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# A systematic review on sustainable E-waste management: challenges, circular economy practices, and a conceptual framework

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## Abstract

**Purpose** – Waste generated from electrical and electronic equipment, collectively known as E-waste, remains a persistent environmental, economic and social problem. Sustainable E-waste management (EWM) has numerous benefits, such as preventing electronic waste from entering landfills, reducing the need for virgin materials by recovering valuable materials from recycling and lowering greenhouse gas emissions. Circular economy (CE) practices are considered the initial steps toward sustainable EWM, but some hurdles have been reported in the adoption of these practices. Therefore, the current study aims to identify the common CE practices, sustainability of the EWM process and the challenges in EWM, and to develop a conceptual framework for effective EWM.

**Design/methodology/approach** – Very few studies have proposed frameworks that acknowledge the challenges and CE practices of EWM. To fill this gap, a systematic literature review (SLR) was performed, and 169 research articles were explored.

**Findings** – A total of seven challenges in the adoption of effective EWM were identified: rules and policy, infrastructure, consumer behaviour, informal sectors, community culture, technology and economy. Eight common CE practices were also found for effective EWM: reuse, recycle, remanufacturing, refurbishment, repair, reduce, recover and repurpose.

**Originality/value** – A conceptual framework guiding sustainable EWM was proposed, which includes solutions for the identified challenges, and CE practices with sustainable benefits.

**Keywords** E-Waste management, Circular economy, Challenges, Sustainability, Framework

**Paper type** Research paper

## 1. Introduction

Consumer products such as electrical and electronic equipment (EEE), information technology devices and telecommunications devices are produced in large quantities because of their huge demand (Bartl, 2014). However, once these products reach their end-of-life or are replaced with newer or updated models, they are not used further and are termed E-waste (Azunre *et al.*, 2021; Cole *et al.*, 2019). E-waste has become a major worldwide issue owing to industrialisation, population growth and the frequent launch of upgraded/innovative products (Arain *et al.*, 2020; Cole *et al.*, 2019).

E-waste contains plastic and heavy metals such as lead, mercury, cadmium, beryllium and chromium polluting air, water and soil. When E-waste is burned, toxic fumes are emitted. These fumes can cause acute and chronic diseases, such as breathing diseases, skin cancer, allergies and even death (Awasthi *et al.*, 2016a; Cook *et al.*, 2020; Hicks *et al.*, 2005). Inappropriate disposal of heavy elements such as lead and mercury in landfills can also lead

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to the leakage of the groundwater (Pathak *et al.*, 2017; Ueberschaar *et al.*, 2017; Vural *et al.*, 2021). Moreover, lead is neurotoxic and can adversely affect the human reproductive system and kidneys. Furthermore, large doses of lead can be lethal and can negatively impact a child's mental development. Mercury affects the kidneys, the immunological system and the central nervous system. When lead passes through mother's milk, it can affect newborns and stunt the foetus's growth. Through microbiological processes, mercury in water bodies can be converted to methylmercury. Methylmercury in its most toxic form can damage the nervous and immune systems (Ankit *et al.*, 2021; Islam *et al.*, 2020; Nogara *et al.*, 2019). Heavy metals can seep directly from E-waste into the soil, causing contamination of the underlying groundwater or crops that may be planted nearby or in the area in the future. Heavy metal contamination of the soil increases the susceptibility of crops to absorb these toxins, which can lead to several illnesses and reduce farmland productivity (Moeckel *et al.*, 2020). Cadmium causes severe pain in the joints and spine. It also affects the kidneys and softens bones. Beryllium, found in switchboards and printed circuit boards, causes lung disease. Chromium is used to protect metal housings and plates in a computer from corrosion and can damage the liver and kidneys. As a result, pollution caused by E-waste is dangerous for both the current and future generations (IT's underbelly, 2010).

The focus of governments, researchers and industries has shifted towards effective E-waste management (EWM) management and circular economy (CE) strategies such as extending the product life cycle, recovering material and functional value from E-waste (Awasthi, 2022; Geissdoerfer *et al.*, 2017; Wilson *et al.*, 2022). CE has several advantages over a linear economy, in which raw natural resources are taken, transformed into products and finally disposed of (Esbensen and Velis, 2016; Rizos and Bryhn, 2022; Velis, 2017). In contrast, the CE encourages system innovation to reduce waste, increase resource efficiency and keep materials in use (Bocken and Konietzko, 2022). E-waste has a significant impact on sustainability, that is on the environment, society and economy (Agarwal *et al.*, 2012). Effective EWM has numerous benefits such as preventing electronic waste from ending up in landfills, reducing the need for virgin materials by recovering valuable materials from recycling and lowering greenhouse gas emissions from processing or manufacturing "virgin material" by using recycled materials (Chaudhary *et al.*, 2017; Ismail and Hanafiah, 2019). Because of the precious metals and materials present in E-waste, recycling and recovery are essential to prevent their disposal in landfills (Ismail and Hanafiah, 2019). The reuse of recycled materials and metals to create new products contributes to the conservation of natural resources (Pathak *et al.*, 2017). Furthermore, reuse and recycling reduces the impact of precious metals and materials on the environment (Khetriwal *et al.*, 2009). Therefore, CE practices can be used for effective EWM.

However, while adopting CE practices and EWM effectively, industries face challenges (Kumar and Dixit, 2018a). Extended producer responsibility (EPR) is a policy approach under which producers are given a significant financial and/or physical responsibility for the treatment or disposal of post-consumer products. Assigning such responsibility could in principle provide incentives to prevent waste at the source, promote environmentally friendly product design and support the achievement of public recycling and material management goals (Alev *et al.*, 2020). The implementation of EPR in the current system or the delay in the implementation of the EPR approach is one of the challenges in the adoption of EWM (Peng *et al.*, 2018). Additionally, the transboundary movement of E-waste, from developed to developing economies, complicates EWM adoption (Bhuyan *et al.*, 2022; Milovantseva and Fitzpatrick, 2015; Osibanjo and Nnorom, 2007). Insufficient technologies for E-waste treatment and disposal, storage and transportation hinder the adoption of EWM (Liang *et al.*, 2020). The adoption of EWM is also hampered by the enormous initial capital investment required by formal recycling plants (Kumar *et al.*, 2022a, b). One hurdle may be the unavailability of a clear theoretical, conceptual or implementation framework (Borthakur and

Govind, 2018; Xavier *et al.*, 2023). Overall, a clear framework is required to overcome these challenges.

