Acronyms

I4.0- Industry 4.0

CE- Circular Economy

EWM- E-waste Management

AHP- Analytic Hierarchy Process

DEMATEL- Decision-Making Trial and Evaluation Laboratory

E-products or EEE- Electrical and Electronic Equipment

IoT- Internet of Things

RFID- Radio Frequency Identification

TCE- Transaction cost economics

RBT- Resource-based theory

TPB- Theory of planned behavior

INT- Institutional Theory

NT- Network theory

ST- Stakeholder theory

AHP Approach

The AHP technique, which was introduced by Thomas Saaty in 1980, is a flexible methodology for making decisions involving several attributes. It has been successfully employed in various problem domains. The efficacy of this approach resides in its capacity to deconstruct intricate matters into manageable tiers of evaluation criteria. The AHP method consists of three primary steps, namely segmentation, paired evaluations, and synthesis of criteria and/or alternative priorities. The following, step-by-step approach is used for determining the weights of the main and sub-practices:

Step 1) Construct the pairwise comparisons between main practices and sub-practices.

Step 2) Compute the total of the values found in each column after doing the pairwise comparisons.

Step 3) In order to get the matrix normalized, divide each element of the column of a pairwise matrix with its corresponding sum.

Step 4) The next step is to sum up all the elements of each row obtained by using step (iii) and dividing it by the number of elements in each row. The outcome indicates each alternative the total priority rating.

Step 5) The last step is to calculate the priority vectors of the alternatives obtained by multiplying the pairwise comparisons of the alternative's matrix and the criteria weight.

Step 6) Comparisons are assumed to be reasonably compatible in the decision matrix if the resulting "Consistency Ratio (CR)" is less than 10 percent. A "Consistency Index (CI)" is specified for the measurement of the CR coefficient, which is determined as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

Where λ_{max} is the maximum eigenvalue of the matrix for a pair comparison However, the CR is determined by dividing the CI value by the "Random Consistency Index (RCI)", as shown in equation (2)

$$CR = \frac{CI}{RCI} \tag{2}$$

When the CR value is smaller than or equivalent to 10 percent, data is considered to be accurate; however, if it is greater than 10 percent, it is not reliable.

DEMATEL Approach

The DEMATEL methodology is divided into six steps that are as follows:

Step 1: Choosing the criteria: The first step is identifying the various factors that needs to be modelled.

Step 2: Generating Average Direct Relation Matrix (A).

Experts were asked to rate the extent to which they thought each challenge affected the others in this step. Five points on a Likert scale (ranging from 0 to 4) were utilised.
Where, 0 → "no influence", 1 → "low influence", 2 → "medium influence", 3 → "high influence", and 4 → "very high influence".
The preliminary data can be gathered in the form of a pairwise matrix. This means creating a non-negative matrix of size (n × n), denoted as $a^k = [a_{ij}^k]$. Each element in this matrix represents how much criterion 'I' influences criterion 'j'. Equation (1) is employed to construct 'A' matrix, considering all responses from "H" respondents.

$$A = \frac{1}{H} \sum_{k=1}^{H} a_{ij}^k \tag{1}$$

where, K → number of respondents with $1 \leq ik \leq H$,
n → number of challenges.

Step 3: Generating Normalised Relation Matrix (X).

Each component of the 'A' matrix is divided by the total largest row or column sum (s) to obtain 'X' matrix.

$$X = sA \qquad (2)$$

$$\text{Here, } s = [\frac{1}{max_{1 \leq i \leq n} \sum_{i=1}^{n} a_{ij}}, \quad i,j = 1,2,..n$$

$$or \text{ } or \text{ } s = \frac{1}{max_{1 \leq j \leq n} \sum_{j=1}^{n} a_{ij}}, \quad i,j = 1,2,..n]$$

Step 4: Calculating the Total-relation matrix (T).

'T' matrix can be computed as,

$$T = X(I - X)^{-1} \qquad (3)$$

where I → identity matrix

Step 5: Calculating priority ranking and categorization of challenges.

