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Sustainable waste electrical and electronic equipment management guide in emerging economies context: A structural model approach

Ashwani Kumar [a], Diptanshu Gaur [a], Yang Liu [b,*], Dheeraj Sharma [a]

[a] Indian Institute of Management Rohtak, Management City, Southern Bye Pass, Sunaria, Rohtak, Haryana, 124010, India
[b] Department of Management and Engineering, Linköping University, SE-581 83 Linköping, Sweden

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ABSTRACT

With globalization and the rapid advancement of information technology, waste electrical and electronic equipment (WEEE) management has become a significant concern among electronic manufacturers. It motivated researchers to identify barriers and enablers of sustainable WEEE management. However, existing literature could not capture multi-stakeholder's perspective while identifying enablers crucial for developing sustainable WEEE management policy, especially in emerging economies. The present study fulfils the gap by considering multi-stakeholder's perspective to identify enablers of sustainable WEEE management in an emerging economy, i.e., India. We identified 23 potential enablers through literature review and discussion with domain experts. Subsequently, the finalized enablers were analyzed to uncover the cause-effect relationship using a hybrid grey-based decision-making trial and evaluation laboratory (DEMATEL) approach. Findings revealed that research and development capabilities and digitization, extended producer responsibility, monitoring of illegal import and dumping, environmental regulations and WEEE policies, and use of green or cleaner technologies for waste recycling were recognized as the most significant causal enablers. The study contributes to the theoretical knowledge by categorizing enablers under different theoretical frameworks. It can also assist policymakers, practitioners, and electronic manufacturers in framing policies related to the circular economy and sustainable WEEE management to meet the sustainable development goals of 2030.

1. Introduction

WEEE is considered a non-homogeneous and complex mixture of electronic components that are potentially toxic (Williams, 2016). Over the years, the changing consumption behaviour related to electronic products has substantially contributed to the rising volume of WEEE worldwide (Awasthi and Li, 2017). WEEE growth increases natural resource depletion, leading to environmental degradation (Kumar and Dixit, 2018a). As per the report 'Global E-waste monitor' (Forti et al., 2020), in 2020, the world has generated 53.6 million metric tons WEEE, which is expected to be around 74.7 million metric tons by 2030. In 2016, the major portion of the WEEE was generated in emerging economies such as China, India, Pakistan, and Thailand, handled by informal recycling networks (Wath et al., 2010). The informal recycling industry's emissions and hazardous waste severely impact the environment and human lives. The tremendous growth in informal recycling networks poses a serious concern for the government and other environmental reformists worldwide (Garlapati, 2016). Therefore, it is essential to focus on WEEE management to promote efficient disposal methods for protecting human health and the environment (Maksimovic, 2018).

With the second-largest population globally, India is a major attraction for leading electronic manufacturers for market expansion (Borthakur and Govind, 2019). It helped India acquire the status of the world's fastest emerging economy; however, it also ranked the country third in the WEEE generation (Forti et al., 2020). According to the recent e-waste assessment by Kiran et al. (2021), India will generate 0.72 million tons of WEEE per annum by 2030. Several developed nations consider India a favourable WEEE dump yard due to cheap labour for recycling (Manomaivibool, 2009; Shittu et al., 2021). Out of the total waste generated in India, 95% is managed by the informal sector for recovery activities. A mere 5% of the total waste gets recycled owing to poor infrastructure, weak policy instruments and framework, which leads to natural resource scarcities, environmental degradation, and causes adverse effects on the individuals engaged in the recycling industry (Awasthi and Li, 2017; Kumar and Dixit, 2018a). Considering the current situation and severity of the WEEE issue in India, sustainability

* Corresponding author.
E-mail address: yang.liu@liu.se (Y. Liu).

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in WEEE management becomes a critical issue to maintain the integrity and stability of the ecosystem (Dhull and Narwal, 2018). Furthermore, UNEP (2016) identified sustainable production and resource consumption as a stand-alone goal for sustainable development for 2030. It also identified various fundamental areas to achieve sustainability goals viz., enabling 3Rs (reuse, recycle and refurbish), adopting green competencies across forward and reverse supply chains, and waste minimization across sectors by following sustainable consumption lifestyle in livelihoods. It motivated to integrate sustainable practices in WEEE management (Qu et al., 2013).

To adopt sustainable practices, existing studies have discussed various enablers in WEEE management for developed countries (Bahers and Kim, 2018; Garlapati, 2016; Khetriwal et al., 2009; Ongondo et al., 2011; Zoeteman et al., 2010). However, these studies lack a suitable framework to comprehensively understand the relationship between the enablers for sustainable WEEE management with the involvement of multiple stakeholders. In emerging economies, various researchers emphasized only the barriers and challenges related to the implementation of WEEE management (Awasthi and Li, 2017; Kumar and Dixit, 2018a; Shumon et al., 2014; Wang et al., 2012; Wath et al., 2010; Zhang et al., 2019). Limited studies identified the enablers in sustainable WEEE management (Arya and Kumar, 2020; Dutta and Goel, 2021; Garg, 2021; Sharma et al., 2020). However, these studies could not capture the multi-stakeholders perspective essential for the holistic development of a sustainable WEEE management ecosystem. These stakeholders play a crucial role in recycling e-waste, policy development, and arranging necessary resources. Therefore, it creates a gap in the literature where enablers from the multi-stakeholders perspective are yet to be identified in emerging economies.

Integrating the concept of sustainable practices into WEEE management systems such as eco-design, green packaging, and cleaner technologies will certainly improve the environmental and economic performance of the electronic industry (Somsuk and Laosirihongthong, 2017; Xu et al., 2018). From the multiple stakeholders' point of view, there are other sustainable factors such as economic, social, environmental, technological, and policy regulations that can influence WEEE management implementation (Abdulrahman et al., 2014; Jabbour et al., 2015; Jadhao et al., 2016; Kumar and Dixit, 2018a; Shaharudin et al., 2017; Xu et al., 2018). The present study aims to identify enablers and investigate the influence of one enabler over other enablers for implementing sustainable WEEE management through the following objectives:

- Explore and evaluate enablers for sustainable implementation of WEEE management through a literature review;
- Establish a cause-effect relationship among identified WEEE management enablers focusing on sustainability; and
- Develop a research framework to organize the WEEE management enablers focusing on sustainability for practical applicability.

To fulfill the above research objectives, the study first identifies 33 enablers, which the experts then evaluated to identify a list of key enablers that can be considered for further analysis. The study employed the Delphi method proposed by Dalkey and Helmer (1963) to finalise the enablers. It resulted in the list of 23 enablers for further analysis. The study used a novel approach, i.e., integrated hybrid grey-based DEMATEL, for prioritizing and establishing a causal relationship among the enablers, which was lacking in previous studies. The approach has enormous capability to deal with uncertainty and limited information in group decision-making (Bouzon et al., 2020; de Campos et al., 2021; Li et al., 2007). It can also help establish cause and effect interdependence among enablers in a complex structured system (Rajesh and Ravi, 2015; Tseng, 2009). Enablers have been prioritized with prominence and relation index values to help managers and practitioners understand which enablers are more critical and need more attention. Further, sensitivity analysis has been performed on the obtained results to check the robustness of the proposed framework.

The study contributes to the existing literature by identifying crucial enablers for sustainable WEEE management from the multi-stakeholder perspective. The causal analysis helped identify cause and effect enablers so that more focused policies can be framed by key stakeholders such as the government, electronic manufacturers, and authorized WEEE recyclers. The study considers the Indian context because it is considered the third-largest WEEE generator globally (Forti et al., 2020) and requires substantial intervention. However, the findings are applicable to other emerging economies, which are eyeing to implement sustainable WEEE management.

The organization of the remaining sections is in the following manner: Section 2 presents the literature review and theoretical foundation of the study. Section 3 explains the material and methods. The results and sensitivity analysis is presented in Section 4 and 5. Section 6 discusses the significance of the study along with research implications. Finally, conclusions, limitations, and future work are presented in Section 7.

2. Literature review

The literature review is divided into three sections. The first subsection discusses various socio-economic theories in the context of WEEE management. The second sub-section presents existing studies that help identify enablers of sustainable WEEE management. The third sub-section highlight the research gap and contribution of the paper. To search relevant literature, we used popular keywords such as WEEE, recycling, WEEE management, recovery, closed-loop supply chain of an electronic product, and end of life management. We considered scientific databases such as ABI/Inform, EBSCO, ProQuest, Science Direct, and Google Scholar for the literature review.