In this regard, Borthakur and Govind (2018) offered a conceptual framework of "Public understandings of E-waste and its disposal" in the Indian context but did not consider any challenges faced and reverse logistics of E-waste. Similarly, Islam and Huda (2018) also recommended a framework that is based on reverse logistics and closed-loop supply chains, but it also does not provide the challenges faced and sustainability of EWM (Islam and Huda, 2018). Kumar *et al.* (2022b) proposed a stochastic framework that does not include CE practices and challenges faced during managing E-waste. A framework for modelling fraud in EWM was proposed by Salmon *et al.* (2021) which was based on the recycling and returning fraud of E-waste but does not consist of other CE practices, and most of the challenges were ignored. Hence, a conceptual framework is needed to fill these gaps, that is a framework acknowledging both CE practices and the challenges faced during EWM.

Based on this discussion, the present study aims to achieve the following research objectives:

- *RO1.* To identify CE practices frequently used in the literature for effective EWM.
- *RO2.* To investigate how effective EWM can lead to sustainability.
- *RO3.* To explore the challenges faced during the adoption of effective EWM with CE practices.
- *RO4.* To propose a conceptual framework that includes the challenges, practices and sustainability of effective EWM.

The remainder of the paper is organised as follows: Section 2 presents the proposed methodology. Section 3 discusses the results of the study. Section 4 discusses the challenges, CE practices and sustainability of EWM. A conceptual framework for effective EWM is discussed in Section 5. Finally, the conclusions, implications and limitations of the study are presented in Section 6.

## 2. Methodology

This study used a qualitative and quantitative research approach to examine the challenges of EWM, CE practices and the sustainability of effective EWM. The five-phase method of preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Andeobu *et al.*, 2021) for conducting a systematic review and analysis of the literature was used in this study to accomplish its research objectives.

Figure 1 depicts the study data extraction flow diagram. Initially, 525 articles were found using the search string in the Scopus database. Scopus filters these articles based on publication year (2012–2022), subject area (environmental science, engineering, energy, business, management and accounting, economics, econometrics and finance, and decision sciences), document type (articles and reviews) and source type (journal). Based on screening and eligibility criteria (see Figure 1), 356 articles were eliminated. As a result, the study included a total of 169 articles.

To conduct a comprehensive analysis of the articles included, we identified key aspects such as year of study, name of the journal outlet, the study's geographical location(s), research area, the challenges encountered during EWM, different circular economy practices regarding EWM, the sustainability aspects of EWM, the established frameworks for EWM, CE practice-EWM challenges wise publications and Sustainable Development Goals (SDGs) (Joshi *et al.*, 2023). To fulfil research objectives, sub-themes were manually identified, and similar sub-themes were categorised into major themes. All major themes are discussed in Sections 3 and 4. To provide a better understanding of EWM, examples of countries and

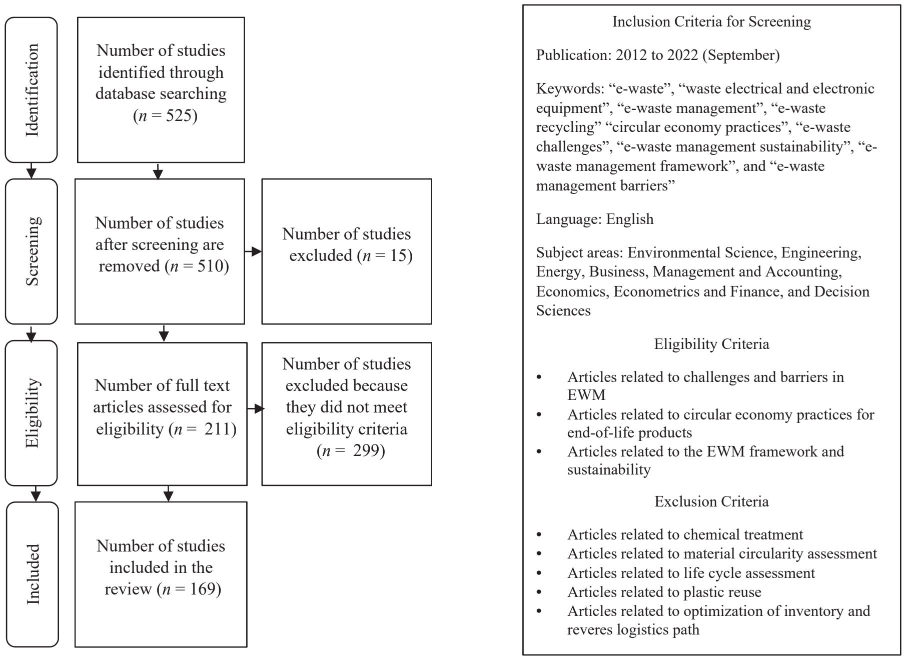


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**Figure 1.**
PRISMA framework

companies that have adopted EWM in their business were given. These examples were taken from the authors' own knowledge and Google search.

