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INVESTIGATING CRITICAL CHALLENGES TO CIRCULAR SUPPLY CHAIN FOR E-WASTE MANAGEMENT IN RAJASTHAN

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ABSTRACT
The circular supply chain (CSC) is indispensable for guaranteeing sustainability in the management of electronic waste (EWM). The recyclers from Rajasthan are trying to adapt to the CSC for EWM; however, they are encountering numerous challenges. The objective of the present investigation is to pinpoint the primary impediments that impede the implementation of CSC for EWM. Twelve significant obstacles that impede the implementation of CSC for EWM have been identified and verified in this study through a comprehensive examination of existing literature and expert validation. The implementation of circular economy principles in electronic waste management is significantly impeded by a variety of obstacles, including a lack of awareness about the impacts of electronic waste and inadequate waste management infrastructure. After conducting a thorough DEMATEL analysis of each challenge, it was determined that the weak enforcement of environmental laws had the highest D+R value, suggesting that it had a substantial impact on the other challenges. We were able to identify the underlying causes of these problems and comprehend their impact on EWM practices by categorizing them according to causal relationships. In essence, this investigation offers a concise strategy that policymakers can employ to surmount substantial obstacles associated with the execution of circular economy strategies through EWM.
Keywords: circular supply chain management, e-waste management, framework.

Introduction
Electrical and electronic equipment (EEE), information technology, and telecommunications equipment are in high demand and are manufactured in large quantities [1]. The mass production of these goods has made all of this an essential part of modern life. However, when these devices reach the end of their lifespan or are scheduled to be replaced with newer, more advanced models, they are classified as E-waste [2]. There are numerous reasons why e-waste has become a global issue. E-waste is a term that refers to the discarded electronic and electrical equipment. This equipment is typically composed of a variety of materials, including plastics and heavy metals such as lead, mercury, cadmium, beryllium, and chromium. These materials have been discovered to have severe environmental consequences and pose health risks to individuals in the event of mismanagement. The population is experiencing numerous health issues as a result of the acute and chronic health effects of the burning fumes from E-waste in the air [3]. These result in acute health consequences, such as respiratory diseases, skin cancer allergic reactions, and fatalities. Individuals residing in close proximity to informal E-waste recycling operations are adversely affected by these chemicals.
In the global community, the management of E-waste has become a formidable challenge that must be addressed through the development of solutions that are capable of addressing the diverse challenges posed by waste generation, disposal, and the resulting environmental impact [4]. Additionally, there is evidence that, similar to the majority of waste management processes, the process is further complicated by the presence of intricate regulations, particularly in the context of international jurisdictions. This issue is addressed by the Extended Producer Responsibility (EPR) policy in CSC, which promotes standard operating procedures that facilitate the implementation of legal compliance and promote consistency among all stakeholders. Consequently, the establishment of appropriate legal procedures in accordance with the CE ensures that environmental standards, policies, and regulations are easily implemented and adhered to across various borders in the context of waste management [5].

There have been numerous studies conducted on the challenges of CSC in order to achieve effective EWM in India [6]. However, the state of Rajasthan has not been subjected to any studies regarding the available challenges. The challenges of EWM in a country like India may vary significantly from one Indian state to another, such as the state of Rajasthan. The primary distinction would be the level of urbanisation and population density, as the various regions of India exhibit varying levels of technological penetration and urban development, resulting in variations in the generation of e-waste. Consequently, the subsequent objectives are addressed in the current investigation:

RO1: To identify the critical challenges that recyclers in CSC encounter in order to implement effective EWM.

RO2: To suggest a conceptual framework that encompasses the sustainability, practices, and challenges of effective EWM.