2.1. Theoretical foundation

Existing studies advocate that a single theory is insufficient to understand complex problems such as sustainable WEEE management implementation and have used multiple organizational theories for sustainable supply chain, reverse logistics, and environmentally collaborative activities (Kumar and Dixit, 2018a; Sarkis et al., 2011; Vachon and Klassen, 2008; Zhu et al., 2013). Rajeev et al. (2017) also reported that most studies in waste management lacked a theoretical foundation. Therefore, the study has used three theoretical frameworks that helped rationalise the identified enablers and provided fruitful insights to explain the phenomena. The theoretical frameworks: Natural Resource-Based View (NRBV), Stakeholder Theory (ST), and Institutional Theory (INT), have been discussed in the next sub-section.

2.1.1. Natural resource-based view (NRBV)

The NRBV theory builds on the theoretical concept of the resource-based view by proposing the inclusion of a natural environment dimension (Hart, 1995). The theory proponents argue that firms can achieve competitive advantage by improving green partners' integration in resource recovery activities (Barney, 2001; Barthélemy and Quélin, 2006; Menguc and Ozanne, 2005; Vachon and Klassen, 2008). NRBV mainly focuses on green core competencies such as eco-design, green packaging, cleaner technologies, green logistics, product stewardship, which enhance the firm's resources and capabilities (Acedo et al., 2006; Lee and Min, 2015).

2.1.2. Stakeholder theory (ST)

The ST theory suggests that focal firms should integrate internal and external stakeholders in pro-environmental decision-making activities (Freeman, 2010). The stakeholders comprise suppliers, manufacturers, consumers, retailers, local communities, green-enabled service providers, media, non-governmental organizations (NGOs), and regulatory bodies (de Brito et al., 2008). Hart (1995) suggests that stakeholder integration helps in product recovery and recycling activities and is a proactive measure for resource management, conservation of natural habitat, and waste minimization.

2.1.3. Institutional Theory (INT)

The INT posits three isomorphic influences for the legitimacy of environmental practices in an organization: coercive, normative, and mimetic (DiMaggio and Powell, 1983). INT explains how external institutional norms and environmental regulations force industries to incorporate green practices in their closed-loop supply chain activities (Kumar and Dixit, 2018a; Shaharudin et al., 2017). According to the INT, focal firms are motivated to voluntarily collaborate with green partners since it helps achieve social and regulatory expectations (Zhu et al., 2013). Table 1 categorizes each enabler of sustainable WEEE management under one theoretical framework to justify its relationship with the organizational theories.

2.2. Enablers of sustainable WEEE management

Sustainable WEEE management is more complex to achieve than traditional WEEE management. The finalized enablers were categorized into five dimensions, i.e., economic, social, environmental, technology & infrastructure, and government policies & regulations support (Table 2). In the following sub-sections, we have explained each dimension and its corresponding enabler in detail:

2.2.1. Economic enablers

Economic enablers play a vital role in sustainable WEEE management implementation (Singh and Sushil, 2017). However, to manage the exponential rise of WEEE, huge investment and skilled workforce are required (Zaman, 2013). Therefore, it is essential to minimize the financial burden of the producer by adopting innovative solutions such as implementing ARF and mentioning it explicitly in the price of the electronic product (Wath et al., 2010). Retailers must inform consumers about ARF, which facilitates recycling and disposal activities at the end of the product lifespan. Along with ARF, the deposit refund system acts as an incentive for the consumers where the fee paid at the time of purchase gets reimbursed after the obsolete product is returned to the

Table 1
Categorizing enablers of sustainable WEEE management under socio-economic theories.

Theory	Enablers
Natural Resource-Based View (NRBV)	Green training programs Clean development mechanism (CDM) Environmental management systems (EMS) Use of cleaner technologies for waste recycling Material and energy recovery R&D capabilities and digitization to improve WEEE management system Green packaging Green logistics and warehousing facilities Green information system
Institutional Theory (INT)	Tax policies and subsidies benefits Advanced Recycling Fee (ARF) Avoiding community landfill disposal Health and safety measures Reduction of hazardous and toxic substances in the environment Environmental regulations and WEEE policies Monitoring of illegal import and dumping
Stakeholder Theory (ST)	Defining the role of stakeholders Joining informal sector with the formal sector Extended producer responsibility (EPR) Collaboration with green partners Green image Financial institutions offering loans to promote green practices Community awareness and involvement

Table 2
Key enablers of sustainable implementation of WEEE management.

Enablers	Code	Explanation	References
Economic enablers			
Advanced recycling fee (ARF)	EN1	Consumers have to pay a tax that covers future reverse logistics and disposal cost	(Hong et al., 2014; Nnorom and Osibanjo, 2008; Wath et al., 2010; Zhou et al., 2017)
Financial institution offers loan to promote green practices	EN2	Financial support provided by financial institutions encourages green practices, eco-design, green product development, remanufacturing, and reuse	Our contribution
Tax policies and subsidy benefits	EN3	Tax credit and subsidy benefit policies to encourage the consumer for returning discarded products	(Abdulrahman et al., 2014; Nnorom and Osibanjo, 2008)
Material and energy recovery	EN4	Asset recovery from the WEEE provides economic benefits to the focal and recycling firm by selling waste and extracting rare earth material. Asset recovery also helps in reducing the consumption of virgin material.	(Coban et al., 2018; Mir et al., 2016)
Social enablers			
Community awareness and involvement	EN5	Community awareness regarding environmental protection may encourage green purchasing and willingness to pay for waste recycling activities.	(Borthakur and Govind, 2019; Sarath et al., 2015; Xu et al., 2018)
Collaboration with green partners	EN6	Establishing a green alliance involves any organized or un-organized collaboration between two or more firms that work on common solutions to achieve sustainability.	Our contribution
Green training programs	EN7	Staff involved in recycling activities require technical and environmental training for recycling and disposal of the WEEE.	(An et al., 2015; Hsu et al., 2013; Zhou et al., 2017)
Health and safety measures	EN8	The recycling firm should adopt health and safety measures and comply with safety standards in practices for employees.	Xu and Yeh (2017)
Environmental management enablers			
Green image of the firm	EN9	Green image of the firm defines the firm's commitment towards green practices.	(Grisi et al., 2010; Xu et al., 2018; Yeh and Chuang, 2011)
Clean development mechanism (CDM)	EN10	Recycling firms should integrate with the focal firm for CDM projects, leading to sustainable development.	Our contribution
Reduction of hazardous and toxic substances in the environment	EN11	Recycling firms should take preventive measures to reduce and control hazardous	(Grant and Marshburn, 2014; Xu et al., 2018)

(*continued on next page*)

Table 2 (*continued*)

Enablers	Code	Explanation	References
		emissions during WEEE recycling.	
Environmental management system (EMS)	EN12	The level of compliance with environmental certifications like ISO 14001, environmental regulations, plans to check whether the organization has its environmental issues controlled.	(Govindan et al., 2015; Hu and Hsu, 2010; Manomaivibool, 2009; Shaharudin et al., 2017)
Avoid community landfills disposal	EN13	Reduce the amount of WEEE to be disposed of in community landfills with the help of product take-back initiatives.	(Arena and Di Gregorio, 2014; Wibowo and Deng, 2015; Xu et al., 2018)
Technology and Infrastructure enablers			
Green packaging	EN14	Green packaging can help reduce the carbon footprints due to recycling and disposal of WEEE.	(Gupta and Barua, 2017; Hsu et al., 2013; Kumar and Dixit, 2018a; Somsuk and Laosirihongthong, 2017)
Green information system	EN15	An efficient green information system is required to improve integration and coordination. It is needed to track the returned product and to forecast inventory management.	Our contribution
R&D capabilities and Digitization	EN16	R&D investment and digital capabilities are required for developing eco-design and green manufacturing technologies, which can assist WEEE management.	(Garrido-Hidalgo et al., 2020; Gupta and Barua, 2017; Hsu et al., 2013; Lucas, 2010; Zuo et al., 2020)
Use of green or cleaner technologies for waste recycling	EN17	Use of green or innovative eco-friendly recycling practices to conserve nature and natural resources and minimize negative impacts on human lives.	(Jadhao et al., 2016; Xu et al., 2018)
Green logistics and warehousing facilities	EN18	Green logistics and warehousing facilities can help reduce environmental pollution and promote the optimum post-consumer collection and environmentally safe disposal.	(Coban et al., 2018; Kannan et al., 2014; Liu et al., 2017; Mairizal et al., 2021; Zhu et al., 2013)
Government policies and regulations-related enablers			
Monitoring of illegal import and dumping	EN19	Regularly monitor and audit the transboundary movement of hazardous waste and record illegal dumping.	(Garlapati, 2016; Khan et al., 2014; Wath et al., 2010)
Integration of informal sector with the formal sector	EN20	Firms should establish cooperation with informal recycling networks to collect and recycle WEEE.	Our contribution
Defined role of stakeholders	EN21	The role of stakeholders should be clear; the formation of the task force for WEEE management is required for regulation and implementation.	(Garlapati, 2016; Kumar and Dixit, 2018a; Mir et al., 2016; Wath et al., 2010)
Extended producer responsibility (EPR)	EN22	Producers should be responsible for managing the entire life cycle of the products, such as take-back of obsolete products, recycling, and safe disposal.	(Garlapati, 2016; Kiddee et al., 2013; Manomaivibool, 2009; Wath et al., 2010; Widmer et al., 2005; Zhou et al., 2017)
Environmental regulations and WEEE policies	EN23	Regulations and policies encourage electronics firms to integrate environmental practices in operational and business activities.	(Garlapati, 2016; Govindan et al., 2016; Kumar and Dixit, 2018a, 2018b; Wath et al., 2010; Xu et al., 2018; Xu and Yeh, 2017)