## 3. Results

This section presents descriptive statistics related to year-wise, journal-wise, country-wise publications, research area-wise, EWM challenges-wise, CE practice-wise publications, CE practice-EWM challenges-wise publications and SDG-wise. As discussed in the methodology section, a total of 38 sub-themes were manually identified. Among these 38 sub-themes, 25 sub-themes were related to EWM challenges, 8 were related to circular economy practices for EWM, three were related to sustainability and the remaining two were related to the framework. Similar sub-themes were categorised into ten major themes such as rules and policy challenges, infrastructural challenges, consumer behaviour challenges, informal sectors challenges, community-cultural challenges, technological challenges, economic challenges, circular economy practices, sustainability of EWM and framework. Seven similar major themes related to EWM challenges were grouped to form one major category – EWM challenges.

### *3.1 Year-wise distribution of publication*

Figure 2 shows the annual frequency of research articles in the selected research domain. The trend line shows an increase in the overall rate of research into the EWM. The number of papers has also significantly increased in recent years (except in 2021), indicating a rapidly expanding interest in the subject. The fact that half of the selected articles were published between 2019 and 2022 demonstrates the importance, timeliness and relevance of articles related to EWM.

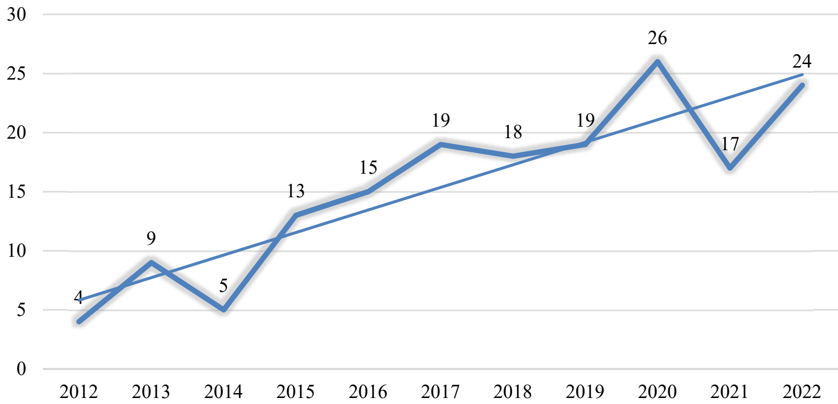

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**Figure 2.**
Year-wise distribution of publication

### *3.2 Journal-wise distribution of publication*

Figure 3 represents the distribution of research papers based on journals. The maximum number of articles were published in *Journal of Cleaner Production* and *Resources, Conservation and Recycling*. The reason may be these two journals cover more environmental and sustainability issues in businesses, governments, educational institutions, geographic areas and societies.

### *3.3 Country-wise distribution of publication*

Figure 4 shows that the maximum research related to EWM has been carried out in India, China, US, UK and Germany. The distribution indicates that both developed and developing countries are paying attention to EWM. However, the number of research articles may not be a good measure of ground reality.

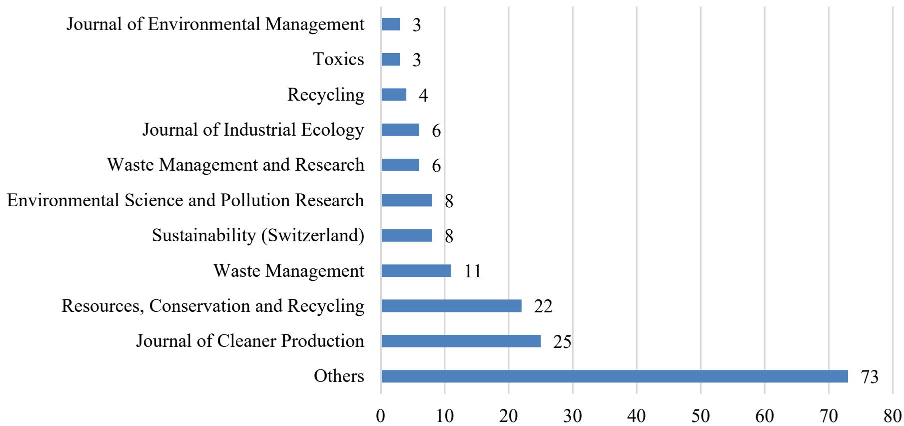

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**Figure 3.**
Journal-wise distribution of publication

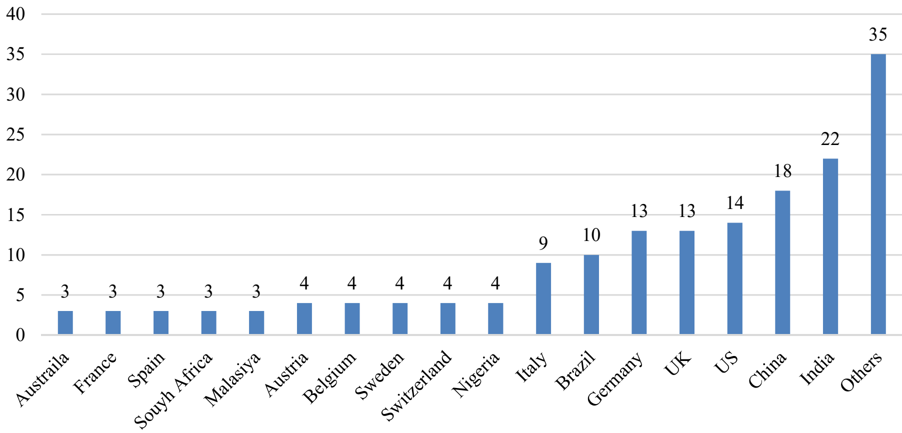


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**Figure 4.** Country-wise distribution of publication

*3.4 Research area-wise distribution of publications*

A total of 169 articles were selected for study. All articles are based on CE practices, and few articles provide frameworks for EWM (as shown in Figure 5).

*3.5 Challenges-wise distribution of publication*

Figure 6 shows that technological challenges, infrastructural challenges and rules and policies challenges are common challenges in the adoption of EWM as they have been discussed in most research articles.

*3.6 Circular economy practice-wise distribution of publication*

Figure 7 indicates that recycling practices are more common than others, and reduce and repurpose are the least common practices in EWM.

