

# **Analyzing Drivers of E-waste Management to Achieve Sustainability: Implications for a Developing Country**

**Md. Zahidul Anam and Md. Tanvir Siraj**

Department of Industrial and Production Engineering  
Bangladesh University of Engineering and Technology  
Dhaka 1000, Bangladesh.  
zahidulmahedi@gmail.com, tanvir25392@gmail.com

**Spandan Basak Payel**

Department of Mechanical Engineering  
Bangladesh University of Engineering and Technology  
Dhaka 1000, Bangladesh.  
spandanbasak@gmail.com

## **Abstract**

Electronic waste (E-waste) generation is increasing throughout the world with the flourishing dependence on electronic goods in a digitalized world, thus creating an adverse impact on social and environmental sustainability. Managing such a huge amount of waste from electronic products is an emerging challenge to the global community, especially in a densely populated developing country like Bangladesh. Research on exploring the drivers of e-waste management in Bangladesh can greatly help developing countries overcome this challenge. Several studies have been conducted to discover the drivers and challenges of managing e-waste. However, in the context of developing countries, none of the earlier studies have presented the ranking of the drivers based on their prominence and explored the causal relationships among them. Therefore, this study applies the fuzzy decision-making trial, and evaluation laboratory (F-DEMATEL) method to find the prominence and examine the cause-effect relations among the drivers of e-waste management in a developing country. Fourteen drivers were accumulated from reviewing literature and expert feedback, which were then analyzed by the F-DEMATEL. The findings revealed that 'E-waste management policy', 'Digitalization', and 'Awareness towards e-waste management' are the three most prominent drivers of e-waste management. The derived cause-effect relations among the drivers show 'Awareness towards e-waste management' to be the most causative and 'Implementing Circular Economy' to be the least causative driver. The outcomes of this study are expected to help developing nations in implementing effective e-waste management to achieve social, environmental, and economic sustainability, thus achieving sustainable development goals (SDGs).

## **Keywords**

E-waste management, Drivers, Developing countries, Fuzzy DEMATEL and Sustainable Development Goals.

## **1. Introduction**

Wide-spreading technological development as a part of the fourth industrial revolution (Industry 4.0) is mobilizing the world towards enormous dependency on electronic devices. This often creates the opportunity to have a more dynamic lifestyle in comparison to the past era. However, waste generation from electronic products consequently has increased which hinders sustainable growth by degrading social, environmental, and economical achievements (Ananno et al. 2021). Most developed countries are managing e-waste by setting up proper facilities, but developing countries are lagging due to economic, infrastructural, and various other constraints (Thakur and Kumar 2021). Therefore, researchers and policymakers need to emphasize studies specifically in the context of developing countries to attain global sustainability by managing toxic solid waste generated from electronic products.

E-waste is considered very harmful to the environment as it contains several hazardous chemicals like lead, mercury, cadmium, nickel, etc. (Parvez et al. 2021). Increasing these chemicals in the surrounding environment not only creates a toxic effect on human health but also threatens the existence of other living organisms (Wang et al.

2022). Moreover, landfilling by non-recycled e-waste causes long-term negative impacts on agriculture, thus hampering social and economic progress in a developing country (Ananno et al. 2021). All these alarming issues created by the failure of e-waste management are directly hampering the attainment of the triple bottom line (TBL) of UNSDGs, which are social, environmental, and economic sustainability.

Though developing countries struggle to manage e-waste properly, there are several drivers which can influence initiating e-waste management as a part of achieving sustainability (Kumar et al. 2022). These drivers create the ground for implementing an e-waste management system, attract policymakers and industry owners, and motivate the common people to be more aware of managing e-waste as a part of achieving sustainability. So, analyzing these drivers of e-waste management can be effective for developing countries.

Several studies have been conducted on various aspects of e-waste management. For instance, Srivastava and Sharma (2015) depicted relationships among the affecting factors to e-waste management by applying interpretive structural modeling (ISM); Kumar and Dixit (2020) examined the causal relationships among the enablers of e-waste management by applying the DEMATEL approach; Ananno et al. (2021) presented the pattern of consumer behavior toward e-waste management by utilizing descriptive statistics; Romel et al. (2021) identified and prioritized the barriers to E-waste management in a developing country by utilizing the best-worst method (BWM); Jangre et al. (2022) analyzed the barriers of e-waste management by using F-DEMATEL and F-ISM, and so on. However, none of the previous works had intended to analyze the drivers of e-waste management that are directly related to achieving sustainability in a developing country, especially in the context of Bangladesh. This research gap is worthy of exploration. Therefore, the prioritizing order as well as the causal relationships among the drivers of e-waste management in Bangladesh is going to be discovered in this study by utilizing a fuzzy-based DEMATEL approach.

In a critical decision-making environment, where prioritizing the alternatives based on their significance, and cause-effect relationships among the alternatives based on their influence, both factors are important for undertaking a decision, different versions of DEMATEL can be effective (Kumar and Dixit 2020). Fuzzy-based decision-making techniques can minimize the vagueness of human judgment (Bari et al. 2022). Therefore, the F-DEMATEL can derive comparatively more precious decisions than the classic DEMATEL technique (Jangre et al. 2022). Therefore, this study is going to apply F-DEMATEL as a numerical analyzing tool to determine the prominence of the drivers to e-waste management, as well as to derive the causal relationships among them.

This study is aiming to contribute to the literature by fulfilling the following objectives:

- a) To identify the most relevant drivers of e-waste management for Bangladesh.
- b) To determine the prioritization of the identified drivers based on their prominence.
- c) To explore cause-effect relationships among the drivers based on their causal ranking.
- d) To discuss the theoretical and managerial implications of the study to achieve SDGs.

The rest of the paper is constructed as, Section 2 will review the closely related literature to this study for having a clear picture of the research gap, Section 3 will present the identification procedure of the drivers as well as an overview of the identified drivers to be analyzed in this study, Section 4 will describe the methodology and calculations, Section 5 will discuss the obtained results from this study, and Section 6 will depict the implications of the study outcomes. Finally, Section 7 will conclude the study by summarizing the interesting observations from this study as well as show some future research scopes by discussing the limitations of this study.

