

Exploring the Barriers to Circular Supply Chain Implementation in the Electric Battery Industry: A Perspective of Developing Country

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Abstract

The demand for electric batteries is rising in developing countries like Bangladesh due to the increased demand for electric vehicles and energy storage systems. However, electric batteries contain toxic substances such as lead (Pb) and sulphuric acid (H₂SO₄) that are extremely detrimental to the environment. Hence, sustainability is crucial for the Electric Battery Industries (EBIs). To make the supply chain circular, it is necessary to identify the underlying obstacles to implementing the Circular Supply Chain (CSC). This study aims to explore the barriers to implementing CSC in Bangladesh's EBIs. Related barriers were defined using the PESTEL (Political, Economic, Social, Technological, Environmental and Legal) framework, and the contextual relationship among the identified barriers was developed using Interpretive Structural Modelling (MICMAC i.e., Cross Impact Matrix Multiplication Applied to Classification technique), followed by a cause-effect analysis of the driving barriers to determine the root causes. Lack of sustainable development planning, lack of knowledge about the environment, health, and future generations, lack of coordination among industries and supply chain partners, increased competition, lack of investment in technological innovation, and low quality of circulated products are the root causes of the driving barriers to implementing CSC in Bangladesh's EBIs. Government and supply chain partners in EBIs must employ a comprehensive strategy for sustainable development. Implementation of CSC facilitates economic development, environmental enhancement, and job creation.

Keywords

CSC Adoption Barriers; Electric Battery Industries; PESTEL Framework; ISM-MICMAC Analysis; Cause-Effect Analysis

1. Introduction

In previous several years, researchers have emphasized on different aspects of Circular Supply Chain Management (CSCM) such as drivers, barriers, practices, models etc. Since drivers and barriers of CSC vary in different context, they need to be investigated in the respective cases (Farooque *et al.* 2019). Now the drivers and barriers have been studied in different geographical regions and different industrial setups. For instance, textile industries of Bangladesh (Tumpa *et al.* 2019) and Finland (Flink, 2017), leather industries of Bangladesh (Moktadir, Rahman *et al.* 2018), Indian context (Mangla *et al.* 2018), information technologies (IT) and electronic industries of China (Park *et al.*, 2010), retail industries of Finland (Aminoff and Kettunen 2016), Indian manufacturing industries (Gupta, Kusi-Sarpong and Rezaei, 2020), building sector of developing countries (Bilal *et al.* 2020; Hart *et al.* 2019) mining sector

(Singh *et al.* 2020) etc. Although some studies have been conducted on textile (Tumpa *et al.* 2019) and leather industries (Moktadir *et al.* 2018; Moktadir *et al.* 2020) of Bangladesh but there is a gap in Electric Battery Industries (EBIs) context. EBIs is one of the most growing industrial sectors in Bangladesh. According to Hasan (Hasan 2020), “In Bangladesh, there are 25 local firms in production which meet 90% of the local demand. The domestic market size is about 80,000,000,000 Taka. Every year the domestic demand is growing at 10-12%. Besides, Bangladesh exports electric batteries in more than 70 countries.” So, there is a great opportunity for Bangladesh in this sector. But there are some challenges too.

The most important challenge of this sector is that few harmful materials like lead (Pb) and dilute sulphuric acid (H₂SO₄) are used in these industries (Enayetullah *et al.* 2006). These materials are harmful for both human being and environment. According to the Institute of Health Metrics Evaluation, due to lead exposure Bangladesh has the world's fourth-highest rate of death (Selim 2021). Different health effects caused by lead pollution are cancer, kidney dysfunction, high blood pressure etc. and the environmental effects of lead pollution are decrease of soil fertility, water pollution, air pollution etc. (Uddin 2019). Sulphuric acid may cause harm to skin and sensitive organs while come into contact (Koehler 2019). If this factor is not considered, the development of this blessing sector will be unsustainable.

The supply chain of EBIs of Bangladesh is unsustainable. According to (Rahman 2021), “There are about 1100 informal and illegal recycling establishments all over the Bangladesh which recycle the lead by unregulated small-scale operators. During this process, vaporised lead contamination occurs in the air while being discarded acid pollutes the environment.” Since direct recycling process is illegal, this process is performed in hidden way (Chakraborty, 2020). Hence the supply chain of these industries should be more sustainable. CSC as a powerful tool of sustainable supply chain can be utilized in this sector.

Though CSC has many benefits, there are many barriers to implement it. For the successful implementation of CSC in EBIs of Bangladesh, the barriers need to be explored first. Now the research question is, “What are the root barriers of the CSC adoption in EBIs of Bangladesh?” It is important to identify the root barriers so that the implementation of CSC in EBIs of Bangladesh becomes easier, beneficial and sustainable. So, the objective of this research is to identify the root barriers of implementing CSC in EBIs of Bangladesh. The remainder of the paper is organized as follows. In Chapter 2, the applied methodologies are briefly described. Chapter 3 proposes a research methodology and conducts a case study on the intended case. Chapter 4 provides a brief discussion. Chapter 5 concludes the investigation by offering suggestions for future research.

2. Material and Methods

2.1 PESTEL Framework

At first, possible barriers should be identified. Most of the researchers have taken their initial input from the literature reviews (Govindan and Hasanagic 2018; Hart *et al.* 2019; Mangla *et al.* 2018; Moktadir *et al.* 2018; Ozkan-Ozen, Kazancoglu and Kumar Mangla, 2020) and very few barriers from the expert panel's opinions (Moktadir *et al.*, 2020). But most of them have not used any structural framework. As a consequence, they have not included many important factors in their initial point. For example, Mangla *et al.*, (Mangla *et al.*, 2018) did not considered any environmental barriers. Even though recently some researchers have structurally taken their initial input (Hart *et al.* 2019; Singh *et al.* 2020), they overlapped some points i.e. did not properly separate them. Both Hart *et al.*, (Hart *et al.* 2019) and Singh *et al.*, (Singh *et al.* 2020) overlapped technological, legal and internal factors. To overcome this problem, both external and internal barriers have been considered in this research. The PESTEL framework has been applied to understand the big picture in which the organisation is working (Issa, Chang and Issa, 2010). PESTEL stands for Political, Economic, Social, Technological, Environmental, and Legal. For the establishment of the CSC model, the PESTEL framework was used so that all types of barriers can be taken and the selection of the related barriers becomes easier (Carl Dalhammar 2019).