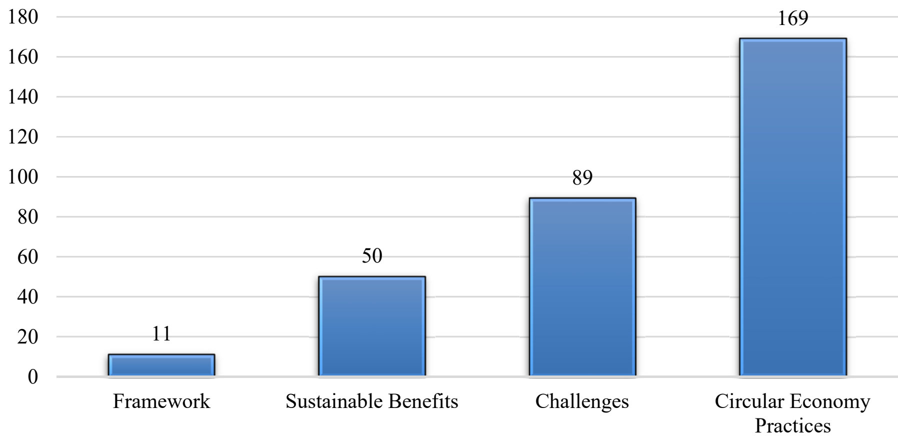


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**Figure 5.** Research area-wise distribution of publications

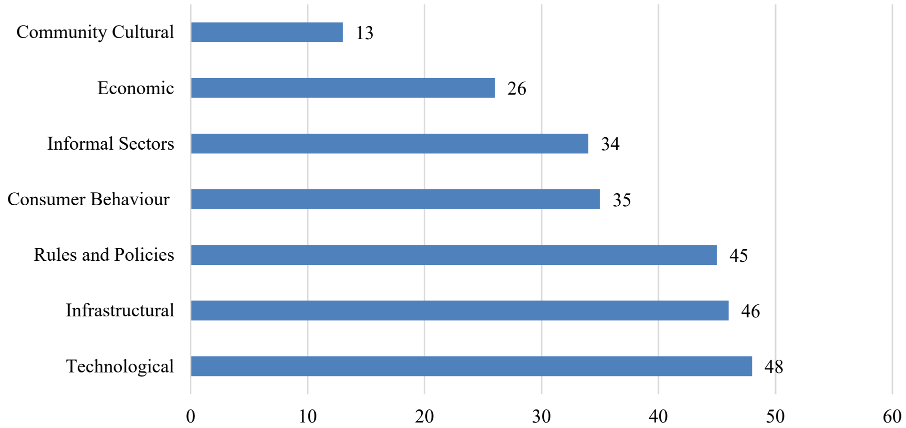


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**Figure 6.** Challenges-wise distribution of publication

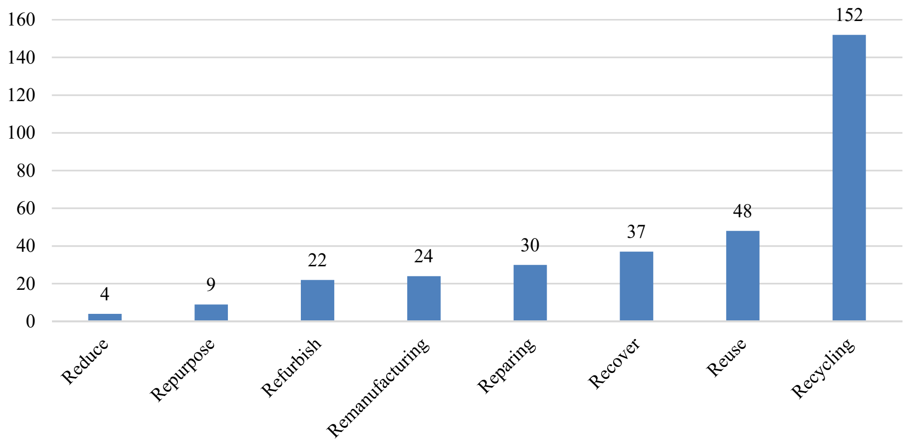


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**Figure 7.** Circular economy practice-wise distribution of publication

### *3.7 Year-wise distribution of publication on circular economy practice and challenges*

Figure 8 shows that there is an increment in the number of publications related to CE practices and challenges to EWM. For the last five years, there has been an increment of 62.7% in the publication based on CE practices, and 68.53% in challenges to EWM. The reason could be EPR, which was implemented mostly after 2015 (OECD Report, 2016).

### *3.8 SDG-wise distribution*

EWM could play a key role in achieving several Sustainable Development Goals (SDGs). The systematic literature review (SLR) of 169 articles shows that the maximum number of articles are based on SDG 12, that is responsible consumption and production (as shown in Figure 9). It could be so because primarily circular economy is based on the principle of reusing materials and products for a longer period (Sharma *et al.*, 2021).

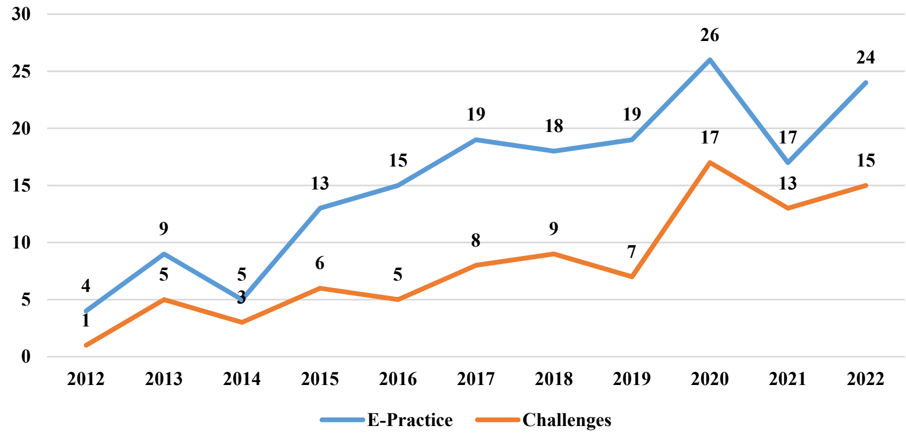


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**Figure 8.** Year-wise distribution of publication on circular economy practice and challenges