In 'T' matrix, the row sum (D_i) and column sum (R_j) were obtained for each challenge (C1 to C9). To determine priority ranking and group challenges into cause-and-effect groups, (D+R) and (D-R) values were calculated respectively. The challenges that have the highest (D+R) value have a greater overall system impact, whereas the challenges that have the lowest (D+R) value are less closely related. (D-R) values signify the type of relationship between the challenges. If it is positive, the challenge goes to the cause group, meaning it influences other challenges. If it is negative, the challenge goes to the effect group, meaning it is influenced by other challenges.

Step 6: Calculating inner-dependency matrix and formation of cause-and-effect relationship diagram.

An inner-dependency matrix was created using the 'T' matrix method to identify significant impacts. Values below a threshold value (θ) determined by averaging the matrix were eliminated from the 'T'. The (D+R) and (D-R) values for each challenge were graphed, by taking (D+R) as Y-axis and (D−R) as X-axis. This was done to generate a cause-and-effect association diagram. The connections between challenges were depicted using one-way and two-way arrows based on the entries in the inner dependency matrix.

Table A1: Pair-wise Comparison of AHP Method

Pairwise comparison	D1	D2	D3	D4	D5	D6	D7	weight
Technological and infrastructural Challenges (D1)	1.00	5.96	8.21	2.21	4.95	7.20	3.41	**32.94**
Economic Challenges (D2)	0.17	1.00	3.72	0.25	0.45	2.21	0.24	8.05
Policies and Legal Challenges (D3)	0.12	0.27	1.00	0.17	0.25	0.50	0.16	2.47
Knowledge Related Challenges (D4)	0.45	3.94	6.00	1.00	4.00	6.44	2.21	**24.04**
Product Related Challenges (D5)	0.20	2.21	4.00	0.25	1.00	3.22	0.45	11.34
Organizational Challenges (D6)	0.14	0.45	2.00	0.16	0.31	1.00	0.15	4.21
Consumer Related Challenges (D7)	0.29	4.23	6.24	0.45	2.21	6.62	1.00	**21.04**
CI = 0.08; CR = 0.06								

Table A2 Average relation matrix

Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Lack of smart technologies for product recovery (C1)	0	0	1.5	0.75	0	0.75	1.25	1.25	0.25	0	0	0
Lack of smart technologies to forecast E-waste generation (C2)	1.25	0	2.25	1.25	1	1	1.25	0.25	1	0	0	0
Lack of awareness about the harmful impact of E-waste (C3)	2.75	1.75	0	1.75	2	2	2	1	1	1	1	1
Lack of acceptability for refurbished/repaired/recycled products (C4)	1	1	1	0	0	0	2	2	0	0	0	0
lack of smart technologies for tracking e-waste (C5)	1	1	2	1	0	2	2	1	1	0	1	0
Lack of machinery and equipment for segregation of E-waste (C6)	2	1	2	1	0	0	1	1	0	0	0	0
Insufficient strategies for integration of Industry 4.0 & C.E (C7)	3.25	3.25	3.25	2.25	2.25	2.75	0	1.75	3.25	1.75	1.75	1.75
Lack of awareness about I4.0 contributions to reverse logistics of E-waste (C8)	3.25	3.25	3.25	2.25	2.25	1.75	3.75	0	2.75	1.25	1	1
Decision support system for EOL treatment of E-waste (refurbishment/recycling) (C9)	1	1	2	1	0	2	1	1	0	0	0	0
Lack of awareness about CE practices (C10)	1.25	1.25	1.25	0.25	1.25	1.25	1.25	1	1.25	0	3	3
Inadequate waste management infrastructure (C11)	1.25	1	2	0.25	1	2	1	1	2	2	0	2
Data Security and Privacy issues (C12)	1.25	1.25	1.25	0.25	1	1.25	1.25	1.25	1	2	1.75	0