formal recycler (Garlapati, 2016; Khetriwal et al., 2009; Wath et al., 2010). Apart from the abovementioned subsidies, the government can probably consider designing tax incentive policies that can encourage electronic manufacturers to adopt green practices, such as eco-design, that minimize hazardous emissions (Govindan et al., 2015; Sarkis et al., 2011; Zhou et al., 2017). Arena and Di Gregorio (2014) pointed out that waste to energy conversion can effectively reduce landfills while having economic and environmental benefits. Recovery of precious and rare earth metals can reduce the use of virgin material in production, which leads to resource conservation and economic benefits (Coban et al., 2018; Pan et al., 2015; Pekarkova et al., 2021; Zhu et al., 2013). The UNEP report also highlights examples from developed nations where economic enablers such as ARF, material and energy recovery, and environmental tax played a crucial role in achieving sustainable WEEE (United Nations Environmental Programme, 2017).

2.2.2. *Social enablers*

Due to climate change, ozone depletion, and greenhouse gas emissions (GHGEs), consumers are becoming more aware of environmental protection, green purchasing, and WEEE recycling and disposal (Eltayeb et al., 2011; Pekarkova et al., 2021). Consumers' green purchasing behaviour minimizes impact on the environment through product reuse, waste reduction, and elimination of toxic substances during recycling and disposal (Chan et al., 2012; Kwatra et al., 2014; Zhou et al., 2017). Therefore, consumer engagement and involvement become key elements in implementing sustainable WEEE management (Alves et al., 2021). It can be achieved by encouraging voluntary participation in designing WEEE management policies (Abba et al., 2013; Pekarkova et al., 2021). In a closed-loop supply chain, green alliances among all the stakeholders can minimize waste generation by providing training to the recycling workers to manage WEEE, setting up common environmental goals, and developing a network for technology and information sharing (Gupta and Barua, 2017; Jabbour et al., 2015). An et al. (2015) also suggests that a green training program can foster cleaner technologies adoption and protect workers' health.

2.2.3. *Environmental management enablers*

The firm's commitment towards green practices helps determine the firm's green image (Grisi et al., 2010; Xu et al., 2018). For developing a green image, firms develop EMS that assists them in setting up environmental goals and frequent monitoring of its supply chain components (Maruthi and Rashmi, 2015; Zhou et al., 2017). EMS certification such as ISO 14000 also enhances the firms' green image in the global market (Manomaivibool, 2009; Xu and Yeh, 2017). Apart from EMS, CDM provides a robust management approach that can minimize GHGEs in the environment (Singh and Debnath, 2012). The World Bank has actively encouraged CDM, particularly for landfill gas projects, as it helps in landfill reduction (Arena and Di Gregorio, 2014; Wibowo and Deng, 2015). For sustainable WEEE management, EMS and CDM are crucial as it helps in reducing harmful emissions (Yeh and Xu, 2013).

2.2.4. Technology and infrastructure enablers

Electronic manufacturers need to be well-equipped with green infrastructure and clean technologies for sustainable WEEE management. It includes green packaging, accessible collection centres, recycling and recovery plants, supply chain integration with the internet of things, and green logistics facilities (Garrido-Hidalgo et al., 2020; Kannan et al., 2014; Liu et al., 2017; Zuo et al., 2020). This initiative will help developing counties convert the growing heap of WEEE into economic opportunities and reduce carbon footprint (Mairizal et al., 2021; Somsuk and Laosirihongthong, 2017). Along with green packaging, firms can also take advantage of modern technologies such as green information system, RFID-labelling system, and internet of things that can aid information flow, better supplier coordination, robust inventory management, and improved forecasting (Garrido-Hidalgo et al., 2020; Grant and Marshburn, 2014; Hsu et al., 2013; Khan et al., 2014). Firms that aim to build a green image should also focus on developing green logistics that minimize the environmental impact of WEEE (Coban et al., 2018; Liu et al., 2017). In the Indian context, a group of experts revealed that promoting green manufacturing activities, digitising statutory filings, investment in R&D, segregation of e-waste, and encouragement for refurbished products is crucial for sustainable WEEE management (Confederation of Indian Industries, 2021; 2020).

2.2.5. Government policies and regulation enablers

Government policies and WEEE directives should ensure that electronics manufacturers take extended responsibility to minimize the impact of their obsolete products (Garlapati, 2016). For instance, policy measures related to EPR cover activities such as used products recovery, recycling, and safe disposal (Kumar and Dixit, 2018a; Rahman and Subramanian, 2012; Wath et al., 2010). Also, the government can consider designing liberal policies for the informal recyclers by providing financial incentives and tax subsidies (Abdulrahman et al., 2014; Chi et al., 2014; Jafari et al., 2017; Wang et al., 2020). Velis et al. (2012) suggested that successful integration of the informal and formal sector can be a robust approach to improve livelihoods, environmental protection, occupational health and safety in developing countries. For all such initiatives, a legal framework with clear and defined roles for all stakeholders, i.e., pollution control boards, local municipal corporations, producers, retailers, consumers, waste recyclers, and non-governmental organizations, is required (Garlapati, 2016). For sustainable WEEE management, the Indian government also made special regulations for EPR, setting up e-waste exchanges for collection and recycling, and assigning specific responsibility to bulk buyers under the e-Waste management and handling rules (Ministry of Environment Forest and Climate Change, 2016).

2.3. Research gaps and contribution

Climate change awareness and environmental protection among consumers and producers initiated sustainable WEEE management implementation (Qu et al., 2013). It motivated researchers to explore the critical factors for implementing sustainable WEEE management (Bahers and Kim, 2018; Khetriwal et al., 2009). However, limited attention has been given to the emerging economies where researchers identified only barriers for implementing sustainable WEEE management (Awasthi and Li, 2017; Kumar and Dixit, 2018a; Nnorom and Osibanjo, 2008; Shumon et al., 2014; Wang et al., 2012; Wath et al., 2010). In emerging economies, existing studies revealed that identifying enablers is crucial for sustainable WEEE management (Arya and Kumar, 2020; Garlapati, 2016; Ongondo et al., 2011; Zoeteman et al., 2010). Our literature review revealed limited studies that aim to identify enablers for sustainable WEEE management (Arya and Kumar, 2020; Dutta and Goel, 2021; Garg, 2021; Sharma et al., 2020). One of the limitations of these studies is that they could not capture the multi-stakeholders perspective, which is essential for developing the entire ecosystem of sustainable WEEE management. In developing countries, recycling e-waste and policy development are more challenging that require substantial attention from all stakeholders, necessitating the identification of enablers from a multi-stakeholder perspective. The present study contributes to the existing literature by identifying crucial enablers for sustainable WEEE management from the multi-stakeholder perspective. The causal analysis presented in the study helps in identifying cause and effect enablers for effective policymaking by involving key stakeholders such as the government, electronic manufacturers, and authorized WEEE recyclers.

3. Materials and methods

Enablers of sustainable WEEE management implementation were identified and finalized based on an exhaustive literature review and a rigorous discussion with a panel of experts. Fig. 1 shows the step-wise proposed research framework of the study.

3.1. Illustrative case and data collection

The present study used a case study approach to capture the phenomenon of interest and the context (Yin, 2009). The study considers India as a research context primarily due to the high growth rate of WEEE generation (Forti et al., 2020) and a limited number of formal recyclers available in the country (Manomaivibool, 2009). A recent conference on e-waste management highlights that in India, mechanism to buy e-waste from informal vendors is absent for formal recyclers. It also highlighted other e-waste management problems, such as no guidelines on refurbishing electronic products, a narrow definition of e-waste not covering electronic vehicles batteries, and the absence of a framework to create a marketplace for e-waste (Confederation of Indian Industries, 2021). From the policy point of view, India has witnessed limited growth in the development of rules and regulations and it is still considered a challenge due to its simplified nature (Awasthi and Li, 2018; Bhaskar and Turaga, 2018; Ministry of Environment Forest and Climate Change, 2016; Patil and Ramakrishna, 2020).