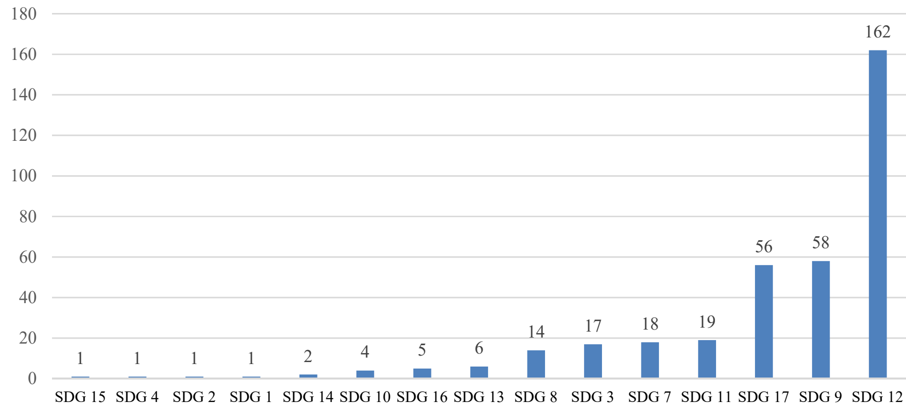


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**Figure 9.** SDG-wise distribution

## 4. Discussion and a way forward

This section discusses challenges faced by practitioners and industries in the adoption of effective EWM, the most common CE practices and the sustainability of effective EWM.

### *4.1 Circular economy practices for effective E-waste management*

The literature review identified eight CE practices: recycling, reuse, recovery, repairing, remanufacturing, refurbishment, repurpose and reduction. The following sections include examples of companies that have adopted CE practices in their businesses. These examples will be helpful for practitioners and industries to sustainably manage E-waste.

*4.1.1 Reduction.* Reduction increases efficiency in manufactured products by consuming fewer natural resources and materials. Industry can produce products that contain minimum or zero harmful substances (Pan *et al.*, 2022). To illustrate the "reduce" practice for EWM, the examples of "Fairphone" and "Dell Electronics" are provided. "Fairphone" is a Dutch company. The company manufactures mobile phones with eco-design. In simple words, they reduced the number of virgin materials and used recycled materials. "Dell Electronics" in selected countries is producing "OptiPlex 990 SFF" devices that are brominated flame retardants (BFRs) and polyvinyl chloride (PVC) free. All newly launched "OptiPlex" devices have a minimum of 10% post-consumer recycled plastics.

*4.1.2 Repurpose.* Repurpose uses an item for a completely different function. In other words, repurpose alters the original goal to serve a new purpose (Kirchherr *et al.*, 2017). "Repurpose Energy", a US-based company, is focused on reusing electric vehicle batteries to create reliable, low-cost, "second life" energy storage systems. This company uses a proprietary diagnostic system to assess the battery's health and assign them a proper destination. Similarly, "Spiers New Technologies" a US-based company that repairs, remanufactures and repurposes advanced battery packs from hybrid and electric vehicles.

*4.1.3 Refurbishment.* Repairs are a part of the refurbishment and could be done if necessary. However, refurbishment is a long process that also involves cleaning, lubrication, oil changes, consumable item replacement, factory resets, cosmetic upgrades, firmware upgrades, factory-specified or in-house recommended changes, replacing and/or upgrading capacitors, packaging the item for resale and a variety of other tasks (Steuer, 2016). To illustrate refurbishment practice for EWM, the examples of "Refurbed" and "Swappie" are provided. "Refurbed" is an Austrian company that has business in seven countries. It provides refurbished mobile phones, tablets and laptops with a minimum twelve-month warranty. "Swappie" is in Finland. It sells refurbished smartphones with a twelve-month warranty.

*4.1.4 Remanufacturing.* Remanufacturing uses a combination of reused, repaired and new parts to rebuild a product to its specifications. If a customer decides to remanufacture an electronic product, then the part would go through various processes and end up looking exactly like the original part. All the CE practices restore a part's functionality, but remanufacturing starts the part's life cycle from scratch (Coughlan *et al.*, 2018). "Circular Computing" is a British start-up. It provides remanufactured BSI KITMARK-marked laptops (HP, Dell and Lenovo laptops). BSI KITMARK certifies that remanufactured laptops are equal to or better than new laptops. "Sun Crafter" is a German company that produces off-grid solar power systems. This company minimises its products' environmental footprint by using fewer resources and remanufacturing solar modules.

*4.1.5 Repair.* Repair is the process of fixing a product by putting something together or replacing it to bring it to its healthy state (Kahhat *et al.*, 2022; Sonego *et al.*, 2022). To illustrate repair practice for EWM, the examples of "Carlow" and "Onsitego" are provided. "Carlow" is a UAE-based company, and it provides repair services at the doorstep. This company also buys old mobiles, tablets, laptops and other electronics products, and repairs or refurbishes them before selling them to customers. "Onsitego" is an Indian company that provides repair services for air-conditioners, laptops and televisions. Customers can request a repair online on a company's website or use a smartphone application. The company provides 30 days warranty for the service, and 90 days warranty for spare parts.

*4.1.6 Recovery.* Recovery is the process of extracting valuable materials from waste and incineration of materials with energy recovery. Many start-ups are providing services for metal recovery from E-waste (Wang *et al.*, 2017). The "Nth Cycle", located in the US, uses "electro-extraction technology" to recover critical minerals from separated E-waste and low-grade ores. Separated minerals are transformed into production-grade feedstocks for transition towards clean energy. Likewise, "NUMix Materials" is a US-based company that developed a sorbent technology solution to remove the concentration of toxic and precious metals from water.