## **2. Literature Review**

There have been a lot of studies on e-waste management based on different countries' perspectives. Kitongal et al. (2022) determined the critical success factors (CSFs) for formulating a successful e-waste management policy in Kenya. The research found legal framework factors and infrastructure status factors as the most influential ones in e-waste management. From the results, it was recommended that the formulation of a standalone e-waste ICT standard policy and continuous audit of government agencies on compliance with ICT standards are required for successful e-waste management in Kenya. Kasper et al. (2022) observed that the e-waste management tendency largely varies according to the demographic background in Kuala Lumpur, Malaysia.

In a recent study by Fadaei (2022) the status quo of e-waste disposal practices in different countries was systematically investigated along with the challenges and solutions. Unsafe practices were observed to be more

prevalent in most of the developing and transitional countries. Based on a survey on electronic waste management in Wroclaw (Poland). Banaszekiewicz et al. (2022) analyzed the product use times, the reasons for buying new electronic products, and the users' behavior consciousness and knowledge regarding Waste from Electrical and Electronic Equipment (WEEE). The driving factors behind consumers' behavior concerning smartphone recycling in Thailand are explored by investigating the interrelations among social influence, attitude, and intentions toward smartphones (Paisarnvirosrak et al. 2022).

Several studies have been done in the context of Bangladesh as well. Masud et al. (2019) comprehensively presented WEEE productions in Bangladesh along with the present E-waste management systems. The study said that most of the E-waste management methods are informal and detached from current technological advancements. Analyzing consumer behavior a sustainable e-waste management framework is proposed by Ananno et al. (2021) for Bangladesh. Roy et al. (2022) designed an e-waste management system based on the material flow analysis (MFA) and life cycle assessment (LCA) models.

There are recent studies on e-waste management from a decision analysis perspective as well. Singh et al. (2022) used the fuzzy DEMATEL approach to explore the CSFs for formulating an e-waste collection policy in the context of India. Green practices, use of technology, license and certification, and mass awareness towards a circular economy are observed to be the key influencing CSFs for the e-waste management policy of India. Jangre et al. (2022) studied the barriers based on expert feedback and existing literature and ranked them to address the challenges in e-waste management in India. Furthermore, a hybrid approach combining the Fuzzy Decision-Making Trail and Evaluation Laboratory (F-DEMATEL) and Fuzzy Interpretive Structural Modeling (F-ISM) methods was employed for identifying the interrelationship between the factors. Chen et al. (2020) evaluated barriers to the implementation of e-waste formalization management systems in Ghana. A three-phase methodology combining the hybrid best-worst method, the Delphi method, and the fuzzy-TOPSIS approach is used. None of the previous works is found to have studied the drivers of e-waste management in achieving sustainability in a developing country, especially in the context of Bangladesh. This study aims to address this gap in the research by identifying the prioritizing order as well as the causal relationships among the drivers of e-waste management in Bangladesh utilizing the F-DEMATEL approach.

### **3. Identification of Drivers to E-waste Management in Bangladesh**

Based on the literature review and experts' opinions, the key drivers of e-waste management to achieve sustainability in Bangladesh are listed with descriptions in Table 1.

Table 1. Drivers to E-waste Management in Bangladesh

Importer of global e-waste (D1)	Expert opinion	Southeast Asian nations are one of the principal recipients of Chinese refurbished outputs. Due to its strong economic ties with China, the rapid expansion of its internal and regional trade, unlawful imports by brokers and dealers, and the use of "waste tourists," Bangladesh is also emerging as a secondary recipient of the world's e-waste export. This drives the management of e-waste in the country.
Health concern (D2)	(Ádám et al. 2021)	Recycling e-waste is currently an unsafe and unjust process. As a result, developing nations have experienced a significant impact on human health. Unfortunately, these unfavorable health effects have been thought to be confined only to certain regions, such as China, India, Ghana, and Nigeria. But, certainly, the migration of people, food chain contamination, and pollution's spread (through air and water) will have an impact on the entire world. A concerted effort needs to be made to better understand the effects on human health.
The need to reuse (D3)	(Raha 2021.)	In addition to recycling, e-waste should be available for repurposing by increasing access to consumers and developing the necessary infrastructure. It creates new devices in different ways bringing non-functional a good back to the operational state e.g. converting a CRT TV into a video game display.
E-waste management policy (D4)	(Department of Environment-GOB, 2021; Parvez et al. 2022)	The Hazardous Waste (e-waste) Management Rules, 2021 were published on June 10, 2021, updating the Bangladesh Environmental Protection Act, 1995. Electrical devices such as home appliances, medical equipment, automatic machines, IT, and communication equipment are covered by this law. It outlines the responsibilities of the product's assembler, manufacturer, seller, and end user. This policy has the potential to significantly improve the management of e-waste and lessen the harm to the environment and human health.
Availing of required technology (D5)	(Masud et al. 2019)	Potential technologies are needed to handle hazardous components and recover precious metals from e-waste. There is a severe lack of industry-standard methods for managing e-waste effectively. Technical advancements in e-waste recycling can boost finances in two major ways: (1) by lowering the cost of recycling through manufacturing or effectiveness improvements, and (2) by bridging the gap between the value of recycled and virgin electronic equipment.