The study followed pattern matching logic and the data triangulation approach suggested by Yin (2009) for data collection. In the case study research, pattern matching is considered the most desirable analysis technique due to its internal validity (Manomaivibool, 2009). We also triangulated the data to ensure the construct validity, i.e., checking the convergence of data collected from multiple sources. For this purpose, key informants were identified from the selected locations, and interview questions and protocols were designed (Narwane et al., 2021). The selection is based on two criteria: first, industry experience of more than ten years; and second, significant contribution in the domain of reverse logistics, waste management, and supply chain in the electronics industry. We approached 25 experts, out of which ten experts agreed to evaluate enablers for implementing sustainable WEEE management (refer to Appendix-V). The interviews lasted around 2.5–3 hours each, in which we conveyed our research problem with a clear definition of each listed enabler to obtain judgment ratings to develop pair-wise comparison matrices. The two-way interaction facilitated the data collection process and helped to maximize reliability. There are no specific guidelines on the number of experts involved in data collection; however, the previous studies have suggested that the sample contain at least ten experts (Okoli and Pawlowski, 2004; Paul et al., 2021). The study further employed the Delphi method, a qualitative technique proposed by Dalkey and Helmer (1963) that aggregates data from a group of respondents (Melnyk et al., 2009). In this method, all possible identified enablers are presented to the knowledgeable and experienced expert panel to collect their opinions (Kembro et al., 2017; Moktadir et al., 2019). The process involves numerous rounds of discussions until unanimity is attained on key enablers.

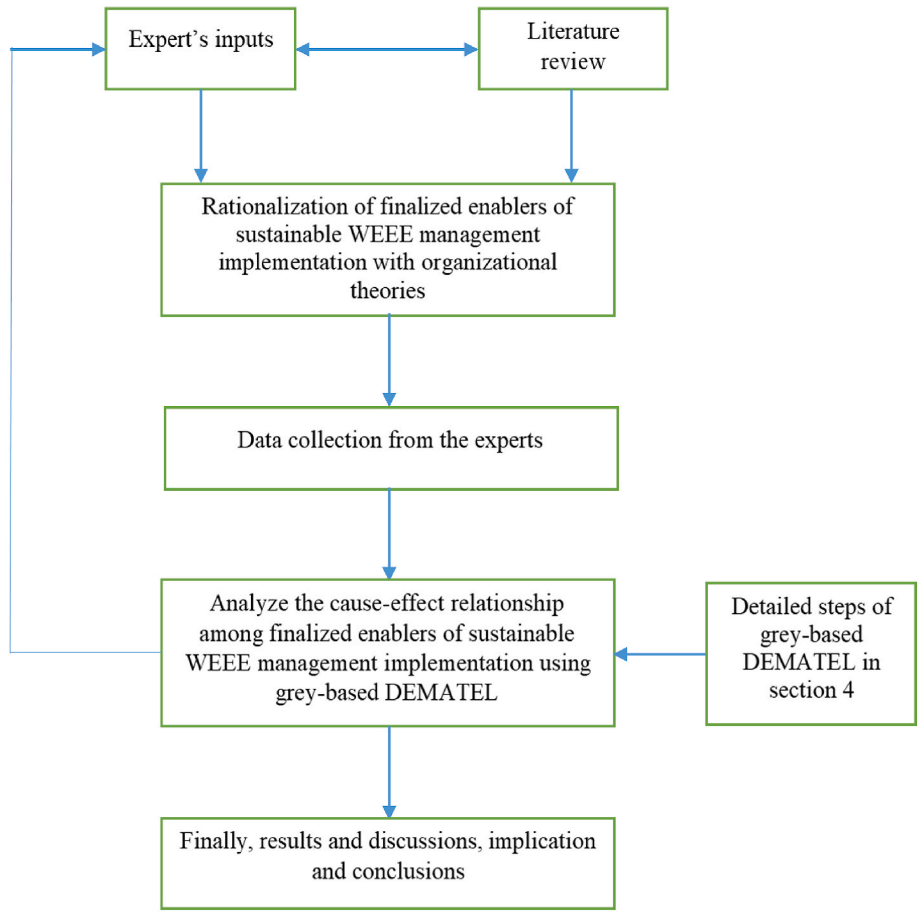

Fig. 1. The proposed research framework of the study.

In India, Maharashtra alone produces 13.9% of the total waste generated in the country, followed by Tamil Nadu, i.e., 9.1%, West Bengal, i.e., 6.9%, Delhi, i.e., 6.7%, and Karnataka, i.e., 6.2% (Singh, 2020). The data has been collected from five different cities of India, i.e., Mumbai, Bangalore, Delhi National Capital Region, and Kolkata, covering top waste generating states. The top contributor is Mumbai that generates roughly 120,000 MT of e-waste, followed by National Capital Region (NCR) of Delhi (around 95,000 MT), Bengaluru (around 90,000 MT), Chennai (around 60,000 MT), and Kolkata (around 55,000 MT), (Central Pollution Control Board, 2020; Joon et al., 2017). These cities generate roughly 50% of the total e-waste. The reasons are the development of telecommunication, technology, and e-commerce hub in Bangalore (Awasthi and Li, 2018) and Mumbai (Singh et al., 2020). Awasthi and Li (2018) suggest that WEEE management is a challenge despite the abovementioned environmental guidelines in Bangalore. Delhi, Chennai, and Kolkata also witnessed rapid growth in WEEE generation due to unauthorized disposal and the growing population (Dutta and Goel, 2021; Joon et al., 2017). The findings revealed that environmental laws are ineffective. Based on the above arguments and suggestions from the existing literature (Awasthi and Li, 2018; Singh et al., 2020), we have selected locations such as Mumbai, Bangalore, Delhi NCR, and Kolkata from all these states for our study.

3.2. Grey-based DEMATEL justification

DEMATEL is an effective technique that helps visualize the structure of complicated inter-relationships among identified enablers with the assistance of causal-map structure (Gabus and Fontela, 1973; Govindan et al., 2015; Hsu et al., 2013). DEMATEL also follows a relationship modelling technique to establish cause and effect interdependence among enablers (Azimifard et al., 2018; Rajesh and Ravi, 2015; Tseng, 2009). Despite these advantages, DEMATEL fails to deal with uncertain scenarios resulting from imprecise human judgment and vague information (Bai and Sarkis, 2013; Bouzon et al., 2020). Although fuzzy methods would resolve the shortcomings of non-fuzzy methods, they suffer from limitations such as mapping a member function (triangular and trapezoidal function) (Khompatraporn and Somboonwiwat, 2017). Therefore, the present study employed a combination of Grey theory and DEMATEL to minimize the limitations of both methodologies.

Ju-Long (1982) proposed the concepts of Grey theory from the grey numbers set. It converts grey numbers into crisp numbers using the modified conversion of fuzzy values into crisp scores (CFCS) (Liu and Qiao, 2014). It is a hybrid approach that combines the grey system theory and the DEMATEL method (Govindan et al., 2021). It is effective in dealing with several ambiguities that arise due to imprecise human decisions and generates satisfactory results in the presence of significant variability in criteria (Fu et al., 2012; Liu et al., 2020; Xia et al., 2015) by improving decision accuracy (Liu and Qiao, 2014; Tseng, 2009). It is suitable to make a meaningful judgment about the given problem even in cases where the sample size is small (Bai and Sarkis, 2013; Fu et al., 2012; Govindan et al., 2016; Gupta and Barua, 2017; Luthra et al., 2017; Rajesh and Ravi, 2015; Shao et al., 2016). Previous literature also suggested the wide acceptability of the Grey-DEMATEL methodology in various fields (see Appendix-I).

4. Results

The present study identifies 23 enablers that facilitate the implementation of sustainable WEEE management. The enablers were identified from a comprehensive literature review and discussions with the expert panel. This study utilized integrated grey-based DEMATEL to determine the cause and effect relationship among sustainable WEEE management implementation enablers to resolve the complexity of the decision problem. The following steps summarize the proposed computation procedure of the grey-based DEMATEL approach presented below:

Step 1: Experts investigated the direct influence of one enabler over the other enablers and developed an initial relation matrix (23 × 23) with the help of defined linguistics scales. Further, to deal with subjective judgements of humans, this study used a grey number scale corresponding to the linguistics variables, as shown in Table 3.
Step 2: Using equation (1), ten different initial grey relation matrices $[(\otimes A^1_{xy}), (\otimes A^2_{xy}), (\otimes A^3_{xy}), (\otimes A^4_{xy})]$ were developed to assess inter-relationships among the enablers using the equation $\left(\underline{\otimes} A^p_{xy} / \overline{\otimes} A^p_{xy}\right)$.

$$\otimes A^p_{xy} = \left(\underline{\otimes} A^p_{xy}, \overline{\otimes} A^p_{xy}\right) \tag{1}$$

where,

$1 \leq p \leq k,\ 1 \leq x \leq n;\ 1 \leq y \leq n$

Step 3: To ensure congruity of experts' judgments, uniformity in ratings was given for all domain experts, and an average grey relation matrix was established by using equation (2).

$$\otimes \check{A}_{xy} = \left(\frac{\sum \underline{\otimes} A^p_{xy}}{k}, \frac{\sum \overline{\otimes} A^p_{xy}}{k}\right) \tag{2}$$

The resultant grey relation matrix $(\otimes \check{A}_{xy})$ is presented in Appendix-II.