*4.1.7 Reuse.* Reusing anything is doing it once more, whether for its intended use (conventional reuse) or a different purpose (creative reuse or repurposing). This conserves energy because manufactured products use a significant amount of energy. This material reuse technique can significantly reduce waste and pollution (Zacho *et al.*, 2018). To illustrate reuse practices for EWM, examples of "Grover" and "Rentomojo" are provided. "Grover" is a German-based start-up. It provides electronic devices for rent. The rent is decided by the customer, and after the expiring rent period, the customer will have to give the product again to the company or extend the rent period. Meanwhile, if any repair or maintenance is required while using the device, the company will cover 90% cost. Similarly, "Rentomojo" is an Indian company that also provides products such as air coolers and televisions on a rent/subscription basis. In addition, the subscription can also be transferred to another customer.

*4.1.8 Recycling.* Recycling is the process of gathering and converting resources into new goods that are otherwise discarded as waste. Compared to the production of products from recycled metal, the production of virgin metal from natural resources emits a significantly greater amount of greenhouse gas emissions and energy (Awasthi *et al.*, 2016a; Gehin *et al.*, 2008). One example of recycling is "Aihuishou" which is a C2B Chinese company that uses bidding to recycle and market used electronics such as mobile phones, tablets and laptops. Customers can request the Aihuishou website to recycle their items, and after recycling, customers will get money. Another example is "Cashify", an Indian company, which is an online platform, where customers can request the recycling of their mobile phones. The agent from "Cashify" will do it at the doorstep and will give money for that. The company plants a tree for recycling mobile devices. More than 10,200 trees have already been planted by Cashify.

### *4.2 E-waste management sustainability*

Effective EWM helps to reduce environmental burden, boost the economy and generate employment. By applying CE practices in business, countries can achieve Sustainable Development Goals (SDGs) and sustainable benefits as well. EWM could be helpful in achieving several SDGs such as SDG 12 (Sustainable Consumption and Production), SDG 9 (Industry, Innovation and Infrastructure) and SDG 17 (Global Partnership for Sustainable Development). Sustainable benefits may be categorised into environmental benefits, economic benefits and social benefits. This section highlights the benefits of effective EWM.

*4.2.1 Environmental sustainability.* EWM checks and controls continuous mining and helps global environmentalists save energy and avoid land wastage (Alev *et al.*, 2020; Dal Bello *et al.*, 2022). It also prevents the release of poisonous gases and dust from nearby mines into agricultural fields. That can otherwise make soil poisonous (Alves and Farina, 2018). A sizable portion of the world's population relies on agriculture as a source of income. Thus, it is important to ensure that the fields are fertile and secure for plant growth (Ardente *et al.*, 2015; Ardi *et al.*, 2020; Moeckel *et al.*, 2020). Likewise, reducing landfills that have harmful effects on the environment, such as water pollution, is another advantage of EWM (Awasthi *et al.*, 2016a). CE practices help to reduce pollution by reusing products or materials.

*4.2.2 Economic sustainability.* The EWM facilities will reduce the burden on the developing economies and non-OECD countries where the scrap was otherwise supposed to be dumped. EWM also provides manufacturers with limited resources, which promotes sustainable development (Arif, 2021; Valente *et al.*, 2021). Additionally, this avoids the costs associated with mining and processing raw materials and minerals (Kazançoglu *et al.*, 2020). The recycling of electronic waste uses less energy and is cheaper than mining raw materials (Borthakur, 2015). Moreover, EWM results in less pollution and reliance on already rare minerals (Böni *et al.*, 2015). Electronic manufacturers have come under intense pressure from international environmental organisations. Therefore, few manufacturers provide financial incentives to customers to purchase their used electronics. Similarly, it also lowers the cost of raw materials for the manufacturer (Butturi *et al.*, 2020; Cesaro *et al.*, 2019; Cheng *et al.*, 2019). This decreases the price of the finished product and raises the average standard of living.

Thus, effective EWM improves economic sustainability from both manufacturer and consumer perspectives.

*4.2.3 Social sustainability.* EWM not only protects the environment from pollution, but it also gives a boost to the economy by creating employment opportunities (Pan *et al.*, 2022). As a result, effective EWM can reduce harmful impacts on the environment and will ultimately help in maintaining the good health of human beings. Creating jobs contributes to the first SDG of reducing poverty (Awasthi *et al.*, 2016b; Bhaskar and Kumar, 2019). It promotes the effective utilisation of resources. Donating cheaper functional or refurbished electronics helps those who cannot afford expensive new devices. EWM reduces the use of new virgin materials, due to which virgin material resources will be available for future generations (Bai *et al.*, 2018; Bimir, 2020). Likewise, recovery of energy from E-waste can be used for various purposes like generating affordable and clean energy (Corsini *et al.*, 2020; Dias *et al.*, 2018; Esenduran *et al.*, 2020).

### *4.3 Challenges in the adoption of effective E-waste management*

The literature review demonstrates that most countries are trying to reduce the possibility of E-waste generation and manage E-waste effectively. However, many challenges have been faced at the manufacturing, consumer, society and government levels which need to be resolved. In this line, after reviewing a plethora of literature, seven challenges and their solutions were identified that hinder the adoption of effective EWM.