Environmental sustainability (D6)	(Parvez et al. 2022)	The processing of various E-waste components harms the environment. When e-waste is disposed of improperly, it can harm the environment. E-waste poses a threat to the soil's composition and can affect the growth of crops if it is illegally disposed of in landfills. The primary causes of the environmental impacts resulting from E-waste in Bangladesh include a lack of awareness about how to properly dispose of electronic trash, ineffective enforcement of E-waste disposal policies, and a lack of institutions or a system to monitor the dumping of electronic items.
Awareness towards e-waste management (D7)	(Kudrat-E-Khuda 2021; Roy and Islam et al.2022)	The harm to the environment, society, and health posed by e-waste is not well understood in Bangladesh. Additionally, it has been found that knowledge of e-waste and educational background have little connection. Therefore, since literacy alone cannot influence people's attitudes toward managing e-waste in emerging countries like Bangladesh, awareness campaigns and training are necessary.
Implementing Circular Economy (D8)	(Roy and Rahman et al. 2022)	Extended producer responsibility (EPR) is now regarded as one of the formal waste management-related policies that are most frequently utilized to support the integration of the informal waste management industry. Electronic products companies must bear full or partial liability for the disposal of their commercially available products under EPR. There are numerous ways to implement EPR policy requirements. One of them is called "Product Take-Back Requirements," and it requires manufacturers to take back their goods in whole or in part after they have been used.
Development of the recycling industry (D9)	(Romel et al.2022)	Bangladesh has no such E-waste processing industry that can generate maximum financial benefit from the collected E-waste.This country still has an incredible scope to transform e-waste into a resource. Systematic recycling through an automation-integrated recycling industry can create a profitable business model in emerging countries like Bangladesh.
Accumulating information on e-waste (D10)	(Ananno et al. 2021; Masud et al. 2019)	Reliable data is needed to conduct a life cycle analysis of electronic products. The absence of technical and socioeconomic information is one of the main obstacles to appropriate E-waste treatment in Bangladesh. The proper accumulation of information will expedite the development of E-waste usage using the proper methods and appropriate time and location.
Formalization of the e-waste management sector (D11)	(Ádám et al. 2021)	The development of the e-waste management sector in emerging countries relies not only on the efficiency of government and the informal recycling industry but also on private manufacturers and community involvement coupled with national initiatives. Integrating the informal sector into the formal could result in reduced pollution and health hazards and at the same time offer the country a lot of reusable resources from this process.
Digitalization (D12)	Expert opinion	By facilitating information transfer, optimizing procedures, and establishing connections between the essential actors along the value chain, digitalization can promote e-waste management, including its prevention, collection, and treatment. To enable the circular design of electronics, artificial intelligence (AI) can enhance the collection and processing of data.
Life cycle analysis (LCA) and Material flow analysis (MFA) (D13)	(Roy and Islam et al.2022)	The combined use of Life cycle analysis (LCA) and Material flow analysis (MFA) can significantly develop the present situation of e-waste management in Bangladesh. For e-waste, the Government of Bangladesh (GoB) follows the rules followed by other countries like India, Australia, and Switzerland and then formulates its policies according to the circumstances. GoB should conduct pilot projects to develop the management policy by employing advanced e-waste management like LCA and MFA. LCA analyzes the environmental effects and development scopes of e-waste management(Hong et al., 2015). MFA demonstrates the flow of products and materials in the process of e-waste management which helps to analyze the unlawful transboundary movement and export of e-waste from developed countries (Graedel and Lifset, 2015).
Emerging Economy (D14)	Expert opinion	With the uprising economy of Bangladesh, people's purchasing power is also increasing. It is causing E-waste to increase exponentially in recent times compared to even four to five years ago. Bangladesh is expected to use an even wider range of electronic products in the years to come, driven by the nation's rising economy. Electronic trash will eventually increase even more as a result of this consumption. This will drive more strongly the urgency to recycle e-waste to compensate for the negative health and environmental consequences.

#### 4. Methodology and Calculations

This research has utilized surveyed responses from purposively chosen 10 experts. The purposive selection of experts depends on the research to fulfill the research objective in the decision-making studies (Bari et al. 2022). Later on in this research, the opinions of the experts collected in linguistic form have been converted to Fuzzy numbers and analyzed with the F-DEMATEL method.

##### 4.1. Fuzzy Logic

Fuzzy logic deals with approximate reasoning rather than precise values and can handle the uncertainty of human judgment (Bari et al. 2022). Let,  $\tilde{A} (a_{ij})$  be a fuzzy judgment that can be expressed as Equation (1).

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \quad (1)$$

Here,  $\tilde{a}_{ji} = \tilde{a}_{ij}^{-1}$  and all  $\tilde{a}_{ij}$  are triangular fuzzy numbers (TFN). The TFN is a well-known fuzzy number type, among several other types. A TFN,  $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$  is with a lower point,  $l_{ij}$  and an upper point,  $u_{ij}$ . Here,  $m_{ij}$  is the point where  $\mu(x) = 1$ , which is a crisp value and  $\mu(x)$  is the membership function of TFN. Chang (1996)

introduced this membership function  $\mu(x)$  of TFN.

#### 4.2. F-DEMATEL Method

Details procedure of F-DEMATEL that was applied in this study (Kumar and Dixit 2020) is discussed as follows:

**Step 1:** Gather linguistic feedback from each of the experts for determining the influence of one driver over another. The linguistic scale shown in Table 2 is used to collect experts' feedback.

Table 2. Linguistic scale and corresponding fuzzy values

Linguistic terms	Fuzzy values
No influence (N)	[0, 0, 0]
Low influence (L)	[0, 1, 2]
Medium influence (M)	[1, 2, 3]
High influence (H)	[2, 3, 4]
Very High influence (VH)	[4, 4, 4]

**Step 2:** Form a fuzzy direct-relation matrix for each of the experts, thus forming a total of 10 direct-relation matrices for 10 experts. The fuzzy direct-relation matrices are as Equation (2).

$$\tilde{A}_{n \times n} = \begin{matrix} D1 \\ D2 \\ D3 \\ \vdots \\ Dn \end{matrix} \begin{bmatrix} (0,0,0) & \tilde{a}_{12} & \tilde{a}_{13} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (0,0,0) & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} & (0,0,0) & \cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{n3} & \cdots & (0,0,0) \end{bmatrix} \quad (2)$$

Here, D1 to Dn are the drivers to be analyzed in this study.

**Step 3:** Aggregate all the direct-relation matrices into an aggregated direct-relation matrix by the arithmetic mean.

**Step 4:** Determine the crisp direct-relation matrix by defuzzification of the fuzzy values.

**Step 5:** Compute the normalized direct crisp-relation matrix, X by using Equations (3) and (4).

$$L = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n a_{ij}} \quad (3)$$

$$X = L \times A \quad (4)$$

Where  $L$  is a normalization factor and  $A$  is a crisp-relation matrix.

**Step 6:** Determine the total-relation matrix with Equation (5).

$$5. \quad T = X \times (I - X)^{-1} \quad (5)$$

Where  $I$  represents the identity matrix.