Literature Review

The vast majority of countries are actively engaged in the global effort to reduce the likelihood of E-waste generation and to effectively manage it. However, a number of obstacles have arisen at the societal, government, consumer, and manufacturing levels that necessitate resolution. Consequently, this literature review identifies seven explicitly delineated negatives or challenges that impede the efficient implementation of EWM, as well as their solutions. The effective management of E-waste is a monumental endeavour, not only on a global scale but also when specifically addressed in specific countries such as India or regions like Rajasthan. EWM is complicated by a variety of factors, and the challenges are not uniform; they are contingent upon the complexities of the context of Rajasthan as well as a broader perspective on India [6]. Therefore, it is imperative to provide assistance to EPR in order to ensure that the appropriate approach to the management of E-waste is developed. Therefore, it is imperative that India has a well-developed infrastructure for the management and disposal of e-waste. Nevertheless, the implementation of effective EWM practices in this country is impeded by a variety of obstacles. These consist of insufficient infrastructure for technology, storage, transportation, collection, sorting, and coordination among various stakeholders [7]. This significantly impacts the efficacies of EWM practices in India, which are significantly influenced by consumer behaviour. Nevertheless, the promotion of sustainable E-waste disposal and recycling initiatives is impeded by specific issues related to consumer awareness and behaviour. Issues of EPR awareness and knowledge regarding green products, as well as inadequate refurbishing and take-back procedures, comprise these obstacles. Although the informal sector is confronted with a multitude of obstacles that impede the implementation of effective waste management practices, it makes substantial contributions to the management of E-waste in India. The informal sector and scrap dealers handled over 95% of the E-waste generation, as indicated by a study conducted by GTZ-MAIT [8], [9]. Consequently, the respective sectors made a significant contribution to the management of E-waste.

The cultural challenges of the community have a significant impact on EWM in India, as they alter the social attitude, behavior, and perception regarding waste disposal and recycling. Furthermore, these cultural challenges are exhibited in a variety of ways, including a lack of public environmental awareness, inadequate consumer purchasing behavior, a lack of willingness to recycle electronic equipment, and poor social conditions for scavengers, recyclers, and waste pickers. Some of the numerous obstacles that the formal E-waste recycling sector faces are particularly noteworthy, including the absence of skilled labor and the use of archaic technologies and processes. The quantity of skilled labor is extremely limited, which means that it is difficult to enhance the efficiency and effectiveness of the processing process [10], [11]. This is since less experienced personnel may lack the necessary knowledge of the specialized techniques involved in recycling.

Upon conducting a literature review, it was determined that no research had been conducted in the state of Rajasthan to address the obstacles to the adoption of CSC in EWM from the perspective of recyclers. The objective of the present investigation is to address this research gap. Twelve challenges were identified, as indicated by the literature review and expert team opinions: Inadequate waste

management infrastructure (C1), insufficient machinery and equipment for e-waste segregation (C2), and insufficient funding (C3). The high operational cost of E-waste treatment (C4), the lack of awareness about government support (C5), the lack of policies and regulations (C6), the weak enforcement of environmental law (C7), the decision support system for EOL treatment of E-waste (refurbishment/recycling) (C8), the complex design of E-products (C9), the lack of collaboration among stakeholders (C10), the lack of awareness about CE practices (C11), and the lack of awareness about the harmful impact of E-waste (C12) [2], [3], [6], [11].

Methodology

Several critical obstacles were identified with the assistance of an expert team and existing literature. DEMATEL was implemented to simulate the critical obstacles that were identified. The Scopus database was employed to extract pertinent studies for the present investigation. An expert team of four highly experienced members (four recyclers) was established to validate the identified challenges in the EWM context of Rajasthan state. In-person interviews were conducted with the expert team. The DEMATEL technique was selected for the current research due to the interdependence of the majority of the challenges. DEMATEL, which is widely recognised for its effectiveness, enables policymakers to develop enduring decision-making strategies that are designed to achieve their objectives by facilitating the identification of causal connections between barriers. The studies [12], [13] can be used as references for the DEMATEL methodology.