Political Barriers:

Political barriers determine the extent to which the government and government policies interfere in a particular sector. Examples include government policy, political stability or unpredictability on domestic and international markets, trade sanctions, fiscal incentives and taxation, labor laws, and environmental law. Companies must be able to adjust their business strategies to accommodate current and prospective regulations. (Carl Dalhammar, 2019)

- **Economic Barriers:** These factors have a direct impact on the economy, which in turn affects the profitability and business capacity of a company. Economic growth, employment rates, interest and exchange rates, inflation, disposable income of consumers, costs of basic materials and energy, etc. are all factors. (Carl Dalhammar 2019)
- **Social Barriers:** These sociocultural factors influence the requirements and desires of consumers, and they are of particular interest to advertisers. They consist of demographics, levels of education, general health status, behaviours and attitudes, as well as other characteristics and shared values and attitudes of the consumer population. (Carl Dalhammar 2019)
- **Technological Barriers:** Rapid technological advancement has a direct impact on the production and distribution of products. The production and distribution of products and services, as well as interactions with consumers, are all influenced by technological factors. Changes in automation and robotics, as well as developments in emergent and mobile technologies, are all important aspects to consider. (Carl Dalhammar, 2019)
- **Environmental Barriers:** These variables pertain to the effects of environmental constraints and conditions. Increasing environmental awareness among both government officials and consumers has increased the significance of environmental considerations. Concerns regarding resource depletion, pollution, carbon footprint, climate change, and other issues motivate companies to adopt more ethical and sustainable practices. CSR (Corporate Sustainability and Responsibility) strategies are growing in significance as the demand for ethically and sustainably sourced products increases. (Carl Dalhammar, 2019)
- **Legal Barriers:** Legal considerations include, among others, employment regulations, consumer rights, health and safety regulations, advertising, privacy, product labelling, warranties, and trade restrictions. Obviously, enterprises must be aware of the legal constraints under which they can operate. This is particularly challenging for organizations that operate internationally, as each country has its own set of rules and regulations. (Carl Dalhammar, 2019)

2.2 ISM-MICMAC Analysis

There are different multi-criteria decision analysis (MCDA) approaches like Best Worst Method (BWM), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Interpretive Structural Modelling (ISM), DEMATEL (Decision Making Trial and Evaluation Laboratory), Graph Theory, Structural Equation Modelling (SEM) etc. to prioritise and find out the interrelationship among the identified barriers. In literature BWM (Gupta, Kusi-Sarpong and Rezaei, 2020; Moktadir *et al.* 2020), ISM-MICMAC (Bilal *et al.* 2020; Mangla *et al.* 2018), AHP (Kumar, Singh and Kumar 2021), ANP (Ozkan-Ozen, Kazancoglu and Kumar Mangla, 2020), DEMATEL (Zhang *et al.* 2019) and Graph Theory (Moktadir, Ali, *et al.* 2018) have been used in sustainable and circular economy context. According to Moktadir *et al.* (Moktadir, Ali, *et al.* 2018) BWM, AHP, ANP and SEM do not provide interdependence of the variables. They also argued that Graph theory is also unable to identify the interaction of the sub-factors. But ISM-MICMAC approach gives a well-structured interactive interaction among the variables (Bilal *et al.* 2020; Mangla *et al.* 2018). On the other hand, some researchers have taken different strategy. They have used hybrid model for better understanding of the interaction among barriers of the CSC. For example, Singh *et al.*, (Singh *et al.* 2020) have adopted AHP to prioritise the barriers and Graph Theory to find out the intensity of the barriers. But they did not investigate the interaction among the barriers. So, the driving barriers need to be identified and the interaction among the barriers should be captured. ISM-MICMAC approach fulfil the purpose completely (Mangla *et al.* 2018). To investigate the interaction among the barriers, ISM-MICMAC approach has been used in this study.

There is a well acceptance of ISM-MICMAC technique in literature. The application of ISM-MICMAC technique in some relevant areas are shown in Table 1.

Table 1. Application of ISM-MICMAC technique in relevant areas

Sl. No.	Application area of ISM-MICMAC technique	References
1	Logistics in reverse	(Ravi and Shankar, 2005)
2	Management of a green supply chain	(Agi and Nishant, 2017)
3	Sustainable supply chain management	(Raut, Narkhede and Gardas, 2017)
4	Circular supply chain management	(Mangla <i>et al.</i> , 2018)
5	Circular economy in building sector	(Bilal <i>et al.</i> , 2020)

The stages in the ISM-MICMAC approach are as follows (Haleem *et al.*, 2016), which are discussed in the light of the challenges of implementing CSC in Bangladesh's EBIs (Mangla *et al.*, 2018).

- i. Using a literature review and expert feedback, identify the initial variables in relation to the research issue (barriers to CSC adoption in Bangladeshi EBIs).
- ii. Establish pair-wise relations between defined barriers to build a Structural Self-Interaction Matrix (SSIM).
- iii. Using SSIM, construct an Initial Reachability Matrix (IRM). To construct the Final Reachability Matrix, transitivity is checked (FRM). For more information on transitivity, readers can review the research of Agarwal, Shankar and Tiwari (2007) and Attri, Dev and Sharma (2013). The FRM is then used to measure driving and dependency power by summing the rows and columns, respectively.
- iv. The reachability sets and antecedent sets for each element are extracted from the FRM and used to determine different levels. A specific barrier is grouped with other barriers that are influenced by that specific barrier in the reachability sets. The antecedent sets, on the other hand, combine a specific barrier with other barriers that influence that specific barrier. The intersection set is generated by combining these two sets.
- v. The identified barriers are then subjected to a MICMAC analysis, which is a graph depicting the driving and dependency power of the variables. The barriers are divided into four groups based on their driving and dependency power (driving, autonomous, dependent and linkage).
- vi. A digraph based on FRM relations is sketched for visual representation of the barriers and their interdependence. It is created with the help of nodes and edge lines.
- vii. Finally, the ISM-based structural model is developed with the help of the digraph.

The flow diagram of the ISM-MICMAC analysis for the research problem is demonstrated in Figure 1.

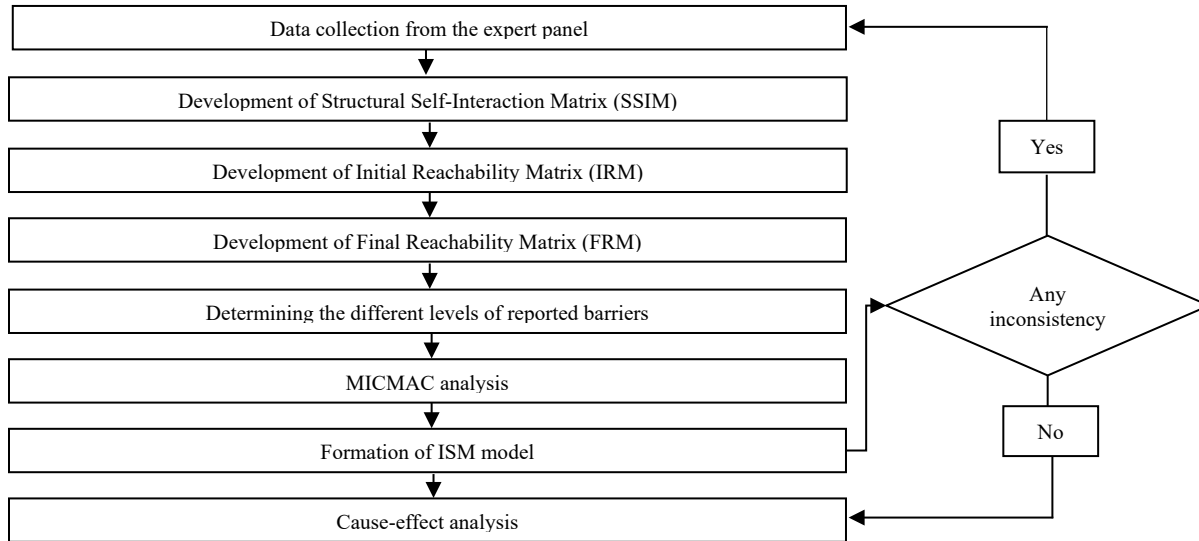


Figure 1. Flowchart of ISM-MICMAC technique

2.3 Cause-Effect Analysis

Finally, the driving barriers from the result of ISM-MICMAC approach need to be analysed so that the root causes behind the driving barriers can be identified. Although some researchers recently wanted to apply cause-effect diagram in CSC (Ozkan-Ozen, Kazancoglu and Kumar Mangla, 2020), nobody applied it yet. Hence there is a research gap.