**Step 7:** Compute the row ( $D_i$ ) and column ( $R_j$ ) sums from the total-relation matrix, T using Equations (6) and (7).

$$D_i = [\sum_{j=1}^n T_{ij}] \quad \forall i \quad (6)$$

$$R_j = [\sum_{i=1}^n T_{ij}] \quad \forall j \quad (7)$$

**Step 8:** Compute the overall prominence ( $P_i$ ) and the net effect ( $E_i$ ) using Equations (8) and (9).

$$P_i = [D_i + R_j] \quad \forall i = j \quad (8)$$

$$E_i = [D_i - R_j] \quad \forall i = j \quad (9)$$

The greater the value of  $P_i$  for a driver, the greater the overall prominence (i.e., the influence, importance, and visibility) of that driver in terms of the overall relationship with other drivers. If  $E_i > 0$  for a driver, then that driver is a *causal* driver, otherwise an *effect* driver.

**Step 9:** Plot  $P_i$  and  $E_i$  values on a two-dimensional axis for each driver to create the cause-effect diagram. How one driver influences another driver can be depicted by the digraph obtained. To avoid comparably negligible effects, a threshold value ( $\theta$ ) is set. Equation (10) is showing the mathematical expression for the threshold value ( $\theta$ ).

$$\theta = 1.25(\mu + \sigma) \quad (10)$$

Here,  $\mu$  is the mean value, and  $\sigma$  the standard deviation of the elements of the total-relation matrix,  $T$ . Here is an example to understand the significance of the threshold value. If,  $T_{ij} > \theta$  for a driver  $B_i$ , then that driver influences or causes the driver  $B_j$ . In the digraph, a directed arrow is incorporated to show this causal relation.

#### 4.3. Calculations

Evaluated fuzzified direct-relation matrices from the experts have been aggregated, and then defuzzified to form a defuzzified direct-relation matrix which can be found in Table 3.

Table 3. Defuzzified direct-relation matrix

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14
D1	0.00	1.33	1.33	1.33	1.67	1.67	1.33	2.00	2.00	2.00	1.33	3.00	1.00	1.33
D2	1.33	0.00	0.67	1.33	0.33	1.67	0.67	1.67	1.67	1.67	2.33	1.67	2.33	3.00
D3	1.67	2.00	0.00	2.33	2.00	1.00	2.00	2.67	2.33	1.00	2.00	1.00	1.00	1.00
D4	4.00	3.33	2.67	0.00	4.00	2.67	1.67	3.00	4.00	3.00	1.67	3.00	2.00	3.00
D5	1.33	1.00	1.00	1.33	0.00	1.00	1.00	1.00	0.00	1.33	0.00	2.00	1.00	2.00
D6	0.00	1.33	1.00	1.33	2.00	0.00	1.33	2.00	1.00	2.00	2.00	2.33	1.00	1.00
D7	1.67	3.33	2.00	2.33	2.00	4.00	0.00	2.67	3.00	4.00	2.67	3.00	3.00	2.00
D8	0.67	0.00	0.00	2.00	1.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	1.00	1.00
D9	1.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00	0.00	1.00	2.00	1.00	1.00	1.00
D10	1.00	0.33	1.00	2.00	1.00	1.00	2.00	2.00	1.00	0.00	1.00	1.00	1.00	2.00
D11	2.00	2.00	1.00	1.33	1.00	1.00	1.00	1.00	2.00	2.00	0.00	2.00	1.00	1.00
D12	1.00	2.00	2.00	2.00	4.00	3.00	2.00	2.00	2.00	2.00	3.00	0.00	3.00	3.00
D13	1.33	1.67	1.00	1.33	0.00	1.00	1.00	1.00	2.33	0.00	2.00	1.00	0.00	2.00
D14	1.00	1.33	2.00	2.00	2.67	1.00	2.00	2.33	3.00	3.00	2.67	2.00	2.33	0.00

After calculating the further steps, the total-relation matrix was achieved, which can be found in Table 4. The colored cells in the total-relation matrix indicate the values which are larger than the threshold value (0.166) set for this study.

Table 4. Total relation matrix for the drivers of e-waste management in achieving sustainability

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14
D1	0.044	0.084	0.076	0.089	0.104	0.096	0.083	0.111	0.112	0.113	0.091	0.134	0.079	0.094
D2	0.076	0.048	0.058	0.085	0.066	0.090	0.064	0.099	0.103	0.101	0.114	0.098	0.108	0.130
D3	0.091	0.103	0.043	0.114	0.112	0.081	0.100	0.129	0.123	0.091	0.107	0.088	0.079	0.086
D4	0.174	0.166	0.137	0.092	0.200	0.154	0.124	0.176	0.202	0.179	0.137	0.175	0.138	0.174
D5	0.066	0.062	0.057	0.073	0.044	0.064	0.061	0.070	0.046	0.079	0.042	0.093	0.064	0.093
D6	0.040	0.078	0.062	0.082	0.102	0.046	0.076	0.102	0.078	0.105	0.098	0.109	0.071	0.078
D7	0.113	0.163	0.117	0.146	0.145	0.182	0.078	0.163	0.173	0.198	0.158	0.169	0.158	0.146
D8	0.047	0.035	0.030	0.086	0.066	0.062	0.082	0.040	0.067	0.093	0.037	0.065	0.060	0.065
D9	0.058	0.062	0.055	0.064	0.092	0.062	0.059	0.067	0.043	0.069	0.089	0.068	0.062	0.067
D10	0.063	0.052	0.061	0.095	0.076	0.069	0.090	0.100	0.078	0.053	0.071	0.075	0.069	0.098
D11	0.090	0.094	0.062	0.081	0.078	0.072	0.067	0.078	0.104	0.104	0.050	0.102	0.071	0.078
D12	0.089	0.122	0.109	0.127	0.182	0.147	0.118	0.134	0.137	0.138	0.153	0.084	0.147	0.157
D13	0.069	0.082	0.058	0.074	0.047	0.065	0.061	0.071	0.108	0.049	0.095	0.071	0.040	0.094
D14	0.083	0.097	0.103	0.119	0.140	0.091	0.111	0.133	0.152	0.151	0.135	0.123	0.123	0.073

## 5. Result and Discussions

The present research employs a combined Fuzzy System Theory with the DEMATEL approach to develop a systematic analysis of the Drivers of E-waste Management to achieve sustainability in a developing country like Bangladesh.