Step 4: In this step, a crisp relation matrix (Z) was computed by converting the average grey number into crisp numbers with the assistance of the modified CFCS method involving a three-step procedure using Equations (3)–(8).
(a) Normalization of the average grey numbers:

$$\underline{\otimes} \dot{A}_{xy} = \left(\underline{\otimes} \check{A}_{xy} - \min_y \underline{\otimes} \check{A}_{xy}\right) \Big/ \triangle^{max}_{min} \tag{3}$$

where $\underline{\otimes} \dot{A}_{xy}$ denotes the normalized lower range value of the grey number $\otimes \check{A}_{xy}$

$$\overline{\otimes} \dot{A}_{xy} = \left(\overline{\otimes} \check{A}_{xy} - \min_y \overline{\otimes} \check{A}_{xy}\right) \Big/ \triangle^{max}_{min} \tag{4}$$

where $\overline{\otimes} \dot{A}_{xy}$ denotes the normalized upper range value of the grey number $\otimes \check{A}_{xy}$

$$\triangle^{max}_{min} = \max_y \overline{\otimes} \check{A}_{xy} - \min_y \underline{\otimes} \check{A}_{xy} \tag{5}$$

(a) Calculate total normalized crisp values.

Table 3
Linguistics indicators and related grey numbers.

Linguistics indicators	Grey numbers
No influence (N)	(0.0, 0.1)
Very low influence (VL)	(0.1, 0.3)
Low influence (L)	(0.2, 0.5)
Medium influence (M)	(0.4, 0.7)
High influence (H)	(0.6, 0.9)
Very high influence (VH)	(0.9, 1.0)

$$Z_{xy} = \left(\left(\underline{\otimes} \dot{A}_{xy} \left(1 - \underline{\otimes} \dot{A}_{xy}\right) \right) + \left(\frac{\overline{\otimes} \dot{A}_{xy} \times \overline{\otimes} \dot{A}_{xy}}{\left(1 - \underline{\otimes} \dot{A}_{xy} + \overline{\otimes} \dot{A}_{xy}\right)} \right) \right) \tag{6}$$

(b) Calculation of final crisp values:

$$Z^*_{xy} = \left(min \underline{\otimes} \check{A}_{xy} + \left(Z_{xy} \times \triangle^{max}_{min}\right) \right) \tag{7}$$

And,

$$Z = \left[Z^*_{xy}\right] \tag{8}$$

Finally, a crisp relation matrix was obtained using the above equations and is presented in Appendix-III.

Step 5: Using Equations (9) and (10), the normalized direct relation matrix (N) was calculated and is presented in Appendix-IV.

$$R = \frac{1}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} Z^*_{xy}},\ x, y = 1, 2, \ldots, n. \tag{9}$$

and,

$$N = Z \times R \tag{10}$$

Step 6: In this step, the total relation matrix (T) was arrived at by processing the normalized direct relation matrix (N) using equation (11) and is shown in Table 4.

$$T = N(N - I)^{-1} \tag{11}$$

Step 7: In this step, we calculate the sum of rows (23 × 1) and the sum of columns (1 × 23) for each enabler using Equations (12) and (13).

$$R = \left[\sum_{y=1}^{n} t_{xy} \forall x\right] \tag{12}$$

$$C = \left[\sum_{y=1}^{n} t_{xy} \forall y\right] \tag{13}$$

'R' denotes the net effect given by enabler *x* towards other enablers, and 'C' denotes the net effects received by enabler *y* from the other enablers. The enablers were prioritized based on (R–C) values presented in Table 5.

Step 8: In this step, the cause-effect relationship diagram was constructed with the help of prominence (R + C) and relation (R–C) values, as shown in Fig. 2. Each enabler was categorized into cause and effect groups based on positive and negative (R–C) values (see Table 4). Relationships among enablers are represented with the help of arrows in the cause-effect relationship diagram (see Fig. 2). Finally, the threshold value (θ) was set to simplify various relationships among enablers that exceed the value of θ. In this study, the threshold value (θ) is determined by adding one standard deviation to the mean of the total relation matrix (T), i.e., (0.2812 + 0.0345 = 0.3158).

To eliminate the insignificant effects among enablers, a threshold value of (0.3158) was fixed in the study. In this analysis, the importance of the enablers is prioritized based on (R + C) values (see Table 5), the enablers are listed according to their ranking as follows: EN5 > EN16 > EN22 > EN17 > EN23 > EN4 > EN18 > EN12 > EN14 > EN13 > EN20 > EN15 > EN6 > EN11 > EN21 > EN7 > EN9 > EN3 > EN19 > EN2 >

Table 4
Total relation matrix (T) for enablers of sustainable WEEE management implementation.

Enablers	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13	EN14	EN15	EN16	EN17	EN18	EN19	EN20	EN21	EN22	EN23
EN1	0.191	0.192	0.194	0.214	0.238	0.232	0.221	0.192	0.195	0.173	0.229	0.209	0.206	0.212	0.219	0.203	0.207	0.227	0.177	0.186	0.196	0.202	0.197
EN2	0.288	0.214	0.262	0.299	0.302	0.295	0.277	0.256	0.242	0.219	0.300	0.302	0.266	0.258	0.269	0.262	0.272	0.286	0.244	0.251	0.267	0.262	0.267
EN3	0.286	0.241	0.228	0.308	0.304	0.280	0.287	0.252	0.269	0.221	0.297	0.304	0.268	0.272	0.272	0.263	0.258	0.284	0.242	0.260	0.276	0.277	0.267
EN4	0.306	0.255	0.260	0.268	0.322	0.309	0.280	0.264	0.267	0.244	0.295	0.309	0.273	0.291	0.280	0.275	0.277	0.300	0.259	0.255	0.276	0.274	0.255
EN5	0.319	0.276	0.284	0.339	0.286	0.299	0.314	0.296	0.284	0.260	0.307	0.321	0.296	0.307	0.294	0.278	0.308	0.319	0.264	0.283	0.287	0.295	0.297
EN6	0.287	0.237	0.258	0.282	0.294	0.242	0.276	0.251	0.240	0.219	0.266	0.297	0.254	0.252	0.257	0.253	0.256	0.287	0.242	0.229	0.235	0.259	0.254
EN7	0.288	0.239	0.241	0.290	0.282	0.294	0.234	0.246	0.245	0.221	0.276	0.286	0.255	0.250	0.269	0.246	0.244	0.265	0.216	0.249	0.240	0.242	0.238
EN8	0.280	0.222	0.257	0.280	0.267	0.268	0.265	0.207	0.246	0.228	0.274	0.299	0.258	0.254	0.282	0.245	0.251	0.273	0.219	0.233	0.241	0.257	0.259
EN9	0.302	0.255	0.271	0.318	0.315	0.307	0.303	0.273	0.234	0.251	0.295	0.310	0.276	0.283	0.291	0.285	0.283	0.309	0.266	0.267	0.271	0.271	0.270
EN10	0.286	0.240	0.257	0.290	0.285	0.286	0.282	0.242	0.256	0.200	0.264	0.296	0.264	0.261	0.280	0.269	0.250	0.301	0.260	0.241	0.265	0.267	0.260
EN11	0.266	0.234	0.245	0.294	0.309	0.295	0.290	0.247	0.264	0.239	0.241	0.284	0.274	0.274	0.277	0.267	0.253	0.297	0.243	0.255	0.254	0.252	0.253
EN12	0.291	0.252	0.267	0.299	0.298	0.291	0.304	0.251	0.253	0.244	0.270	0.262	0.265	0.274	0.295	0.272	0.283	0.306	0.247	0.254	0.278	0.267	0.284
EN13	0.304	0.266	0.286	0.330	0.319	0.309	0.323	0.280	0.282	0.264	0.292	0.334	0.255	0.287	0.315	0.294	0.287	0.306	0.239	0.269	0.294	0.296	0.298
EN14	0.313	0.267	0.289	0.337	0.333	0.332	0.314	0.271	0.291	0.263	0.325	0.337	0.299	0.255	0.302	0.296	0.289	0.334	0.257	0.294	0.287	0.291	0.290
EN15	0.290	0.263	0.262	0.305	0.314	0.301	0.296	0.248	0.254	0.242	0.287	0.302	0.273	0.271	0.244	0.266	0.272	0.308	0.238	0.273	0.277	0.256	0.270
EN16	0.346	0.304	0.320	0.369	0.363	0.360	0.323	0.297	0.306	0.287	0.325	0.367	0.336	0.318	0.326	0.277	0.334	0.341	0.293	0.323	0.297	0.334	0.331
EN17	0.341	0.300	0.303	0.353	0.356	0.342	0.318	0.284	0.315	0.297	0.335	0.354	0.320	0.304	0.314	0.302	0.272	0.336	0.284	0.304	0.299	0.317	0.314
EN18	0.297	0.260	0.277	0.317	0.320	0.317	0.303	0.261	0.273	0.245	0.301	0.299	0.281	0.262	0.292	0.269	0.290	0.264	0.272	0.266	0.262	0.289	0.260
EN19	0.301	0.261	0.281	0.312	0.320	0.298	0.306	0.266	0.267	0.247	0.292	0.313	0.282	0.275	0.292	0.276	0.286	0.312	0.217	0.261	0.257	0.294	0.271
EN20	0.334	0.290	0.289	0.345	0.330	0.334	0.330	0.300	0.285	0.257	0.321	0.328	0.307	0.284	0.304	0.294	0.301	0.324	0.256	0.248	0.306	0.317	0.301
EN21	0.321	0.283	0.291	0.305	0.315	0.315	0.299	0.277	0.278	0.243	0.286	0.305	0.287	0.270	0.286	0.287	0.283	0.308	0.233	0.265	0.239	0.284	0.288
EN22	0.349	0.307	0.313	0.356	0.364	0.340	0.331	0.303	0.308	0.275	0.344	0.340	0.333	0.311	0.335	0.328	0.316	0.345	0.268	0.295	0.299	0.275	0.316
EN23	0.335	0.290	0.326	0.358	0.347	0.350	0.332	0.302	0.299	0.268	0.334	0.344	0.329	0.308	0.318	0.313	0.322	0.345	0.269	0.312	0.322	0.318	0.270