Cause-effect diagram is also called Fishbone diagram or Ishikawa diagram. It is one of seven basic quality tools. The purpose of this diagram is to represent the relationship between the causes and effect (Transactions, Fabi and Domaga, 2017). The general procedure to draw a cause-effect diagram is given below:

- i. By the agreement on a problem statement (effect), it is written in a box at the centre right of the drawing area and a horizontal arrow is drawn running to it.
- ii. The major categories of causes of effect are written as branches from the main arrow.
- iii. Then the possible causes of each category are determined by brainstorming and written as a branch of relevant category.
- iv. The deeper levels of causes are produced until the group runs out of ideas.

3. Research Methodology

3.1 Proposed Research Framework

The proposed framework for identifying, prioritising and analysing the major barriers of CSC implementation of EBIs in Bangladesh have been shown in Figure 2. This framework is not only applicable but also has reliable nomenclature (Baines, Kay and Hamblin, 1994; Platts and Gregory, 1990). Suggestions given by Platts and Gregory (1990) and from the identified research gaps have been used in this research framework.

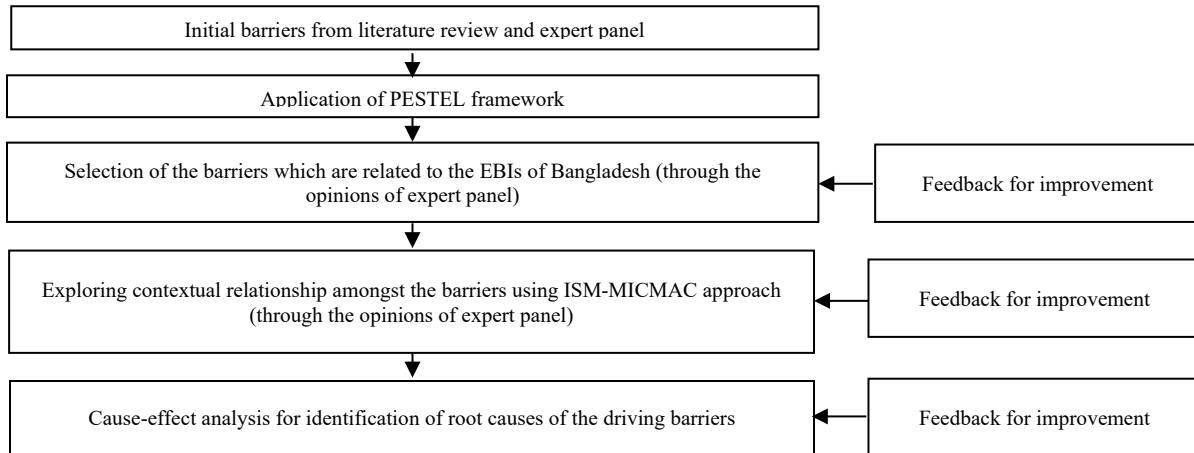


Figure 2. Proposed research framework

In the sub sequent section, the proposed research framework has been applied for the intended research problem.

3.2 Application of Proposed Research Framework

The major barriers of CSC implementation have been identified in context of EBIs of Bangladesh. For that purpose, the initial barriers have been categorised with the help of PESTEL framework. The initial barriers were collected from existing literature. Then the expert panel have chosen the utile barriers. The opinions of the expert panel were collected by an online survey with the help of “Google Form”. After that, the contextual relationship amongst the barriers was established by means of ISM-MICMAC technique. Finally, the cause-effect diagram was applied to find out the major barriers from the driving barriers.

The information for this study was gathered from two leading battery manufacturing industries of Bangladesh called “Confidence Batteries Limited” and “Rohimafrooz Batteries Limited”. Both the industries use ‘Recycling’ as the circular strategy. These industries were chosen based on the principle of convenience sampling. Initially nine experts were selected for the surveys and four experts gave their valuable opinion to select and analyse the barriers of CSC adoption in EBIs of Bangladesh. The expert panel consisted of one manager, one deputy manager and two senior executives. In terms of experience, expertise, and decision-making, they are highly qualified.

3.2.1 Classification of the Initial Inputs

At first the initial barriers have been taken from the literature. These barriers are shown in Table 2 (Ozkan-Ozen, Kazancoglu and Kumar Mangla, 2020). Classification of the initial input helps to cover all the possible barriers. If the initial barriers are selected randomly, there is a possibility to miss some of the important variables. To overcome the shortcoming, PESTEL framework is a suitable tool.

Table 2. The initial barriers of CSC adoption

Sl. No.	Barriers	References
1	Lack of industry incentives for ‘greener’ activities	(Mangla <i>et al.</i> , 2018)
2	Lack of rules and regulations about the environment	
3	The indifference of management and lack of planning for CSC adoption	
4	Lack of favorable tax systems for supporting CSC	
5	Lack of environmental certification systems	

6	Lack of middle and lower level managers' support and involvement in promoting 'greener' products	
7	Lack of customer consciousness and involvement around CSC activities	
8	Poor demand for environmentally preferred technologies	
9	Inadequate technology transfer initiatives	
10	Lack of awareness and consciousness about CSC among the organizational members	
11	Inadequate training and improvement programs for SC (Supply Chain) members and HR (Human Resources)	
12	Ineffective management of CSC concepts	
13	Unsystematic information systems	
14	Lack of coordination and collaboration amongst the SC partners	
15	Low financial benefits in the short-run	
16	Lack of transportation and infrastructure	(Bressanelli <i>et al.</i> , 2018)
17	Uncertainty of return flows	
18	Lack of suitable supply chain partners	
19	Cultural concerns (linear mindset of the customers)	
20	Lack of eco-efficient technological processes	
21	Lack of technological improvement	
22	Lack of data privacy and security	
23	Lack of vision	(Saroja, Garg and Luthra, 2018)
24	Lack of standard systems	
25	Higher initial cost	
26	Lack of funding	
27	Higher production cost	
28	Inadequacy in information sharing among the SC partners	
29	Unskilled workers	
30	Inadequate information about the best available technology	(Pan <i>et al.</i> , 2015)
31	Lack of local technologies	
32	Difficulty of selecting cost-efficient technology	
33	Internal bureaucracy for implementing CSC	
34	Lack of environmental effect measurement (certification)	(Levering and Vos, 2019)
35	Lack of transparency within the stakeholders	
36	High costs to develop circular alternatives	
37	Lack of standard method for performance indicators about evaluating CSC	(Govindan and Hasanagic, 2018)
38	Lack of clear vision about CSC	
39	Lack of economic incentives to implement CSC	
40	Higher costs of recycled materials than the virgin materials	
41	Lack of technology for tracking circulated materials	
42	Difficulty to maintain the product quality throughout the lifecycle	
43	Challenges to design circulated products	
44	Difficulty to take proper decision for implementing CSC	
45	Lack of information systems for tracking circulated products	
46	Lack of leadership and management towards CSC	
47	Unfavorable organizational structure to implement CSC	
48	Inadequacy in triumphant business models and frameworks to adopt CSC	
49	Lack of interest towards CSC	