For the present study, the threshold value is calculated to be 0.166 using Equation (10) to avoid visual complexity. The values greater than 0.166 are highlighted in green color in Table 4. This value was used to evaluate the significant relationships between the drivers. From the expert's input, the degree of influential impact D and degree of influenced impact R is calculated using Equation (6) and equation (7), respectively. Table 5 is developed using the crisp values of D, R, D + R, and D - R to demonstrate the impact diagram by collecting quantities of columns and rows of Table 4.

Table 5. Group effect of all drivers of e-waste management in achieving sustainability

	D	R	D+R	D-R
D1	1.31	1.10	2.41	0.21
D2	1.24	1.25	2.49	-0.01
D3	1.35	1.03	2.37	0.32
D4	2.23	1.33	3.56	0.90

D5	0.91	1.45	2.37	-0.54
D6	1.13	1.28	2.41	-0.15
D7	2.11	1.18	3.28	0.93
D8	0.84	1.47	2.31	-0.64
D9	0.92	1.53	2.44	-0.61
D10	1.05	1.52	2.58	-0.47
D11	1.13	1.38	2.51	-0.25
D12	1.84	1.45	3.30	0.39
D13	0.98	1.27	2.25	-0.29
D14	1.63	1.43	3.07	0.20

From the values of D+R and D-R, an impact diagram is developed depicting the significant relationships between the drivers which are shown in Figure 1.

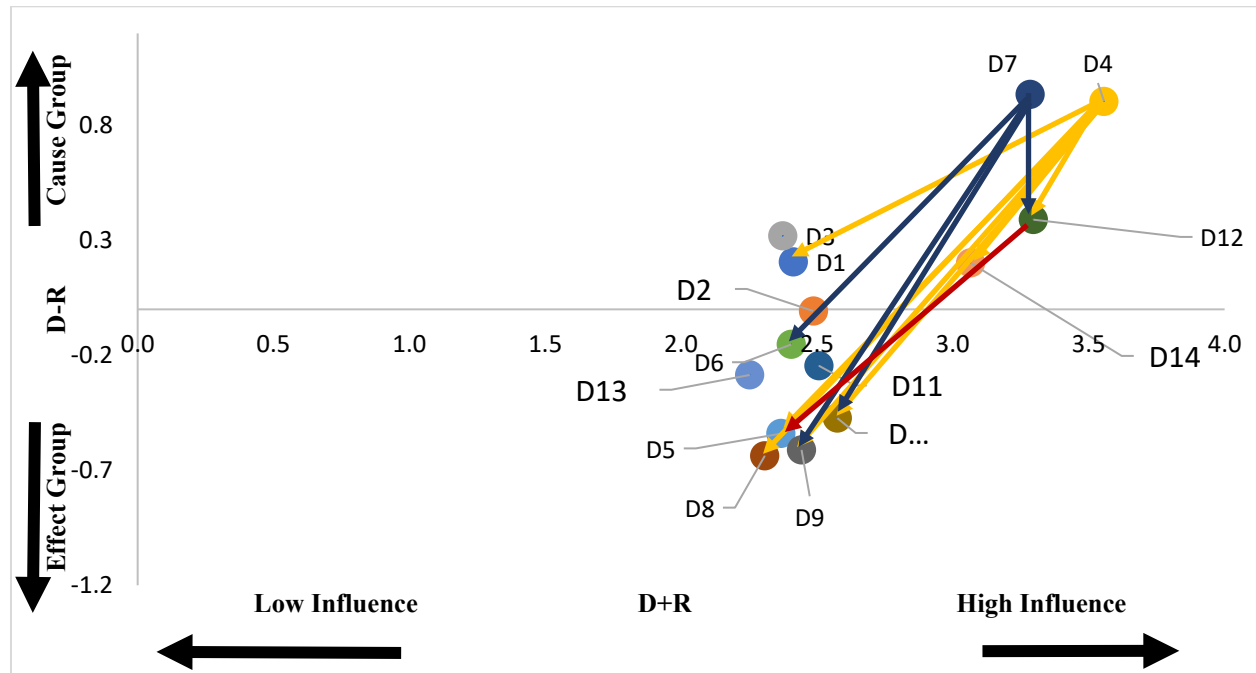


Figure 1. Cause-effect diagram of the drivers of e-waste management to achieving sustainability

### 5.1 Prominence ranking

The value of (D+R) expresses the ‘prominence’ or ‘importance degree’ of each driver. A factor with a high prominence value significantly affects another factor while it can simultaneously be affected by other factors (Zhu et al. 2014). The higher the (D+R) value is, the more the influence of the drivers and the interaction between the other drivers are. The identified values of the fourteen drivers are arranged in descending order based on the D+R score, as presented in Table 6. This evaluation helps to identify the most prominent and critical drivers. Among 14 identified drivers, E-waste management policy (D4) is identified to be the most influential driver followed by Digitalization (D12), Awareness towards e-waste management (D7), Emerging Economy (D14), and Accumulating information on e-waste (D10). The prominence ranking of drivers is of great importance for the decision-makers and investors for ensuring sustainability in the e-waste management system in developing nations.

Table 6. Prominence ranking

Rank	Code	Driver	D+R
1	D4	E-waste management policy	3.56
2	D12	Digitalization	3.30
3	D7	Awareness towards e-waste management	3.28
4	D14	Emerging Economy	3.07

5	<b>D10</b>	Accumulating information on e-waste	2.58
6	<b>D11</b>	Formalization of the e-waste management sector	2.51
7	<b>D2</b>	Health concern	2.49
8	<b>D9</b>	Development of the recycling industry	2.44
9	<b>D1</b>	Importer of global e-waste	2.41
10	<b>D6</b>	Environmental sustainability	2.41
11	<b>D3</b>	The need to reuse	2.37
12	<b>D5</b>	Availing required technology	2.37
13	<b>D8</b>	Implementing Circular Economy (CE)	2.31
14	<b>D13</b>	Life cycle analysis (LCA) and Material flow analysis (MFA)	2.25

To explore the drivers of e-waste management more, it is necessary to identify the cause-and-effect drivers. The value of (D–R) shows the ‘relationship’ between the drivers and can be clustered into two groups: the cause group and the effect group. Positive values of (D–R) represent the cause group which means that these drivers are independent. Negative values of (D–R) are positioned in the effect group, which implies that these factors are influenced by causal group factors. The causal ranking of the drivers indicating the cause group and effect group is presented in Table 7.