*4.3.1 Rules and policies (PC).* Implementation of EPR in the current system or delay in EPR approach implementation, which may be due to the unavailability of clear policies or financial support to producers, is one of the challenges in the adoption of EWM (Anyango Tocho and Mwololo Waema, 2013; Jangre *et al.*, 2022; Peng *et al.*, 2018). According to the Basel Ban Amendment (adopted as the decision of the second meeting of the Conference of the Parties in March 1994), no country is allowed to transport E-waste to another (http://www.basel.int/default.aspx). However, the OECD (*Organisation for Economic Co-operation and Development* Countries *works to create better policies for better lives*) or developed countries do not follow this amendment and transport E-waste to developing countries or non-OECD countries such as India and China (Awasthi *et al.*, 2018; Milovantseva and Fitzpatrick, 2015; Zacho *et al.*, 2018). This has resulted in a large quantity of E-waste in these countries. Developing countries are not in such a position that they can handle or recycle this large quantity of E-waste effectively and do not have policies and rules addressing environmentally sound E-waste recycling practices (Mishra and Mishra, 2023). In addition, these countries are also unable to systematically monitor and audit E-waste (Bhuyan *et al.*, 2022; Kumar and Dixit, 2018a). Meanwhile, most countries face issues with EWM because of unavailability or unclear policies, rules and regulations.

Several countries have implemented E-waste policies for effective EWM. EPR is one of the main key factors in policies (Chaudhary and Vrat, 2018). To fulfil EPR, the government could force the producers to collaborate with third-party organisations to collect and treat E-waste in an eco-friendly manner. For example, Motorola is giving facilities to consumers to give their end-of-life mobile or other devices for recycling. They collaborated with third-party organisations for effective collection. Additionally, it designed the mobiles in such a way that recycling becomes easier. Several recyclers like "Karo Sambhav", which is an Indian producer responsibility organisation, are giving incentives to consumers for their E-waste. Strict rules could be made to stop the transboundary movement of E-waste (Arya and Kumar, 2020).

*4.3.2 Infrastructural challenges (IC).* Infrastructural facilities also pose a challenge to the adoption of EWM (Cheng *et al.*, 2019; Gunarathne *et al.*, 2020). Insufficient technologies, lack of storage, transportation facilities, collection of E-waste, sorting and inhomogeneity of waste and disposal hinder EWM (Bhatia and Srivastava, 2018; Dutta *et al.*, 2021). Limited planning and forecasting of E-waste generation is a common issue in several countries. Lack of coordination and collaboration between stakeholders may lead to infrastructural challenges in the adoption of EWM (Chaudhary and Vrat, 2018; Prakash and Barua, 2015; Rizos and Bryhn, 2022).

To overcome infrastructural challenges, producers or recyclers could collaborate with authorised third-party E-waste collectors (Alev *et al.*, 2020; Favot *et al.*, 2022). This will help in the collection, transportation and storage of E-waste. Producers could develop collection centres at their service centres or nearby service centres. For example, Samsung provides recycling facilities at their service centre location. Consumers could request to pick E-waste from their location by sending an email to the company. The next example is Oppo, which is taking the help of third-party organisations for collection of E-waste. Government could develop such policies so that stakeholders could collaborate. This could help in forecasting and planning of E-waste generation.

*4.3.3 Consumer behaviour challenges (KC).* According to EPR, producers have the right to collect advance-recycling fees (ARF) from consumers so that when a product reaches the end-of-life, it can be taken back and recycled (Arya and Kumar, 2020; Govindan and Bouzon, 2018). Although most customers pay for a product, they do not know ARF. As a result, instead of returning the product to the producer for recycling, consumers throw it away or dump it into a landfill. Green products are eco-friendly and do not harm the environment. According to Kumar and Dixit (2018b), consumer behaviour is extremely important in environmental activities such as buying environment-friendly electronics, using electronics to lessen harmful effects on the environment and criticising disposal practices (Kumar and Dixit, 2018a). Customers purchase non-eco-friendly products because they are unaware of the benefits of green products (Mehta and Chahal, 2021), which harm the environment both during and after a product's lifespan (Kwatra *et al.*, 2014; Ofori and Opoku Mensah, 2022). Online e-markets such as Amazon sell refurbished products. They take old or damaged products, repair or refurbish them and sell them to customers. Due to a lack of awareness, consumers do not take advantage of these facilities, which help reduce the environmental burden (Bouzon *et al.*, 2016; Singh *et al.*, 2020). Even take-back programmes are conducted by start-ups or emerging companies (e.g., Recono is a London-based start-up that provides convenient collections, repair, reuse and recycling of E-waste- https://recono.me/about-us/), but consumers have insufficient awareness of it (Prakash and Barua, 2015). Therefore, knowledge and awareness challenges may be considered crucial for effective EWM.

ARF could be mentioned on the packaging of electrical and electronic equipment (EEE). Social programmes for awareness about eco-friendly products, recycling and reclaimed products could be conducted by educational institutions and the government. For example, in 2015, the Ministry of Electronics and Information Technology (MeitY) started a programme called "Environmental Awareness through Digital India" to educate people about the dangers of improper electronic waste recycling. They wanted to promote eco-friendly recycling methods instead of the ones used by unorganised groups. The programme targeted government officials, students, community associations, manufacturers, dealers, refurbishers, recyclers and informal workers to spread this message. Many manufacturers such as Dell Electronics and Lenovo are selling reclaimed products at low prices with warranties. These companies are enhancing consumer awareness towards reclaimed products in several ways like advertisements. Such companies are providing take-back schemes also.

*4.3.4 Informal sectors challenges (SC).* According to a GTZ-MAIT study, over 95% of the E-waste generated is managed by the informal sector and scrap dealers in this market, and there are only a small number of formal recycling units operating in this sector because of strict policy norms and a lack of financial support (Mhatre *et al.*, 2023). Informal recyclers use outdated technologies and processes for recycling that are very harmful to the environment and are not recognised by the government (Arya and Kumar, 2020; Cheng *et al.*, 2019; Dutta *et al.*, 2021). Even the workforce is unsafe in informal recycling industries because of harmful emissions (Gunarathne *et al.*, 2020; Meng *et al.*, 2022). This can result in health problems for the workforce, and over time, this can also lead to the death of personnel handling E-waste.