External Barriers

- **Political Barriers:** Many countries are taking initiative for promoting CSC. For example, to promote CSC, Sweden has lowered value added tax (VAT) on repair services and labour taxes for repair work. (Carl Dalhammar, 2019). In Bangladesh, however, there are no strict regulations about CSC. As a result, in the sense of Bangladesh's EBIs, this is a critical category.
- **Economic Barriers:** Since organisations give top priority to their economic growth, these factors should be considered carefully.
- **Social Barriers:** The success of any business is entirely dependent on customer satisfaction. As a result, every company strives to please its customers. Customers' requirements are, after all, what quality is known as.
- **Technological Barriers:** Now-a-days, it is the age of science and technology. So, businesses rely heavily on this factor.
- **Environmental Barriers:** Since CSC is an emerging research topic, there are few confusions among the researchers about the environmental benefits. So, these factors need to be analysed in respect to different circular business model.
- **Legal Barriers:** Recently many EBIs of Bangladesh are exporting their products in more than 70 countries of the world like Singapore, Australia, Russia, India, Chile, Middle East etc. (Hasan, 2020). Therefore, these types of barriers are relevant to the intended case.

Internal Barriers

Internal barriers are the barriers that are related to the internal operations and management of the organisations. There are many internal barriers which many organizations are facing for the implementation of circular business (Vermunt *et al.*, 2019). Since a new model of closed-loop is adopted by the organisation, it has to change many things (Singh *et*

al., 2020). There are several circular business models available, including product-as-a-service, resource recovery, product life extension, circular supply, and hybrid models (Vermunt *et al.*, 2019) and strategies like reducing, reusing, recycling, recovering etc. (Kirchherr *et al.*, 2018). The barriers vary depending on the circular business models and strategies employed. Hence appropriate internal barriers of CSC implementation in context of EBIs of Bangladesh also need to be considered.

We classified the external barriers of Table 1 as per the PESTEL framework. But the industry related barriers of Table 1 were taken as internal barriers. The classification of the initial barriers is shown in Table 3.

Table 3. Classification of the initial barriers

Types of Barriers	Barriers
Political	<ol style="list-style-type: none"> 1. Lack of rules and regulations about the environment 2. Lack of favorable tax systems for supporting CSC 3. Lack of environmental certification systems
Economic	<ol style="list-style-type: none"> 1. Low financial benefits in the short-run 2. Higher initial cost 3. Lack of funding 4. Higher production cost 5. High costs to develop circular alternatives 6. Lack of economic incentives to implement CSC 7. Higher costs of recycled materials than the virgin materials
Social	<ol style="list-style-type: none"> 1. Lack of customer consciousness and involvement around CSC activities 2. Poor demand for environmentally preferred technologies 3. Cultural concerns (linear mindset of the customers)
Technological	<ol style="list-style-type: none"> 1. Inadequate technology transfer initiatives 2. Unsystematic information systems 3. Lack of eco-efficient technological processes 4. Lack of technological improvement 5. Lack of standard systems 6. Inadequate information about the best available technology 7. Lack of local technologies 8. Difficulty of selecting cost-efficient technology 9. Lack of standard method for performance indicators about evaluating CSC 10. Lack of technology for tracking circulated materials 11. Challenges to design circulated products 12. Inadequacy in triumphant business models and frameworks to adopt CSC
Environmental	<ol style="list-style-type: none"> 1. Lack of environmental effect measurement (certification)
Legal	<ol style="list-style-type: none"> 1. Lack of data privacy and security 2. Warranty issues with circulated products 3. Lack of health and safety standards in CSC 4. Uncertainty of return flows
Internal	<ol style="list-style-type: none"> 1. Lack of industry incentives for 'greener' activities 2. The indifference of management and lack of planning for CSC adoption 3. Lack of middle and lower level managers' support and involvement in promoting 'greener' products 4. Lack of awareness and consciousness about CSC among the organizational members 5. Inadequate training and improvement programs for SC members and HR 6. Lack of effective planning and management for CSC concepts 7. Lack of coordination and collaboration amongst the SC partners 8. Lack of transportation and infrastructure 9. Lack of suitable supply chain partners 10. Lack of vision 11. Inadequacy in information sharing among the SC partners 12. Unskilled workers 13. Internal bureaucracy for implementing CSC 14. Lack of transparency within the stakeholders 15. Lack of clear vision about CSC 16. Difficulty to maintain the product quality throughout the lifecycle 17. Difficulty to take proper decision for implementing CSC 18. Lack of information systems for tracking circulated products 19. Lack of leadership and management towards CSC 20. Unfavorable organizational structure to implement CSC 21. Lack of interest towards CSC

3.2.2 Contextual Relationship among the Identified Barriers

Selection of Initial Barriers

The important barriers related to CSC implementation in EBIs were selected though an online survey among the expert panel. To select any barrier at least 50% or more experts' positive opinion was considered as selection criteria. Selected 16 barriers are shown in the Table 4.

Table 4. Initial barriers for ISM model

Barriers	% Experts' Positive Opinion
Lack of rules and regulations about the environment (B1)	75%
Lack of favorable tax systems for supporting CSC (B2)	50%
Low financial benefits in the short-run (B3)	75%
Higher costs of recycled materials than the virgin materials (B4)	50%
Lack of customer consciousness and involvement around CSC activities (B5)	75%
Cultural concerns (linear mindset of the customers) (B6)	50%
Inadequate technology transfer initiatives (B7)	50%
Unsystematic information systems (B8)	50%
Lack of technology for tracking circulated materials (B9)	50%
Inadequacy in triumphant business models and frameworks to adopt CSC (B10)	50%
Lack of environmental effect measurement (certification) (B11)	100%
Warranty issues with circulated products (B12)	75%
Lack of industry incentives for 'greener' activities (B13)	75%
The indifference of management and lack of planning for CSC adoption (B14)	50%
Lack of awareness and consciousness about CSC among the organizational members (B15)	50%
Lack of effective planning and management for CSC concepts (B16)	50%

Description of the initial barriers is shown in **Appendix A**.