Table 5
Cause-effect parameters for enablers of sustainable WEEE management implementation.

Enablers	R	C	R + C	R–C	Ranking	Relation Category
EN1	4.714	6.922	11.636	−2.208	23	effect
EN2	6.159	5.948	12.106	0.211	20	cause
EN3	6.218	6.261	12.479	−0.043	18	effect
EN4	6.395	7.168	13.562	−0.773	6	effect
EN5	6.814	7.184	13.998	−0.370	1	effect
EN6	5.926	6.996	12.922	−1.070	13	effect
EN7	5.856	6.807	12.663	−0.950	16	effect
EN8	5.867	6.067	11.934	−0.200	21	effect
EN9	6.504	6.153	12.658	0.351	17	cause
EN10	6.102	5.608	11.710	0.494	22	cause
EN11	6.104	6.757	12.861	−0.653	14	effect
EN12	6.307	7.104	13.410	−0.797	8	effect
EN13	6.731	6.457	13.189	0.274	10	cause
EN14	6.869	6.332	13.201	0.537	9	cause
EN15	6.313	6.611	12.924	−0.298	12	effect
EN16	7.476	6.319	13.794	1.157	2	cause
EN17	7.264	6.394	13.658	0.869	4	cause
EN18	6.478	6.977	13.455	−0.498	7	effect
EN19	6.487	5.706	12.193	0.782	19	cause
EN20	6.982	6.073	13.055	0.909	11	cause
EN21	6.547	6.224	12.771	0.323	15	cause
EN22	7.351	6.396	13.747	0.955	3	cause
EN23	7.310	6.311	13.621	1.000	5	cause

EN8 > EN10 > EN1.

According to the (R–C) values, 12 enablers for sustainable implementation of WEEE management are ranked in accordance with their relative positive relation values as: EN16 > EN23 > EN22 > EN20 > EN17 > EN19 > EN14 > EN10 > EN9 > EN21 > EN13 > EN2. These enablers fall under causal enablers whereas EN1 > EN6 > EN7 > EN12 > EN4 > EN11 > EN18 > EN5 > EN15 > EN8 > EN3 falls under effect enablers in cause-effect relationship matrix (refer Table 5). Based on relation values (R–C), the most affected enabler is R&D capabilities and digitization (EN16), followed by environmental regulations and WEEE policies (EN23), green training programs (EN7), EMS (EN12), and green packaging (EN14). Material and energy recovery (EN4) and community awareness for WEEE recycling (EN5) can be influenced by other causal enablers such as avoiding community landfills disposal (EN13), green packaging (EN14), R&D capabilities and digitization (EN16), use of green or cleaner technologies for waste recycling (EN17), green logistics and warehousing facilities (EN18), integration of informal sector with the formal sector (EN20), EPR (EN22) and environmental regulations and WEEE policies (EN23). Additionally, EPR (EN22) and environmental regulations and WEEE policies (EN23) belong to the cause group whereas, community awareness (EN5) and development of green logistics and warehousing facilities (EN18) belong to the effect group have a duple effect which signifies their inter-dependency represented by a dotted arrow in Fig. 2.

4.1. Zone-wise categorization of enablers

On a detailed investigation of the results, enablers for sustainable implementation of WEEE management can be categorized into four different zones based on their mutual dependency (see Fig. 3).

- Zone 1 depicts enablers with nominal relations and are least significant among others. These enablers can be categorized as independent enablers. Enablers belonging to Zone 1 are EN1, EN3, EN6, EN7, EN8, EN11, and EN15.
- Zone 2 comprises causal enablers that can drive other enablers; however, their influence is superficial over enablers of the driven group. EN2, EN9, EN10, EN19, and EN21 are associated with this zone.
- Zone 3 represents enablers falling under causal group having strong driving significance over other enablers. These enablers are

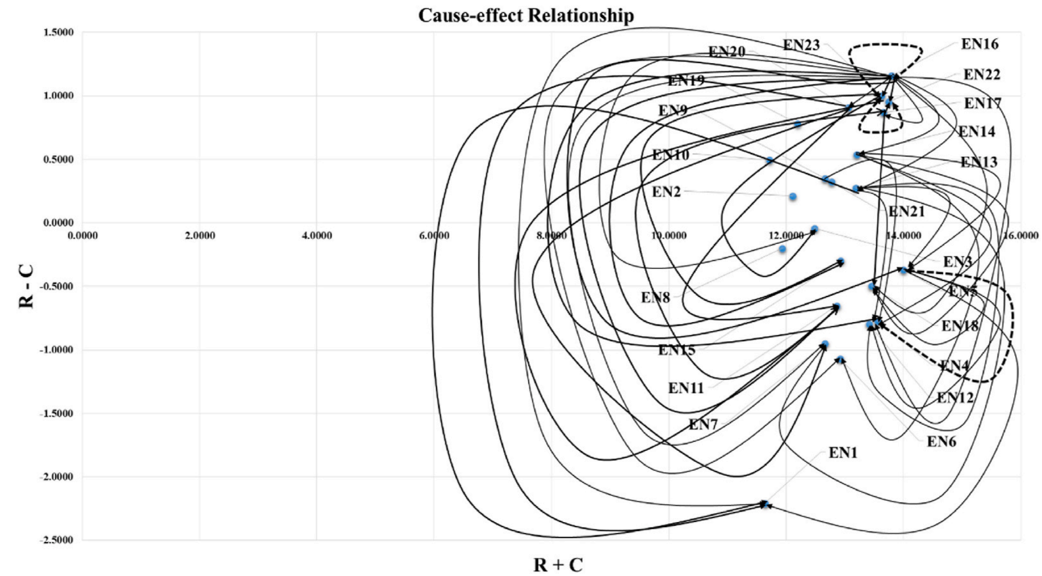

Fig. 2. Cause-effect diagram for enablers of sustainable WEEE management implementation.