Table 7. Causal ranking

Rank	Code	Driver	D-R	Group
1	<b>D7</b>	Awareness towards e-waste management	0.93	<b>Cause Group</b>
2	<b>D4</b>	E-waste management policy	0.90	
3	<b>D12</b>	Digitalization	0.39	
4	<b>D3</b>	The need to reuse	0.32	
5	<b>D1</b>	Importer of global e-waste	0.21	
6	<b>D14</b>	Emerging Economy	0.20	
7	<b>D2</b>	Health concern	-0.01	<b>Effect Group</b>
8	<b>D6</b>	Environmental sustainability	-0.15	
9	<b>D11</b>	Formalization of the e-waste management sector	-0.25	
10	<b>D13</b>	Life cycle analysis (LCA) and Material flow analysis (MFA)	-0.29	
11	<b>D10</b>	Accumulating information on e-waste	-0.47	
12	<b>D5</b>	Availing required technology	-0.54	
13	<b>D9</b>	Development of the recycling industry	-0.61	
14	<b>D8</b>	Implementing Circular Economy (CE)	-0.64	

### 5.2 Influencing drivers

In Table 5, according to the positive (D–R) values, six causal group drivers are sorted as follows: D7>D4>D12>D3>D1>D14. These causal drivers can play an important role in influencing the sustainable management of e-waste in Bangladesh. Improvement in these cause group drivers results in an improvement in the effect group drivers. Therefore, firstly, need to concentrate more on these drivers. Awareness towards e-waste management (D7), E-waste management policy (D4), Digitalization (D12), and The need to reuse (D3) are the four most important drivers that have a significant influence on other drivers.

From Table 5 it is visible that ‘Awareness towards e-waste management (D7)’ has the maximum (D-R) value among the cause drivers (0.93). At the same time, this driver has the second-highest value of the degree of influential impact D (2.11) among all the drivers. This means awareness among mass people towards e-waste management has a significantly high effect on driving successful e-waste management to achieve sustainability in Bangladesh. This can be justified by Figure 1 as it influences several effect group drivers such as Environmental sustainability (D6), Development of the recycling industry (D9), Accumulating of information on e-waste (D10), and Digitalization (D12). According to (Pouikli 2020), awareness among each level of entity involved with electronic waste generation is very important in decreasing the environmental and economic impact of e-waste generation. Crucial measures have to be taken by authorities to eliminate the wide knowledge gap among the different stakeholders of e-waste (Ali and Akalu 2022).



According to Table 6, 'D4: E-waste management policy' has the second highest prominence value (0.90) among all causal drivers. Hence policy regarding E-waste management like The Hazardous Waste (e-waste) Management Rules, 2021 has a remarkable influence on the establishment of a sustainable e-waste management system in developing countries. The poor policy framework is identified as the most critical constraint on the adoption of e-waste management in another developing country Ghana (Kwabena et al. 2018).

Next, the third most important causal driver is 'D12: Digitalization' and it has the largest influential value (0.39) among all the drivers. Digitalization can aid electronic waste management including its collection, prevention, and treatment – by increasing data processing information, developing processes, and integrating the relevant factors across the value chain (Šipka 2021). In Bangladesh, the 'Digital Bangladesh' project taken by the government of Bangladesh for leveraging digital technologies will increase the consumption of electronic products in the upcoming years (Aziz 2020). Then, 'D3: The need to reuse' ranks fourth among all causal drivers in the whole system (0.32). Accordingly, it is observed that the Emerging Economy (D14) is not a factor that significantly affects electronic waste management.

These six cause group drivers are crucial for effective and sustainable adoption of e-waste management in Bangladesh. The key performance indicators for assessing the execution level of the prominent cause group drivers need to be critically analyzed by policymakers.

### **5.3 Influenced drivers**

From the negative values of (D-R), effect drivers are ranked in terms of their influence levels as follows: D2 > D6 > D11 > D13 > D10 > D5 > D9 > D8. These eight drivers of e-waste management are categorized under influenced group. These drivers are influenced by the six cause group drivers. From the analysis, 'D8: Implementing Circular Economy (CE)' is the most affected driver (-0.64) for the implementation of sustainable electronic waste management. Roosna (2022) affirms the finding and mentions that scarcity of earth elements, high demand for consumer electronics, and limiting carbon production are causing the urgency to move towards CE. Figure 1 shows that the implementation of CE is affected by the second most influential cause driver 'D4 E-waste management policy'.

After that, the 'Development of recycling industry (D9)' is the second most affected driver for establishing sustainable e-waste management. 'Availing required technology (D5)' is the third most affected driver that is caused by the other drivers followed by the driver 'Accumulating information on e-waste (D10)'. Likewise, 'Health concern (D2)' is positioned close to the causal group having a D-R value (-0.01).

These effect group drivers are the benefits of the cause group driver of e-waste management. To improve the performance of effect group drivers, it is needed to improve the impact of the cause group drivers by putting more focus on effective adoption (Werning and Spinler 2020). This is because these eight effect group drivers have a high dependency on the six cause group drivers.

## **6. Implications of the Study**

The findings of this research have several theoretical and practical implications for the decision-makers to contribute to e-waste management to achieve sustainability in Bangladesh.

- This research provides an extensive list of drivers of e-waste management that are reported by various researchers in previous literature along with expert opinion. The study on the identified drivers will aid the practitioners in understanding the relative importance of the drivers as well as the cause-and-effect relationships among them for the sustainable development of e-waste management in Bangladesh. This will help the practitioners to implement the CE effectively and sustainably.
- Six drivers are identified as cause group drivers and eight drivers are identified as effect group drivers. It implies that drivers like mass awareness, regulatory policy, and the need to reuse electronic waste must be addressed to get the successful implementation of CE, development of an advanced recycling industry, etc as the outcome to overall improve the e-waste management system in Bangladesh.
- From the prominence ranking, the regulatory policy is the most prominent driver of all. It implies that government policies like Hazardous Waste (e-waste) Management Rules-2021 if implemented properly, have the potential to significantly upgrade the overall e-waste management scenario in Bangladesh ensuring

sustainability. Moreover, this proposed research framework in this study can assist the decision-makers to formulate more targeted strategies to get maximum outcomes by removing the barriers of CE.