Development of Structural Self-Interaction Matrix (SSIM)

The relationship among the selected 16 barriers have been identified by the help of experts' opinion. The relationship was 'lead to' type relation i.e., whether a particular barrier leads to another particular barrier? This pairwise comparison represents the direction of relation between the barriers. Some well-known symbols (Mangla *et al.*, 2018) have been used in this step. They are as follow:

- V – Barrier i will help to get to barrier j
- A – Barrier j will help to get to barrier i
- X – Barriers i and j will help to get each other
- O – There are no relation between barriers i and j

The Structural Self-Interaction Matrix is demonstrated in the Table 5.

Table 5. Structural Self-Interaction Matrix (SSIM)

Barriers	B16	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2
B1	V	O	V	V	O	V	O	V	O	O	V	V	V	O	V
B2	V	O	X	X	O	O	O	O	O	O	O	O	V	V	
B3	A	A	V	V	O	O	A	A	A	A	O	O	A		
B4	A	A	V	O	O	O	O	A	A	O	O	O			
B5	A	O	A	X	A	A	A	O	V	O	X				
B6	O	V	X	X	A	A	O	O	O	O					
B7	O	V	V	V	O	V	V	V	V						
B8	X	O	X	X	O	V	O	X							
B9	V	O	V	V	O	O	O								
B10	X	A	X	X	O	A									
B11	X	X	X	X	O										
B12	O	O	V	V											
B13	V	X	X												
B14	V	X													
B15	V														

Development of Initial Reachability Matrix (IRM)

The IRM was generated by replacing the entries in SSIM with binary numbers (0 and 1). The replacement logics are as follows:

- For every V in SSIM, we put '1' in (i, j) entry and '0' in (j, i) entry.
- For every A in SSIM, we put '0' in (i, j) entry and '1' in (j, i) entry.
- For every X in SSIM, we put '1' in both (i, j) and (j, i) entries.
- For every O in SSIM, we put '0' in both (i, j) and (j, i) entries.

The IRM is demonstrated in the Table 6.

Table 6. Initial Reachability Matrix (IRM)

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
B1	1	1	0	1	1	1	0	0	1	0	1	0	1	1	0	1
B2	0	1	1	1	0	0	0	0	0	0	0	0	1	1	0	1
B3	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0
B4	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0
B5	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0
B6	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	0
B7	0	0	1	0	0	0	1	1	1	1	1	0	1	1	1	0
B8	0	0	1	1	0	0	0	1	1	0	1	0	1	1	0	1
B9	0	0	1	1	0	0	0	1	1	0	0	0	1	1	0	1
B10	0	0	1	0	1	0	0	0	0	1	0	0	1	1	0	1
B11	0	0	0	0	1	1	0	0	0	1	1	0	1	1	1	1
B12	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0	0
B13	0	1	0	0	1	1	0	1	0	1	1	0	1	1	1	1
B14	0	1	0	0	1	1	0	1	0	1	1	0	1	1	1	1
B15	0	0	1	1	0	0	0	0	0	1	1	0	1	1	1	1
B16	0	0	1	1	1	0	0	1	0	1	1	0	0	0	0	1

Development of Final Reachability Matrix (FRM)

The IRM was transformed into FRM using the transitivity rule. Transitivity rule represents nothing but the indirect links between two barriers. For example, barrier B1 leads to barrier B2 but not barrier B3. On the other hand, barrier B2 drives barrier B3. So, there is an indirect link between the barriers B1 and B3. This indirect link is represented by bolded one i.e., **1**. The FRM is shown in the following Table 7. The driving power (DR_p) was calculated by adding up the FRM's row entries, and the dependence power (DE_p) was calculated by adding up the FRM's column entries.

Table 7. Final Reachability Matrix (FRM)

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	DR _p
B1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	14
B2	0	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	12
B3	0	1	1	0	1	1	0	1	0	1	1	0	1	1	1	1	11
B4	0	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	12
B5	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	13
B6	0	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	12
B7	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	14
B8	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	13
B9	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	13
B10	0	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	12
B11	0	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	12
B12	0	1	0	0	1	1	0	1	0	1	1	1	1	1	1	1	11
B13	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	13
B14	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	13
B15	0	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	12
B16	0	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	12
DE _p	1	15	15	14	16	16	1	16	8	16	16	1	16	16	16	16	199

Level Partitioning

After the construction of FRM, the barriers have been partitioned into different levels to know the relative importance. At first the reachability set and the antecedent set have been constructed from the FRM. A specific barrier was grouped with other barriers that are influenced by that specific barrier in the reachability sets. The antecedent sets, on the other hand, combine a specific barrier with other barriers that influence that specific barrier. The intersection set was then generated by combining the reachability and antecedent sets. This process is carried out for each obstacle. Finally, the obstacles have been leveled with which the reachability and intersection sets are similar. If a barrier has been levelled, it can no longer be used. The iterations are shown in **Appendix B**. The barriers' final levels are listed in Table 8.

Table 8. Levels of the barriers

Sl. No.	Level Number	Barriers
1	1 st	<ul style="list-style-type: none"> • Low financial benefits in the short-run • Higher costs of recycled materials than the virgin materials • Lack of customer consciousness and involvement around CSC activities • Cultural concerns (linear mindset of the customers) • Unsystematic information systems • Inadequacy in triumphant business models and frameworks to adopt CSC • Lack of environmental effect measurement (certification) • Lack of industry incentives for 'greener' activities • The indifference of management and lack of planning for CSC adoption • Lack of awareness and consciousness about CSC among the organizational members • Lack of effective planning and management for CSC concepts
2	2 nd	<ul style="list-style-type: none"> • Lack of favorable tax systems for supporting CSC
3	3 rd	<ul style="list-style-type: none"> • Lack of technology for tracking circulated materials • Warranty issues with circulated products
4	4 th	<ul style="list-style-type: none"> • Lack of rules and regulations about the environment • Inadequate technology transfer initiatives

MICMAC Analysis

The MICMAC study assists in getting a deeper understanding of the causes and implications of the troublesome issues (Mangla *et al.*, 2018). Based on the driving and dependency power, MICMAC analysis divides the barriers into four different categories. According to Mangla *et al.*, (Mangla *et al.*, 2018), they are as follows:

- Autonomous:** These barriers are characterized by low driving and dependency power (lower left quadrant), as well as being fairly detached from the system.
- Dependent:** Poor driving power and high dependency power (lower right quadrant); and coming on top of an ISM-based hierarchical model are among these obstacles. These barriers should be considered essential since their heavy dependency indicates that they require the elimination of all other barriers in order to implement CSC concepts.
- Linkage:** The barriers which have strong driving and dependence power (upper right quadrant) are categorised as linkage, which are located in the centre of the ISM-based hierarchical model. Since these obstacles are unpredictable, they require careful study, and practitioners should keep an eye on them at all levels of implementation.
- Drivers:** These barriers have high driving power and low dependence power (upper left quadrant); and located at the bottom of the ISM model.

The MICMAC analysis diagram is demonstrated in the following Figure 3.