Results and Discussion

Twelve challenges were identified (refer to Section 2), as determined by literature and the opinions of experts. All challenges were prioritised and categorised into cause-and-effect groups in accordance with the DEMTEL methodology (refer to Table 1). The priority ranking can be arranged in descending order based on the (D+R) value of each challenge: C7> C8> C3> C2> C6> C11> C10> C12> C9> C1> C5> C4. The challenges C7 received the highest value of (D+R), indicating that they have a significant impact or relationship with other challenges. Several challenges are identified as cause challenges as a result of their greater influence on other factors, as per the DEMATEL analysis. These create challenges C3, C7, C8, C10, C11, and C12.

Table 2 Priority ranking and categorization

Challenge	D	R	D+R	D-R	Ranking	Group
C1	0.10	0.29	0.39	-0.19	4	Effect
C2	0.17	0.29	0.47	-0.12	5	Effect
C3	0.34	0.32	0.66	0.02	2	**Cause**
C4	0.09	0.20	0.29	-0.12	12	Effect
C5	0.19	0.20	0.39	-0.01	9	Effect
C6	0.17	0.29	0.46	-0.12	6	Effect
C7	0.49	0.31	0.79	0.18	1	**Cause**
C8	0.44	0.26	0.70	0.18	3	**Cause**
C9	0.17	0.24	0.41	-0.07	10	Effect
C10	0.28	0.15	0.43	0.13	8	**Cause**
C11	0.25	0.20	0.45	0.05	7	**Cause**
C12	0.24	0.18	0.42	0.06	11	**Cause**

On the other hand, the effect challenges, which are more influenced by other factors, include inadequate waste management infrastructure (C1), lack of machinery and equipment for segregation of E-waste (C2), the high operational cost of treatment of E-waste (C4), lack of awareness about government support (C5), lack of policies and regulations (C6), and complex E-product design (C9). These categorizations help in understanding the interdependencies among the challenges and in

identifying the root causes that need to be addressed to mitigate the effects. Lack of funds, weak environmental law enforcement, and stakeholder collaboration were the biggest influencers in the identification cause challenges. These root causes must be addressed to remove barriers to CSC transition. However, effect issues like poor waste management infrastructure and high E-waste treatment operational costs are caused by other factors. Targeted interventions that address causal challenges will reduce effect challenges and result in a more resource-efficient and cleaner EWM system. The current study is important for several reasons. It provides an inclusive framework for understanding contextual CSC implementation challenges in EWM. The identification and validation of these challenges provide a solid foundation for EWM sustainability research and policy. Second, DEMATEL analysis prioritises challenges based on influence and interdependencies, providing a strategic way to overcome these barriers. The methodology will identify the most important issues and their interrelations, allowing policymakers to develop targeted, effective interventions with other stakeholders. Third, regulatory reform and stakeholder collaboration are urgently needed. The weak enforcement of environmental laws and lack of stakeholder collaboration suggest areas where immediate action may improve EWM practices. This study shows that addressing root causes can support CE practices that improve resource efficiency and reduce environmental harm. It offers practical suggestions to improve EWM by applying CE principles better. This document is essential for policymakers, industry leaders, and researchers developing sustainable and efficient EWM systems. By addressing the issues related to identified causes, strategic initiatives can be created to promote CE practices in the E-waste sector for a more sustainable future.

Conclusion

CSC for electronic products is involved in the issues of extending their lifecycle through recycling, refurbishment, and repair to reduce waste generation and save resources. Such transition into these systems encounters many challenges that need to be addressed comprehensively. This literature review identified and validated twelve key challenges to the adoption of CSC for EWM through detailed literature research and subsequent expert validation. A detailed DEMATEL analysis was, therefore, conducted in order to further prioritize these challenges with respect to their degree of influence. The results showed that weak enforcement of environmental laws had the highest value of D+R, which means that it has a greater effect on the other challenges. From the results, this underlines more emphatically the stringent regulatory enforcement that needs to be pursued as the drive towards CE practices. Cause-and-effect grouping of the challenges further enlightened the root causes and their consequent effects on EWM practices.

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