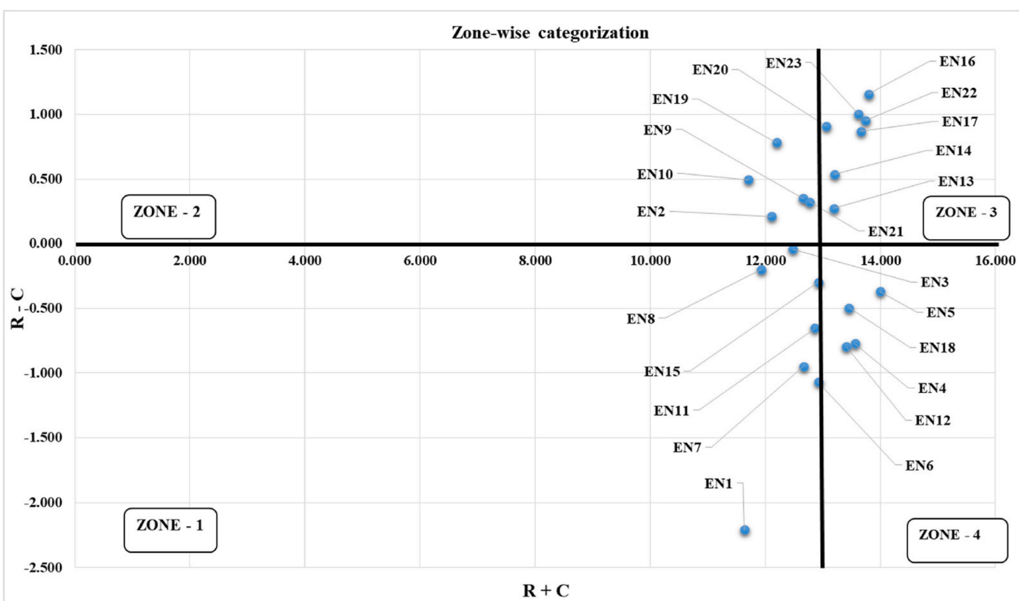

Fig. 3. Zone-wise categorization of enablers for sustainable implementation of WEEE management.

considered the most crucial enablers for solving the WEEE management implementation issue. The enablers belonging to Zone 3 are EN13, EN14, EN16, EN17, EN20, EN22, and EN23.

- Zone 4 represents enablers with a high prominence index value, but they fall under the dysfunctional group. These enablers are influenced mainly by other cause group enablers in the relationship mapping. To facilitate effective decision-making, they need to be looked upon and controlled immediately by the stakeholders. The enablers belonging to Zone 4 are EN4, EN5, EN12, and EN18.

5. Sensitivity analysis

Sensitivity analysis can be performed to test the reliability and robustness of the solution methodology. To perform sensitivity analysis, we altered the weight of an individual expert to investigate the effect on the overall system (Kumar and Dixit, 2018b; Rajesh and Ravi, 2015). For smooth conduct of the analysis, equal weight can be assigned to each expert, and later, weights can be altered for each scenario, as shown in Table 6. To check the variation for Scenario 1, a higher weight was given to Expert 1, and the rest of the experts were given equal weights. Similarly, sensitivity analysis was also performed for other experts by allocating higher weight to individual experts. Five independent total relationship matrices were computed based on the sensitivity analysis. From the total relationship matrix, relation and prominence values were obtained, and five separate rankings based on (R–C) index values are

Table 6
Weight allocation for each expert analyst.

	Expert 1	Expert 2	Expert 3	Expert 4
Scenario 1	0.4	0.2	0.2	0.2
Scenario 2	0.2	0.4	0.2	0.2
Scenario 3	0.2	0.2	0.4	0.2
Scenario 4	0.2	0.2	0.2	0.4
Scenario 5	0.1	0.1	0.1	0.1

shown in Table 7. Results of the sensitivity analysis show no serious variation in the ranking of the enablers. Hence, this study is free from biases, and the results obtained are robust.

6. Discussion and conclusions

The present study identifies 23 important enablers for implementing sustainable WEEE management. The results presented in Table 5 revealed that in the Indian context, community awareness (EN5) could be considered as the most crucial enabler for sustainable WEEE management, which focuses on building awareness regarding waste recycling and disposal, product reuse, and elimination of toxic substances (Chan et al., 2012; Kwatra et al., 2014; Zhou et al., 2017). Engaging and involving consumers is also crucial (Alves et al., 2021). Research and development capabilities and digitization (EN16) ranked second in priority based on (R + C) values. Existing literature also suggests that research and development investment plays a key role in technology advancement and process innovation (Gupta and Barua, 2017). EPR (EN22) is the third most crucial enabler for sustainable WEEE management as it maximizes organizational performance and economic benefits (Atasu and Subramanian, 2012; Barba-Sánchez and Atienza-Sahuquillo, 2016). Policy initiatives related to EPR increase the onus of electronic manufacturers to dispose electronic products through downstream activities such as reverse logistics, disassembling, recycling, and resource recovery (Garlapati, 2016; Zhou et al., 2017).

The use of cleaner technologies for WEEE recycling (EN17) ranked fourth in the priority list according to (R + C) values. Cleaner technologies reduce the negative impact on the recycling industry (Kumar and Dixit, 2018a) and can be developed through collaboration with research and development agencies (Xu et al., 2018). Environmental regulations and WEEE policies (EN23) are considered the fifth most important enabler in line with the existing literature (Garlpati, 2016; Wath et al., 2010). Material and energy recovery (EN4) is the sixth most crucial enabler. Arena and Di Gregorio (2014) pointed out that energy recovery can effectively reduce landfills and benefit economically. Recovery of precious and rare earth metals can reduce the use of virgin material in production, which leads to resource conservation and economic benefits (Coban et al., 2018; Pan et al., 2015; Pekarkova et al., 2021; Zhu et al., 2013). As per the priority rating list, green logistics and warehouse facilities (EN18) are the seventh most important enabler. Well-equipped green logistics and warehousing infrastructure play a vital role in reducing carbon footprints (Kannan et al., 2014). Apart from these seven crucial enablers, the ARF is the least important enabler. It highlights that despite mentioning ARF in the product's price, it may not help in sustainable WEEE management (Wath et al., 2010) because the final responsibility to dispose of the product lies with the retailer.

The results of the cause-effect relationship revealed that EN16, EN23, EN22, EN20, EN17, EN19, EN14, EN10, EN9, EN21, EN13, and EN2 falls under the causal group. However, EN1, EN6, EN7, EN12, EN4, EN11, EN18, EN5, EN15, EN8, EN3 fall under effect enablers. One of the crucial dimensions of the causal group is government policies and regulations (EN19, EN20, EN21, EN22, EN23). It highlights the importance of monitoring illegal imports, integration of informal with the formal sector, the role of stakeholders, EPR, and environmental regulations enablers in sustainable WEEE management. It is crucial to prioritize government policies and regulations because they can have a spillover effect on other dimensions. On the contrary, the enablers categorized under the effect group are easily driven or influenced by cause group enablers. The results revealed that social and economic (except one) enabler dimensions are in the effect group. It highlights that economic or social enablers are influenced by other enablers such as government policy and regulations enablers, technology and infrastructure, and environment management enablers.

The zone-wise analysis revealed that material and energy recovery (EN4), community awareness (EN5), EMS (EN12), and green logistics and warehousing facilities (EN18) are crucial enablers that should be controlled immediately. Initial steps may include organizing awareness programs to motivate consumers to return their WEEE to formal recyclers (Alves et al., 2021). It will help recycle the e-waste and help recover precious metals from the waste. Also, there is an urgent need to promote green logistics and warehousing facilities by promoting initiatives such as supply chain planning, procurement, and metrics (Dekker et al., 2012).

The findings aligned with the previous literature and highlighted the difference in enablers of WEEE management between developed and developing countries (Awasthi and Li, 2017; Xavier et al., 2021). For instance, in India, we found that monitoring of illegal import and dumping (EN19), integration of informal sector with the formal sector (EN20), and avoiding community landfills disposal (EN13) as crucial enablers. However, these might not be enablers in developed countries

Table 7
Sensitivity analysis of cause/effect enablers for each scenario.