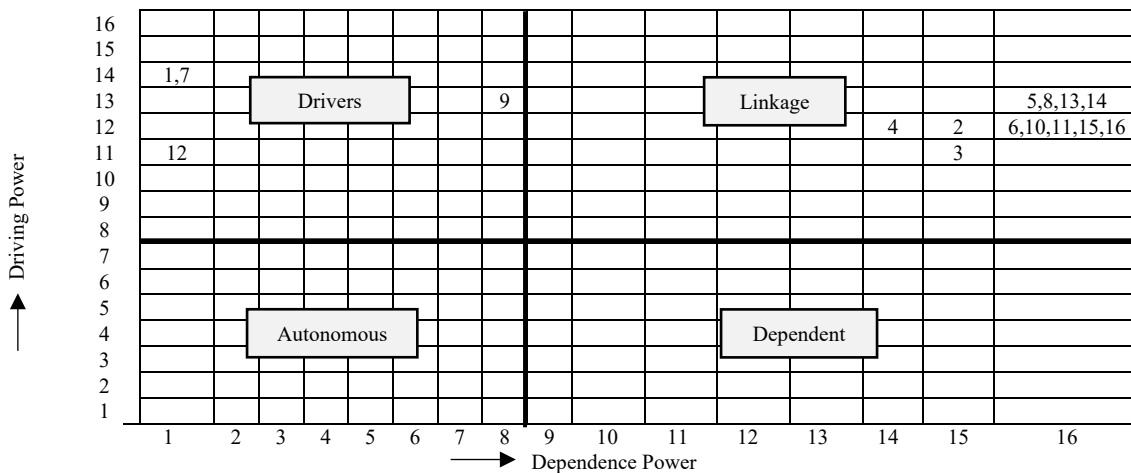


Figure 3. MICMAC analysis diagram

Development of Digraph and ISM Model

The digraph is a structural model constructed using the FRM (Mangla *et al.*, 2018). The digraph for the intended problem is shown in Figure 4.

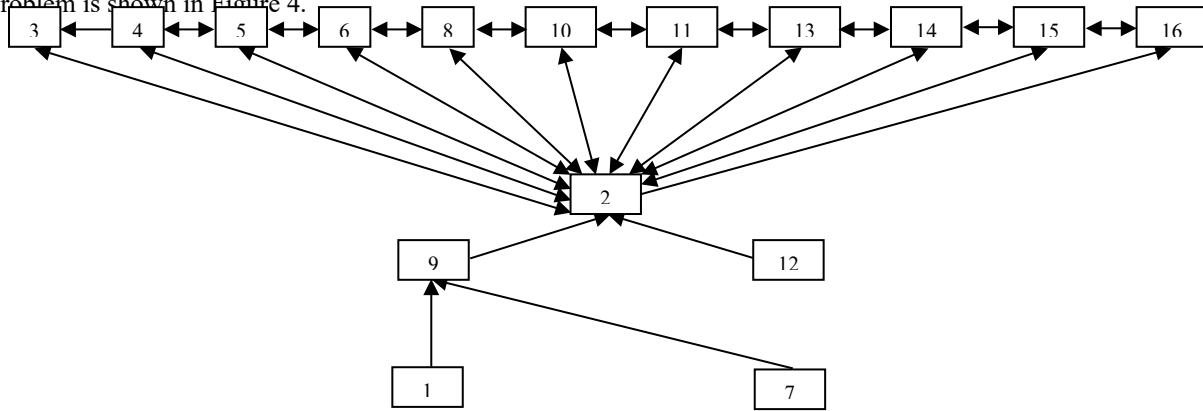


Figure 4. Digraph of the barriers of CSC adoption

The digraph was then converted into an ISM-based model by placing the barriers in the appropriate nodes. The ISM model is presented in Figure 5.

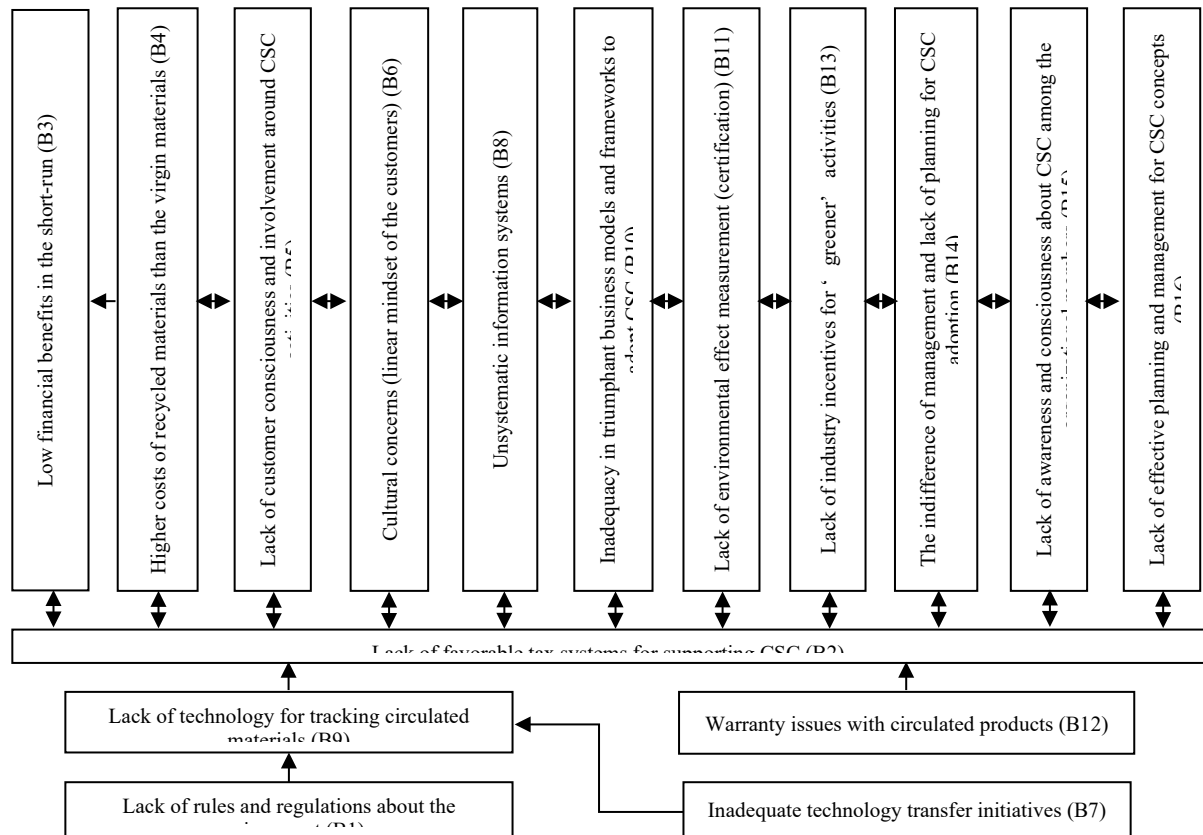


Figure 5. ISM model of the barrier of CSC

The MICMAC diagram shows that there are four driving barriers called “Lack of rules and regulations about the environment (B1)”, “Inadequate technology transfer initiatives (B7)”, “Lack of technology for tracking circulated materials (B9)” and “Warranty issues with circulated products (B12)”. Among the four driving barriers, “Lack of rules and regulations about the environment (B1)” and “Inadequate technology transfer initiatives (B7)” drive “Lack of technology for tracking circulated materials (B9)”. Finally, the cause-effect analysis has been conducted to find out the root causes of the driving barriers.

