced into the market, which have been developed through CE practice, remains in inventory. Next, short-term goals (E3) are another important barrier in CE practice in e-waste management. To relish the benefits of CE practice, reaching a consensus among the various stakeholders involved is very critical. Since, in CE practice, it takes some time to acquire profit over the rate of investment, many stakeholders involved are mainly focused on short-term goals rather than long-term sustainable development. As a result, due to a lack of commitment from the stakeholders involved, the transition towards the CE business model remains a difficult task [12]. Lack of space (EN9) is another barrier in CE practice in e-waste management. In e-waste recycling and management, a series of activities (collection, sorting, washing, resizing, and compounding) are carried out. For carrying out these activities seamlessly, adequate space is needed. Most of the companies engaged in e-waste management are operating in minimal space [9]. As a result, these companies are struggling to recover value from the e-waste.

The involvement of informal recyclers (S5) is one of the crucial barriers to CE practice in e-waste management. Compared to the formal recycling sectors, the informal recycling sectors are well-established and well-connected. In most cases, the informal sectors are in direct contact with society. In addition to that, the rag-pickers are also contacting the informal sectors in comparison to formal sectors [38]. Hence, the informal sectors involved in e-waste management are booming in numbers in comparison with formal sectors. The fifth important barrier is a difficulty in finding qualified personnel and expertise (S3). The knowledge and awareness regarding the need for CE practice is still in the budding stage in India. Furthermore, sufficient training and education on CE practice have not been provided, resulting in an insufficiency of skilled expertise in CE practice. Owing to a shortage of skilled personnel, the CE practice in the industrial community is being carried out by semi-skilled technicians [13]. This results in adverse environmental impacts.

5. Implications of Study

The outcomes of the study offer significant contributions to the literature on CE practice and e-waste management. First, the study summarises a list of barriers to the incorporation of CE practice in e-waste management. The provision of a list of barriers may help industrial practitioners who are entering e-waste management for the first time. By knowing the barriers, some proactive steps may be taken by the concerned industrial management. Thus, this study offers both theoretical and managerial implications. Next, an integrated MCDM approach comprising fuzzy DEMATEL and ANP has been employed. To the best of the knowledge of the authors, such kind of integration has not been previously used. Understanding the causal interrelationship and prioritization may provide better insights into the barriers.

Uncertainty about the profitability of the circular business (E8) has been identified as the top most crucial barrier. It is well known that most industrial sectors are mainly concerned with profit. However, these industrial sectors must also be advised to be concerned for the environment. Regarding this, the government has to regularly monitor the environmental performance of the industrial sectors. Furthermore, the certification for the industrial community must be issued based on environmental performance. Lack of awareness about the CE practice and the need for environmental conservation has resulted in insufficient market demand (E6). As mentioned in much earlier research works [17,24], the understanding and implementation of CE practice by developing nations are still in the infant stage. Hence, awareness regarding CE practice is also modest in developing nations. Therefore, in India, products developed through CE practice has failed to receive good reception. Here, the government can play a moderating role in awareness rising within society. Apart from raising awareness, it is also critical to arrive at a concrete definition for CE practice. Despite two decades from its inception, a clear and global consensus definition for CE practice has not been framed. This has resulted in a lack of successful circular business models (E5). The absence of successful circular business models limits the industrial community's preference for CE practice. Thus, it is the responsibility of the global bodies to frame a definition and conceptualise the CE business model. One essential matter that needs to be executed is the establishment of a robust and reliable reverse supply chain network for collecting discarded e-waste. Industries following CE practice are currently faced with a shortage of an adequate quantity of e-waste materials. Earlier studies [1,10] indicate that only a small portion of discarded e-waste is recycled, while the remaining e-waste is dumped in landfills. To sort out this issue, the closed-loop supply chain network for collecting e-waste has to be established.

6. Conclusions and Future Work

E-waste has turned out to be an imminent threat to global nations. Compared with developed nations, the problem related to e-waste has become multi-folded for developing nations. Bearing this in mind, this study focuses on collecting and analysing the barriers to the incorporation of CE practice in e-waste management from an Indian backdrop. Uncertainty about the profitability of the circular economy (E9), insufficient market demand (E6), lack of successful circular business models (E5), shortage of high-quality recycling materials (E4), and lack of adequate technology (EN6) has been identified as the top five barriers to the adoption of CE practice in e-waste management. From the results, it has been understood that the incorporation of CE practice in e-waste management in India is still in an infant stage. Hence, the formal sectors engaged in e-waste management are also facing several challenges. Next, it has been identified that the societal awareness regarding e-waste management is low in India. Most of the public are discarding e-waste in landfills and are not returning it back to an e-waste management plant.

This study offers some notable contributions to the literature on CE practice and also on e-waste management. First, this study sheds light on the significance of incorporating CE practice in e-waste management. Second, the current e-waste management scenario in India has been better discussed. Third, using an integrated MCDM approach, the causal interrelationship among the barriers is revealed and also prioritised. Such information can assist industrial management in taking effective steps to overcome the barriers to incorporating CE practice in e-waste management. Apart from contributing significantly to the literature, this work also has some limitations. In this study, only the causal interrelationship among the barriers has been explored. To exhibit the structural relationship, the same barriers have to be analysed using structural equation modelling (SEM) technique. Furthermore, only India has been taken as a case nation. Hence, the outcome of this study is not applicable to all developing nations. This is because the difference in the socio-economic conditions of other countries may influence the study and yield different results. Therefore, case studies from multiple developing nations need to be carried out. Moreover, a life cycle assessment (LCA) can be done on e-waste in India.

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