- Awareness is found as the most significant causal factor for sustainably driving e-waste management. Stakeholders' awareness influences sustainable e-waste management in Bangladesh. This consciousness can ensure full utilization of e-waste including reuse, reduction, recycling, and recovery. Awareness will help stakeholders to understand the importance of and develop their business accordingly and sustainably.
- Health and environmental sustainability are found in the effect of group drivers as part of outcomes influenced by cause group drivers. Thus, severe health issues resulting from hazardous e-waste including contamination of soil, air, and water can be avoided. This will work as a catalyst in addressing several goals of the Sustainable Development (SDGs) related to Good health and Well-being (SDG3), Clean Water and Sanitation (SDG6), Sustainable Cities and Communities (SDG11), Life Below Water (SDG14).
- According to the causal ranking result, the most influenced outcome is the successful implementation of CE. This outcome will support Bangladesh to reach the 12<sup>th</sup> Sustainable Development Goal of 'Responsible Consumption and Production' by substantially decreasing the generation of e-waste and making manufacturing and consumption more sustainable.
- Furthermore, the development of the recycling sector as well as the formalization of the informal e-waste collection sector will create new opportunities for employment contributing to expediting the economic growth of Bangladesh (SDG8).
- 'D3: The need to reuse' is found to be a cause driver for the development of e-waste management ensuring sustainability in Bangladesh. According to Raha (2021), if managed properly, e-waste can be a good source of power supporting Bangladesh with a considerable amount of energy that it currently lacks. This way, it can contribute to ensuring sustainable energy in a developing country like Bangladesh.

## **7. Conclusions**

This study aims to explore the drivers of e-waste management in Bangladesh to achieve sustainability which can help to overcome the challenges involved in it. Although several research works have been done to explore the drivers of e-waste management none of them ranked the drivers based on their influence and explore the causal relationship among them. In this regard, this study employs the fuzzy decision-making trial and evaluation laboratory (F-DEMATEL) method to identify the prominence and study the cause-effect relations among the drivers of e-waste management in a developing country. From an extensive review of existing literature and also expert opinion a total of fourteen drivers were identified. These drivers are then analyzed using the F-DEMATEL method. From the prominence ranking, the policy is the most prominent driver of all. Moreover, in the causal ranking, six drivers are identified as cause group drivers and eight drivers are identified as effect group drivers. It implies that drivers like mass awareness, regulatory policy, and the need to reuse electronic waste must be addressed to get the successful implementation of a circular economy, development of an advanced recycling industry, etc as the outcome to improve the e-waste management system in developing countries. On the other hand, the successful implementation of CE is the most influential factor from the results obtained. The outcomes of this study are expected to play a crucial role in adopting circular activities in business organizations for profit gain through the application of the F-DEMATEL approach. This can help to achieve several SDGs like Good health and Well-being, Clean water and Sanitation, Sustainable Cities and Communities, Responsible Consumption and Production, Life Below Water, and Decent Work and Economic Growth.

However, this study has a few limitations as well. For example, the F-DEMATEL approach is used based on the subjective judgment of the experts in the relevant field. So, in the obtained results there can be an effect of subject bias. Moreover, the status of the e-waste management scenario is changing in Bangladesh. Thus, the key drivers identified in this study may become outdated within 5 to 10 years. In the future, researchers could use other MCDM approaches and make a comparative analysis of the results of different methods. Finally, future researchers can employ the same methodology to explore other relevant sectors.

## **References**

Ádám, B., Göen, T., Scheepers, P. T., Adliene, D., Batinic, B., Budnik, L. T., ... and Au, W. W., From inequitable to sustainable e-waste processing for reduction of impact on human health and the environment. *Environmental Research*, vol.194, 110728, 2021.