3.2.3 Cause-Effect Analysis

Here the effect was “Less CSC practices in EBIs of Bangladesh” and the causes were identified in respect to the driving barriers of ISM. The cause-effect diagram is shown in Figure 6.

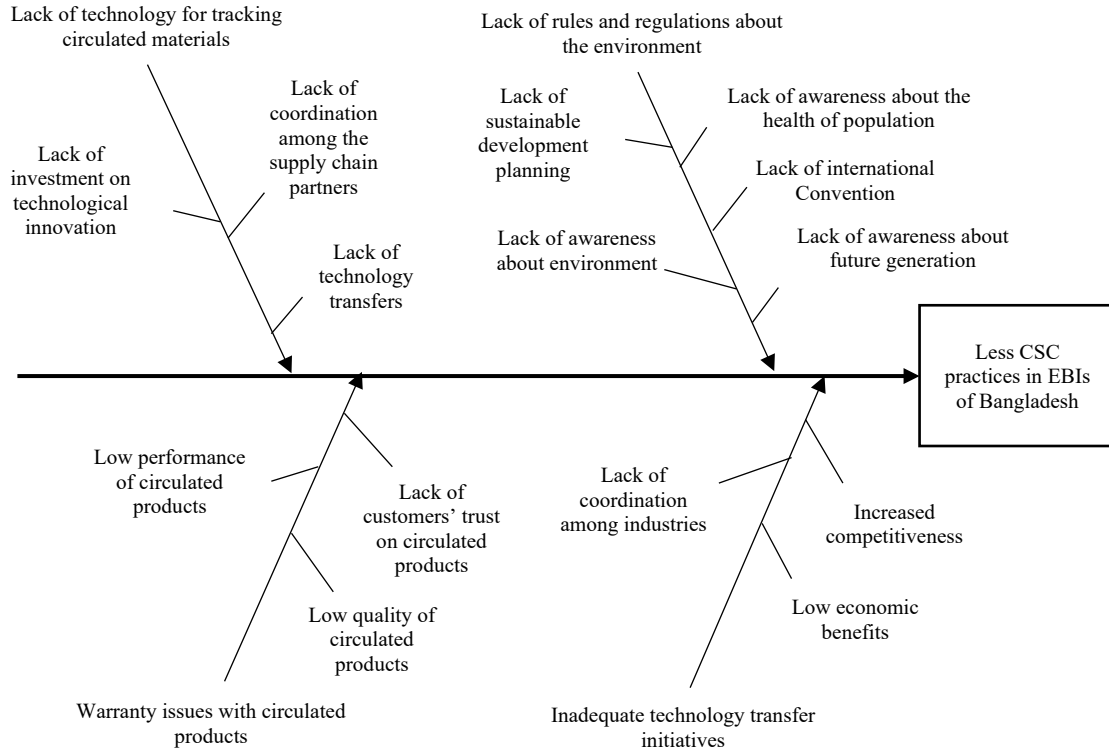


Figure 6. Cause-Effect Analysis

4. Discussion

Bangladesh's electric battery industry faces a number of fundamental obstacles due to the absence of environmental laws and guidelines. These include the lack of planning for sustainable development, limited awareness of environmental issues, insufficient consideration of population health, the absence of international conventions, and deficient awareness of future generations. To overcome these obstacles, comprehensive efforts are required to develop sustainable plans, raise awareness, prioritize health concerns, advocate for international agreements, and stress the significance of environmental preservation for future generations.

Inadequate technology transfer in the Bangladeshi electric battery industry is caused by obstacles such as a lack of coordination between industries, increased competition, and low economic benefits. To overcome these obstacles, collaboration must be fostered, competitive concerns must be addressed, and the economic benefits of technology transfer must be highlighted.

Several obstacles account for the absence of technology for tracking circulated materials in the Bangladeshi battery industry. First, the lack of technology transmission impedes the acquisition and implementation of sophisticated tracking systems. Second, the dearth of coordination between supply chain partners complicates the industry-wide

adoption of a unified tracking technology. Insufficient investment in technological innovation impedes the creation of effective monitoring solutions. Promoting technology transfers, enhancing supply chain partner coordination, and increasing investment in technological advances for enhanced material tracking capabilities are required to overcome these obstacles.

Several obstacles can be attributed to warranty issues with circulating products in the Bangladeshi battery industry. Customers' reluctance to rely on warranty provisions is hampered, initially, by their lack of faith in widely distributed goods. Second, the poor performance of resold products diminishes customer satisfaction and faith in the warranty coverage. Lastly, the poor quality of widely distributed products diminishes the perceived value and dependability of warranties. In order to overcome these obstacles, it is necessary to develop customer trust through transparent practices, improve the performance of products that are circulated, and ensure high-quality standards in order to instill confidence in warranty provisions and increase customer satisfaction.

5. Conclusion and Future Work

The primary objective of this study was to investigate and identify the barriers to implementing a circular supply chain (CSC) in the Bangladeshi electric battery industries (EBIs). The objective was to acquire an understanding of the barriers impeding the industry's transition to a more sustainable and circular approach. This study has identified the main obstacles and their underlying causes that impede the implementation of a circular supply chain in the Bangladeshi battery industry. Regarding environmental rules and regulations, the absence of sustainable development planning, a lack of environmental awareness, and insufficient consideration for future generations were identified as root causes. Concerning technology transfer initiatives, the fundamental causes include a lack of coordination among supply chain partners, increased competitiveness resulting in limited knowledge sharing, and inadequate investment in technological innovation. Lack of technology transfers, lack of coordination among supply chain partners, and inadequate investment in technological innovation are identified as the primary causes for the lack of technology for tracking circulated materials. Lastly, the fundamental causes for warranty issues with circulated products are discovered to be a lack of customer trust in circulated products, poor performance and poor quality of circulated products. To address these fundamental causes, comprehensive sustainable development planning, improved stakeholder coordination, increased investment in technological innovation, and efforts to increase customer trust are required. By addressing these obstacles and their underlying causes, the implementation of a circular supply chain can be facilitated, resulting in sustainable development, economic growth, environmental improvement, and increased employment opportunities in the Bangladeshi battery industry.

The findings of this investigation have substantial implications for the Bangladeshi EBIs. To address the identified barriers to implementing a circular supply chain, the government, industry stakeholders, and supply chain partners must coordinate their efforts. Enhancing technology transfer, adopting advanced tracking systems, and enhancing the performance and quality of circulated products are essential for fostering sustainability and establishing consumer confidence. These initiatives will contribute to sustainable development, economic expansion, environmental enhancement, and job creation. To successfully transition to a circular supply chain in the EBIs, which will benefit both the industry and the broader socioeconomic landscape, a holistic approach and the implementation of collaborative measures are essential.