Ranking order	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Enabler	R–C	Enabler	R–C	Enabler	R–C	Enabler	R–C	Enabler	R–C
1	EN16	1.407	EN16	1.172	EN16	1.107	EN16	1.230	EN16	1.157
2	EN22	1.285	EN22	0.951	EN22	1.088	EN22	1.115	EN23	1.000
3	EN19	0.987	EN19	0.820	EN19	1.061	EN19	1.088	EN22	0.955
4	EN17	0.665	EN23	0.813	EN23	0.902	EN23	0.825	EN20	0.909
5	EN23	0.601	EN14	0.725	EN17	0.726	EN14	0.453	EN17	0.869
6	EN14	0.474	EN17	0.690	EN20	0.634	EN17	0.444	EN19	0.782
7	EN13	0.414	EN9	0.586	EN14	0.540	EN9	0.276	EN14	0.537
8	EN21	0.222	EN20	0.484	EN21	0.275	EN13	0.246	EN10	0.494
9	EN2	0.103	EN13	0.480	EN9	0.167	EN21	0.180	EN9	0.351
10	EN20	0.099	EN5	0.468	EN13	0.140	EN10	0.168	EN21	0.323
11	EN15	0.095	EN15	0.412	EN5	0.120	EN5	0.143	EN13	0.274
12	EN9	0.042	EN21	0.323	EN10	−0.008	EN20	0.063	EN2	0.211
13	EN4	0.021	EN10	0.058	EN2	−0.089	EN3	−0.039	EN3	−0.043
14	EN5	−0.061	EN2	−0.190	EN3	−0.182	EN2	−0.053	EN8	−0.200
15	EN8	−0.131	EN8	−0.326	EN8	−0.263	EN8	−0.100	EN15	−0.298
16	EN3	−0.148	EN3	−0.435	EN15	−0.313	EN18	−0.111	EN5	−0.370
17	EN12	−0.390	EN12	−0.490	EN18	−0.372	EN15	−0.330	EN18	−0.498
18	EN10	−0.466	EN11	−0.550	EN12	−0.611	EN4	−0.455	EN11	−0.653
19	EN18	−0.591	EN6	−0.714	EN11	−0.616	EN12	−0.621	EN4	−0.773
20	EN11	−0.885	EN4	−0.751	EN4	−0.681	EN11	−0.641	EN12	−0.797
21	EN7	−1.001	EN18	−0.767	EN7	−0.959	EN7	−0.862	EN7	−0.950
22	EN6	−1.022	EN7	−1.490	EN6	−1.098	EN6	−0.958	EN6	−1.070
23	EN1	−1.719	EN1	−2.270	EN1	−1.568	EN1	−2.059	EN1	−2.208

as they have strict rules and regulations regarding WEEE management (Shooshtarian et al., 2021). In developing countries, the existence of the informal sector emerged as a significant challenge (An et al., 2015; Awasthi and Li, 2017) that requires integration with the formal sector. The integration will have a positive environmental impact as it may reduce the mining of precious metals and provide income-generating activities for both individuals and enterprises (Manish and Chakraborty, 2019).

In the Indian context, Garg (2021) revealed that top management initiation, commitment towards return management, effective implementation of e-waste policy, EPR, ARF, technological and green innovations in recycling network, and strategic alliance among supply chain partners are the crucial enablers for sustainable WEEE management. Similarly, Sharma et al. (2020) identified EMS, eco-friendly products, developing strict legislations, building green image, and supporting the producers to implement CE practices as crucial enablers. The findings of Arya and Kumar (2020) and Dutta and Goel (2021) complemented the existing studies and identified the integration of informal with the formal sector, eco-product design, circular resource management, polluter pays principle, life cycle assessment, 4R principle, and bioleaching as enablers. The present study builds on the existing literature by identifying enablers such as financial institutions offering loans to promote green practices, CDM, and green information systems to implement sustainable WEEE management.

6.1. Implications to theory and practice

The study contributes to the NRBV by reaffirming that the firms can achieve competitive advantage through enablers such as green training programs and packaging, CDM, EMS, cleaner technologies, and R&D capabilities and digitization (see Table 1). These enablers also broaden the dimensions of NRBV. The study also contributes to the INT by identifying enablers such as ARF, community landfill disposal, health and safety measures, and environmental regulation requiring institutions' intervention (see Table 1). The benefits of these enablers can only be realized if the institutions provide a sufficient policy framework. The study further contributes to the ST by identifying different stakeholders for enablers such as EPR, integrating informal with the formal sector, collaboration with green partners, and community awareness and involvement (see Table 1). The stakeholder involvement may vary as per the local context.

The findings of the study also provide useful insights for industry. First, there should be an extensive focus on community awareness (EN5). It can be done by taking an example from the Kingdom of Bahrain, where one government organization placed different colour boxes for glass, paper, and electronic waste (Maderazo and Pineda, 2021). They also conducted various training programs to create awareness in the country (Maderazo and Pineda, 2021). Further, electronic manufacturers can organize awareness programs that can motivate consumers to return their WEEE to formal recyclers. Second, for promoting R&D capabilities and digitization, a robust framework is required that focuses on the decentralization of the internet infrastructure (Garrido-Hidalgo et al., 2020). Third, the study suggests that electronic manufacturers should implement the EPR initiative to define the roles and responsibilities clearly by adopting measures such as differentiating producers' responsibilities, focusing on rural areas, and informal sector involvement (Johannes et al., 2021). It assists in product recycling by integrating environmentally-sound activities such as reverse logistics, green packaging, and safe disposal of hazardous waste. Fourth, the use of green technologies (EN17) should be promoted by targeting the habits of young consumers and promoting green technologies in public places (Aboelmaged, 2021). Fifth, electronic manufacturers should adhere to policies and directives such as environmental regulations, WEEE policies, and RoHS. In particular, Indian electronic manufacturers should acquire EMS or ISO 14000 series certification, which also helps to improve manufacturers' image or branding (Shaharudin et al., 2017).

Sixth, material and energy recovery (EN4) can provide enormous economic benefits and is suggested to recover precious metals from WEEE. According to Arya et al. (2021), on average, e-waste recovery can roughly generate 428 Million INR (Haryana), 562 Million INR (Punjab), 105 Million INR (Himachal Pradesh) revenue. Material recovery can also fulfil the demand for metal belonging to the platinum group and reduce the import of crucial raw materials such as antimony (Panchal et al., 2021). It is estimated that around 42% of the Indian population will live in urban areas by 2025, increasing the possibility of e-waste generation (Rajput et al., 2021). Therefore, it is suggested to develop more formal recycling centres and policies that promote e-waste collection for economic benefits (Singh et al., 2021).

6.2. Implications for cleaner production policies

The enablers falling under the causal group are vital and can channel the overall system. One of the critical dimensions is government policies and regulations for cleaner production to assist sustainable WEEE management in emerging economies (Peng and Liu, 2016). Therefore, the study provides insights for policymakers aiming to implement cleaner production policies. The policymakers can establish a well-equipped platform to monitor and control the transboundary movement of WEEE flow at the regional or state level (Pariatamby and Victor, 2013). To achieve the Sustainable Development Goals of 2030, the Indian government should allocate adequate funds and force electronic manufacturers to invest some portion of their profits in research and development initiatives, which encourage strategies such as eco-design for new product development, process innovation for resource recovery, and innovative green material. Existing studies also revealed that waste recycling plays a crucial role in the circular economy (Salmenperä et al., 2021; Woodard, 2021; Zhang et al., 2019).

For the environment management dimension, it is suggested that policymakers can probably focus on enablers with high prominence index in the short run. There is a need to develop a stringent policy framework, which assists in successfully implementing WEEE management by considering socio-economic conditions and ways to integrate the informal recycling sector into the formal sector. In this context, the Ministry of Environment and Forests are now paying more attention to formulating a dedicated regulatory framework for electronic manufacturers such as EPR, WEEE, and RoHS directives. It aims to reduce the negative environmental impact of post-production (Awasthi and Li, 2018; Garlapati, 2016). The study also contributes towards better implementation of the circular economy by identifying enablers such as EPR, use of cleaner technologies for WEEE recycling, and integration of informal with the formal sector that can contribute towards WEEE recycling.

6.3. Limitations and future studies

The overall contribution of the study is to provide valuable insights about the enablers by assessing multiple stakeholders' perspectives, which helps reduce uncertainties in holistically implementing WEEE management. This study also uncovered influential enablers vital for developing strategies in electronic industries to manage product return.

Along with the benefits, the present study also has certain limitations. First, the study could not classify the enablers based on the context, i.e., developing and developed. The study only considered India as a context and tried to identify enablers for sustainable WEEE management. Future researchers can classify the literature according to the context and build causal relationship patterns. Second, this study uses integrated grey theory and DEMATEL approach; however, other MCDM techniques such as the Best-Worst method, TOPSIS, ANP, MAUT, and ELECTRE can be used for the same problem and the results compared in future studies.

Further, future studies can extend the idea by including other criteria for sustainable WEEE management implementation and validate with a large sample by employing structural equation modelling. Finally, real-time data collection is a challenge for technology and infrastructure enablers, especially in India, where data availability on e-waste is scarce. Therefore, it creates a need for real-time data collection regarding e-waste in India to understand the existing state and guidance for future measures. It is suggested that future studies can assess the causal impact of these 23 enablers on sustainable WEEE management by collecting primary data, which is beyond the scope of the current study.

CRediT authorship contribution statement

Ashwani Kumar: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft. **Diptanshu Gaur:** Conceptualization, Investigation, Resources, Data curation, Writing – original draft. **Yang Liu:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision. **Dheeraj Sharma:** Conceptualization, Validation, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.130391.

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