- Ali, A. S., and Akalu, Z. K., E-waste Awareness and Management Among People Engaged in E-waste Selling, Collecting, Dismantling, Repairing, and Storing Activities in Addis Ababa, Ethiopia. *Environmental Health Insights*, vol.16, 11786302221119145, 2022.
- Ananno, A. A., Masud, M. H., Dabnichki, P., Mahjabeen, M., and Chowdhury, S. A., Survey and analysis of consumers' behaviour for electronic waste management in Bangladesh. *Journal of Environmental Management*, vol. 282, 111943. <https://doi.org/10.1016/J.JENVMAN.2021.111943>, 2021.
- Aziz, A., Digital inclusion challenges in Bangladesh: The case of the National ICT Policy. *Contemporary South Asia*, vol.28, no. 3, pp.304-319, 2020.
- Bari, A. M., Siraj, M. T., Paul, S. K., and Khan, S. A., A hybrid multi-criteria decision-making approach for analyzing operational hazards in Heavy Fuel Oil-based power plants. *Decision Analytics Journal*, 100069, 2022.
- Chang, D. Y., Applications of the extent analysis method on fuzzy AHP. *European journal of operational research*, vol.95(3), pp.649-655, 1996.
- Department of Environment-GOB., E Waste Rules. Retrieved from <http://www.doe.gov.bd/>, 2021.
- Graedel, T. E., and Lifset, R. J. Industrial ecology's first decade., *Taking Stock of Industrial Ecology*, pp.3–20, [https://doi.org/10.1007/978-3-319-20571-7\\_1/COVER](https://doi.org/10.1007/978-3-319-20571-7_1/COVER), 2015.
- Hong, J., Shi, W., Wang, Y., Chen, W., and Li, X., Life cycle assessment of electronic waste treatment. *Waste Management*, vol.38, no. 1, pp.357–365. <https://doi.org/10.1016/J.WASMAN.2014.12.022>, 2015.
- Jangre, J., Prasad, K., and Patel, D., Analysis of barriers in e-waste management in developing economy: An integrated multiple-criteria decision-making approach. *Environmental Science and Pollution Research*, pp.1-15, 2022.
- Kitongal, K. B., Godfrey, M., Samuel, W., Critical success factors for e-waste management among government of kenya ministries. *Int Journal of Social Sciences Management and Entrepreneurship*, vol.38(3), pp.83-94, 2022.
- Kudrat-E-Khuda., Electronic Waste in Bangladesh: Its present statutes, and negative impacts on environment and human health. *Pollution*, vol.7, no. 3, pp.633–642. <https://doi.org/10.22059/POLL.2021.321337.1056>, 2021.
- Kumar, A., and Dixit, D., Examine the Causal Relationship Among Enablers of Sustainable WEEE Management Using DEMATEL Approach. In Examine the Causal Relationship Among Enablers of Sustainable WEEE Management Using DEMATEL Approach (December 21, 2020). *e-journal-First Pan IIT International Management Conference–2018*, December 2020.
- Kwabena, B.-Y., Clifford, A., and Kwasi, K. A., Stakeholders perceptions on key drivers for and barriers to household e-waste management in Accra, Ghana. *African Journal of Environmental Science and Technology*, vol.12, no. 11, pp.429–438. <https://doi.org/10.5897/AJEST2018.2409>, 2018.
- Masud, M. H., Akram, W., Ahmed, A., Ananno, A. A., Mourshed, M., Hasan, M., and Joardder, M. U. H., Towards the effective E-waste management in Bangladesh: a review. *Environmental Science and Pollution Research International*, vol. 26, no. 2, pp.1250–1276. <https://doi.org/10.1007/S11356-018-3626-2>, 2019.
- Parvez, S. M., Hasan, S. S., Knibbs, L. D., Jahan, F., Rahman, M., Raqib, R., ... and Sly, P. D., Ecological Burden of e-Waste in Bangladesh—an Assessment to Measure the Exposure to e-Waste and Associated Health Outcomes: Protocol for a Cross-sectional Study. *JMIR research protocols*, vol.11, no. 8, e38201, 2022.
- Parvez, S. M., Jahan, F., Brune, M. N., Gorman, J. F., Rahman, M. J., Carpenter, D., ... and Sly, P. D., Health consequences of exposure to e-waste: an updated systematic review. *The Lancet Planetary Health*, vol.5, no. 12, pp.e905-e920, 2021.
- Pouikli, K., Concretising the role of extended producer responsibility in European Union waste law and policy through the lens of the circular economy. *ERA Forum 2020 20:4*, vol.20(4), pp.491–508. <https://doi.org/10.1007/S12027-020-00596-9>, 2020.
- Raha, U.L., E-waste management in bangladesh: An overview. *2nd International Conference on Urban and Regional Planning*, pp. 1-8, 2021.
- Romel, M. A., Kabir, G., Ali, S. M., and Ng, K. T. W., Identification of Critical Barriers for E-Waste Management in an Evolving Economy Using Best Worst Method. In *The International Workshop on Best-Worst Method*, pp. 194-208, Springer, Cham, June 2021.
- Roosna, H., We Need to Move to a Circular Economy Right Now. Retrieved from <https://www.fairown.com/post/we-need-to-move-to-a-circular-economy-right-now>, 2022.
- Roy, H., Islam, M. S., Haque, S., and Riyad, M. H., Electronic waste management scenario in Bangladesh: policies, recommendations, and case study at Dhaka and Chittagong for a sustainable solution. *Sustainable Technology and Entrepreneurship*, vol.1, no. 3, 100025. <https://doi.org/10.1016/J.STAE.2022.100025>, 2022.
- Roy, H., Rahman, T. U., Suhan, M. B. K., Al-Mamun, M. R., Haque, S., and Islam, M. S., A comprehensive review on hazardous aspects and management strategies of electronic waste: Bangladesh perspectives. *Heliyon*, vol.8, no. 7, e09802. <https://doi.org/10.1016/J.HELIVON.2022.E09802>, 2022.

- Šipka, S., Towards circular e-waste management: How can digitalisation help? *Sustainable Prosperity for Europe Programme*. <https://epc.eu/en/publications/Towards-circular-e-waste-managementHow-can-digitalisation-help~425c48>, September 2021.
- Srivastava, R., and Sharma, D., Factors affecting e-waste management: an interpretive structural modeling approach. In 2015 *Fifth international conference on communication systems and network technologies*, pp. 1307-1312., IEEE, April 2015.
- Thakur, P., and Kumar, S., Evaluation of e-waste status, management strategies, and legislations. *International Journal of Environmental Science and Technology*, pp.1-10, 2021.
- Wang, X., Teng, Y., Wang, X., Xu, Y., Li, R., Sun, Y., ... and Luo, Y., Effects of combined pollution of organic pollutants and heavy metals on biodiversity and soil multifunctionality in e-waste contaminated soil. *Journal of Hazardous Materials*, vol.440, 129727, 2022.
- Werning, J. P., and Spinler, S., Transition to circular economy on firm level: Barrier identification and prioritization along the value chain. *Journal of Cleaner Production*, vol. 245, 118609. <https://doi.org/10.1016/J.JCLEPRO.2019.118609>, 2020.
- Zhu, Q., Sarkis, J., and Lai, K. H., Supply chain-based barriers for truck-engine remanufacturing in China. *Transportation Research Part E: Logistics and Transportation Review*, vol.68, pp.103–117. <https://doi.org/10.1016/J.TRE.2014.05.001>, 2014.

## **Biographies**

**Md. Zahidul Anam** is a graduate student in the department of Industrial and Production Engineering at the Bangladesh University of Engineering and Technology (BUET). He completed his Bachelor of Science in Electrical and Electronics Engineering in 2014 from the Islamic University of Technology. Currently, he is working as a Quality, Reliability and Safety Engineer at Singer Bangladesh Limited. His research interest includes Renewable Energy, Energy Management, Decision Science, Operations Research, and Optimization.

**Md. Tanvir Siraj** is a graduate student in the department of Industrial and Production Engineering at the Bangladesh University of Engineering and Technology (BUET). He completed his Bachelor of Mechanical Engineering in 2016 from BUET. Currently, he is working as a Boiler Safety Engineer at RMG Sustainability Council, Bangladesh. His research interest includes Operations Research, Decision Science, Optimization, Renewable Energy, and so on.

**Spandan Basak Payel** is a Sub-divisional Engineer of Northern Electricity Supply Company Ltd., Bangladesh. He completed his Bachelor of Mechanical Engineering in 2016 from the Bangladesh University of Engineering and Technology (BUET). His research interest includes Waste Management, Operations Research, Decision Science, Optimization, and Renewable Energy.