Future research should investigate strategies for overcoming the identified obstacles to instituting a circular supply chain in the Bangladeshi battery industry. The findings are applicable to other industries and promote sustainable development. Further research should investigate the applicability of these obstacles and strategies in a variety of contexts, thereby advancing the understanding and implementation of circular supply chains.

This study concludes by highlighting the obstacles to implementing a circular supply chain in the Bangladeshi battery industry. The findings highlight the importance of coordinated efforts to overcome these obstacles and promote sustainability. Adopting circular supply chain practices is necessary for the industry to achieve sustainable development and resource efficiency.

Conflict of Interest

The author(s) declare no conflict of interest (financial or non-financial).

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Biography

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Appendices

Appendix A. Description of Selected Barriers

- Lack of rules and regulations about the environment (B1): The government organizations must formulate rigorous environmental rules and regulations for increased carbon emissions, energy demand and ecological issues (Mangla *et al.*, 2018). Though there are some environmental laws in Bangladesh, there is not strict regulatory structure to adopt CSC models.
- Lack of favourable tax systems for supporting CSC (B2): Loans with lower interest rates and tax benefits help to promote CSC concepts. Bangladesh Bank, the central bank of Bangladesh, encourages the banks and financial institutions for financing the green projects to ensure sustainable development in the country (Bhuiyan *et al.*, 2020). However, there are still no preferential tax schemes in place to attract companies.
- Low financial benefits in the short-run (B3): The circular business models take longer time to stabilize than linear business models. As a result, there is Low financial benefits in the short-run and it is considered as an important hurdle.
- Higher costs of recycled materials than the virgin materials (B4): Consumers aren't often conscious about the lifecycle of the product because of the lower price of the virgin materials than recycled materials (Govindan and Hasanagic, 2018).
- Lack of customer consciousness and involvement around CSC activities (B5): There is a natural apathy for circulated products among the customers. As a result, it is one of the main roadblocks to the implementation of circular supply chain models.
- Cultural concerns (linear mind-set of the customers) (B6): Internal resistance to change, particularly in light of the prevalent linear mind-set and systems, acts as a roadblock to implement CSC.
- Inadequate technology transfer initiatives (B7): Technology transfer is the process of passing on cutting-edge technology from an inventor to a secondary recipient in order to increase the efficacy of CSC initiatives (Mangla *et al.*, 2018). However, due to the lack of incentives for inventors, there are insufficient technology transfer initiatives.
- Unsystematic information systems (B8): Because of the nature of CSC models, they require a systematic information system. But such systems are lacking in the EBIs of Bangladesh.
- Lack of technology for tracking circulated materials (B9): There are lack of technologies to track the circulated products. As a result, recovering and reusing goods and parts is becoming more difficult.
- Inadequacy in triumphant business models and frameworks to adopt CSC (B10): Since CSC is a new concept, there are few successful business models and frameworks.
- Lack of environmental effect measurement (certification) (B11): Lack of measuring environmental impact acts as a barrier. If there is proper certification system, the importance of CSC will be realized properly.
- Warranty issues with circulated products (B12): Since there is lack of faith in circulated products, the business organizations need to assure customers by giving warranty facilities.
- Lack of industry incentives for 'greener' activities (B13): For the association of additional costs in greener activities, the industries show less interest in this area.

- The indifference of management and lack of planning for CSC adoption (B14): Without management commitment and proper initiatives, it is impossible to implement CSC. In reality, however, management is uninterested in CSC. As a result, it is regarded as one of the major roadblocks to CSC adoption.
- Lack of awareness and consciousness about CSC among the organizational members (B15): Since CSC is an emerging topic, there is lack of scientific knowledge among the organizational members about the business models and frameworks of CSC. Without proper knowledge and skills, it is not possible to implement CSC.
- Lack of effective planning and management for CSC concepts (B16): Effective planning and management are required to implement CSC strategies (repair, reuse, remanufacturing and recycling). Supply chain players are misled into focusing on the crucial issues in CSC adoption due to a lack of strategic planning and management.

Appendix B. Iterations of Level Partitioning

1st Iteration

Element (P _i)	Reachability Set: R(P _i)	Antecedent Set: A(P _i)	Intersection Set: R(P _i) & A(P _i)	Level
1	1,2,3,4,5,6,8,9,10, 11,13,14,15,16	1	1	
2	2,3,4,5,6,8,10,11,13,14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15	2,3,4,5,6,8,10,11, 13,14,15	
3	2,3,5,6,8,10,11,13,14,15,16	1,2,3,4,5,6,7,8,9,10, 11,13,14,15,16	2,3,5,6,8,10,11,13, 14,15,16	1
4	2,3,4,5,6,8,10,11,13, 14,15,16	1,2,4,5,6,7,8,9,10,11,13,14,15,16	2,4,5,6,8,10,11,13, 14,15,16	1
5	2,3,4,5,6,8,9,10,11, 13,14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,9,10,11, 13,14,15,16	1
6	2,3,4,5,6,8,10,11,13, 14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,10,11, 13, 14,15,16	1
7	2,3,4,5,6,7,8,9,10,11,13,14,15,16	7	7	
8	2,3,4,5,6,8,9,10,11, 13,14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,9,10,11, 13,14, 15,16	1
9	2,3,4,5,6,8,9,10,11, 13,14,15,16	1,5,7,8,9,13,14,16	5,8,9,13,14,16	
10	2,3,4,5,6,8,10,11,13, 14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,10,11,13,14,15,16	1
11	2,3,4,5,6,8,10,11,13, 14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,10,11, 13,14,15,16	1
12	2,5,6,8,10,11,12,13, 14,15,16	12	12	
13	2,3,4,5,6,8,9,10,11, 13,14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,9,10,11, 13,14,15,16	1
14	2,3,4,5,6,8,9,10,11, 13,14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,9,10,11, 13,14,15,16	1
15	2,3,4,5,6,8,10,11,13, 14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	2,3,4,5,6,8,10,11, 13,14,15,16	1
16	3,4,5,6,8,9,10,11,13, 14,15,16	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	3,4,5,6,8,9,10,11, 13,14,15,16	1

2nd Iteration

Element (P _i)	Reachability Set: R(P _i)	Antecedent Set: A(P _i)	Intersection Set: R(P _i) & A(P _i)	Level
1	1,2,9	1	1	
2	2	1,2,7,9,12	2	2
7	2,7,9	7	7	
9	2,9	1,7,9	9	
12	2,12	12	12	

3rd Iteration

Element (P _i)	Reachability Set: R(P _i)	Antecedent Set: A(P _i)	Intersection Set: R(P _i) & A(P _i)	Level
1	1,9	1	1	
7	7,9	7	7	
9	9	1,7,9	9	3
12	12	12	12	3

4th Iteration

Element (P _i)	Reachability Set:	Antecedent Set:	Intersection Set: R(P _i) & A(P _i)	Level
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R(P_i)		A(P_i)	
1	1	1	4
7	7	7	4