Table A3 Normalised relation matrix

Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Lack of smart technologies for product recovery (C1)	0	0	0.06	0.03	0	0.03	0.05	0.05	0.01	0	0	0
Lack of smart technologies to forecast E-waste generation (C2)	0.05	0	0.08	0.05	0.04	0.04	0.05	0.01	0.04	0	0	0
Lack of awareness about the harmful impact of E-waste (C3)	0.1	0.06	0	0.06	0.07	0.07	0.07	0.04	0.04	0.04	0.04	0.04
Lack of acceptability for refurbished/repaired/recycled products (C4)	0.04	0.04	0.04	0	0	0	0.07	0.07	0	0	0	0
lack of smart technologies for tracking e-waste (C5)	0.04	0.04	0.07	0.04	0	0.07	0.07	0.04	0.04	0	0.04	0
Lack of machinery and equipment for segregation of E-waste (C6)	0.07	0.04	0.07	0.04	0	0	0.04	0.04	0	0	0	0
Insufficient strategies for integration of Industry 4.0 & C.E (C7)	0.12	0.12	0.12	0.08	0.08	0.1	0	0.06	0.12	0.06	0.06	0.06
Lack of awareness about I4.0 contributions to reverse logistics of E-waste (C8)	0.12	0.12	0.12	0.08	0.08	0.06	0.14	0	0.1	0.05	0.04	0.04
Decision support system for EOL treatment of E-waste (refurbishment/recycling) (C9)	0.04	0.04	0.07	0.04	0	0.07	0.04	0.04	0	0	0	0
Lack of awareness about CE practices (C10)	0.05	0.05	0.05	0.01	0.05	0.05	0.05	0.04	0.05	0	0.11	0.11
Inadequate waste management infrastructure (C11)	0.05	0.04	0.07	0.01	0.04	0.07	0.04	0.04	0.07	0.07	0	0.07
Data Security and Privacy issues (C12)	0.05	0.05	0.05	0.01	0.04	0.05	0.05	0.05	0.04	0.07	0.06	0

Table A4 Total relation matrix

Challenge	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	D
Lack of smart technologies for product recovery (C1)	0.04	0.03	0.09	0.05	0.02	0.05	0.07	0.07	0.03	0.01	0.01	0.01	0.49
Lack of smart technologies to forecast E-waste generation (C2)	0.09	0.03	0.12	0.08	0.06	0.07	0.08	0.04	0.06	0.01	0.02	0.01	0.67
Lack of awareness about the harmful impact of E-waste (C3)	0.17	0.12	0.08	0.11	0.11	0.13	0.14	0.09	0.08	0.06	0.07	0.06	1.23
Lack of acceptability for refurbished/repaired/recycled products (C4)	0.08	0.07	0.08	0.03	0.03	0.04	0.11	0.10	0.03	0.02	0.02	0.02	0.61
lack of smart technologies for tracking e-waste (C5)	0.10	0.08	0.13	0.08	0.03	0.12	0.12	0.07	0.07	0.02	0.06	0.02	0.91
Lack of machinery and equipment for segregation of E-waste (C6)	0.11	0.07	0.11	0.06	0.02	0.03	0.07	0.06	0.03	0.01	0.01	0.01	0.60
Insufficient strategies for integration of Industry 4.0 & C.E (C7)	0.23	0.20	0.24	0.15	0.14	0.19	0.10	0.13	0.18	0.10	0.11	0.10	1.88
Lack of awareness about I4.0 contributions to reverse logistics of E-waste (C8)	0.23	0.20	0.24	0.16	0.14	0.16	0.23	0.07	0.17	0.08	0.08	0.08	1.85
Decision support system for EOL treatment of E-waste (refurbishment/recycling) (C9)	0.08	0.07	0.12	0.07	0.02	0.10	0.07	0.06	0.03	0.01	0.01	0.01	0.66
Lack of awareness about CE practices (C10)	0.12	0.10	0.13	0.05	0.09	0.11	0.11	0.08	0.10	0.04	0.14	0.14	1.19
Inadequate waste management infrastructure (C11)	0.12	0.09	0.15	0.05	0.07	0.13	0.10	0.08	0.12	0.10	0.03	0.10	1.14
Data Security and Privacy issues (C12)	0.11	0.10	0.11	0.05	0.07	0.10	0.10	0.08	0.08	0.10	0.09	0.03	1.02
R	1.47	1.17	1.60	0.95	0.81	1.24	1.31	0.93	0.99	0.57	0.66	0.61	