The government could make policies for the integration of informal sectors with formal sectors or the formalisation of informal sectors by giving tax subsidies and tax incentives to them. Attero, which is the largest recycling company in India, is collaborating with informal sectors for the collection and treatment of E-waste in an environmentally friendly manner. It also conducts awareness programmes and collection drives in several locations for EWM.

*4.3.5 Community cultural challenges (CC).* Poor social conditions for scavengers, recyclers and waste pickers; low public environmental consciousness; poor purchasing behaviour of consumers; and lack of willingness to recycle electronic equipment are common community cultural challenges (Mathiyazhagan and Vrat, 2017; Mhatre *et al.*, 2023; Prakash and Barua, 2015).

Consumers could be educated about the harmful impacts of e-waste and the benefits of EWM with the help of social media, newspapers, social programmes and CSR activities. Incentives on end-of-life product return could play an important role in increasing E-waste collection and recycling. For example, HMD Global (branded as HMD and Nokia Mobile, a Finnish mobile phone manufacturer), along with Reteck, runs e-CAP, which is an awareness programme on E-waste collection and its recycling. Such a programme emphasises creating awareness for people and all the stakeholders who in one way or the other deal with e-waste.

*4.3.6 Technological challenges (TC).* E-waste recycling is difficult for formal sectors because of the lack of skilled labour. Less experienced workers lack sufficient knowledge of recycling techniques (Abdulrahman *et al.*, 2014; Gunarathne *et al.*, 2020). Additionally, developed countries like Switzerland have implemented green recycling practices, but developing countries continue to struggle with a lack of understanding of such practices (Chakrabarty and Nandi, 2021; Jin *et al.*, 2020). Moreover, owing to the lack of new machinery for recycling, the formal sectors continue to use outdated technologies and procedures (Azadnia *et al.*, 2021). This is due to the absence of standards and certification for companies that recycle E-waste. In developing countries, the biological treatment of E-waste remains a problem (Bocken and Konietzko, 2022; Jin *et al.*, 2020). Although some nations, including China and India, have received the most advanced equipment for better recycling, the workforce and management are not adaptable enough to replace old practices with new ones (Bocken and Konietzko, 2022; Dutta *et al.*, 2021; Zailani *et al.*, 2017).

Many recyclers such as "Electronic Recyclers International", "Enviro Hub Holdings Ltd" and "MBA Polymers" are using advanced technologies for sorting, segregation, recycling and disposal of waste. Such companies provide training sessions to workers about new technologies introduced for effective EWM. Automated technologies could reduce requirements of skilled workers.

*4.3.7 Economic challenges (EC).* One of the major issues faced in EWM is the availability of funds required for technology upgradation, training of labourers and safety equipment (Bouzon *et al.*, 2016; Ravi and Shankar, 2005). Kumar and Dixit (2018b) determined that industries also face trouble while funding their collection centres and keeping track of E-waste after it has been collected. Additionally, the government provides less financial support to formal recyclers than required (Kumar *et al.*, 2022a, b). The recycling process includes many environmental challenges because toxic waste disposal requires a high level of safety and cutting-edge technology, which requires significant investment (Gunarathne *et al.*, 2020; Kumar *et al.*, 2022a). The adoption of EWM is hampered by the enormous initial capital investment required by formal recycling plants (Kumar and Dixit, 2018b).

Government could provide financial support to stakeholders for effective EWM. For example, China took steps to help its recycling industries. They introduced a special tax initiative that benefits recycling businesses. This initiative, known as Circular No. 115, was issued by the State Administration of Taxation in the Ministry of Finance in 2011. Since 1 August 2011, China has waived the value-added tax (VAT) for services related to waste and sludge treatment if specific conditions are met. Additionally, they offer a 50% VAT refund for certain products like household appliances and pipes that are made by the recycling companies themselves. China also has policies that provide financial support for recycling during the product's reuse and recycling stage.

## 5. Conceptual framework for effective E-waste management

After reviewing the plethora of literature, it can be concluded that only a few studies proposed a framework for EWM (see Table 1), and they have not considered all aspects, that is, 8R CE approaches, challenges in the adoption of effective EWM, solutions for challenges and sustainable benefits of EWM. To fill this gap, the current study proposed a conceptual framework (see Figure 10) with the help of a literature review. It can be an effective framework that could be used by industries, government and consumers for effective EWM. In the following table, we discussed steps towards using the framework.

### *5.1 Manufacturing*

The results of our literature review show that there could be three challenges, inamely, rules and policies challenges (such as EPR implementation, lack of systematic monitoring of EWM practices and lack of clear framework for EWM), infrastructure challenges (such as limited forecasting of E-waste generation and lack of collaboration among supply chain partners) and consumer behaviour challenges (such as lack of awareness about green and reclaimed products), that are commonly encountered during manufacturing.

The government could enforce EPR rules to manufacturers to adopt "reduce" practices in manufacturing of EEE. Random auditing of EWM practices could play an important role in ensuring that manufacturers are following laws and regulations. For example, Australia has enforced E-waste laws to stakeholders for effective EWM (Dias *et al.*, 2018). Financial support and incentives can be provided to the manufacturers for their contribution towards sustainability by developing E-waste recycling, return monitoring systems, green product generation and collection centres. For example, Japan and Switzerland are providing financial support to stakeholders (Khetriwal *et al.*, 2009). A clear framework could be developed by the government for every stakeholder for effective EWM. A system or platform could be made for stakeholders (such as manufacturers, recyclers, consumers and collectors) where they can share their information related to E-waste. This could be helpful in collaboration among stakeholders and could help to forecast E-waste effectively. Government and manufacturers could enhance awareness about reclaimed products and green products to consumers so that consumers will buy sustainable products without any fear (Bhatia and Srivastava, 2018). Awareness could be created through social media, newspapers, awareness programmes and television.

### *5.2 Use*

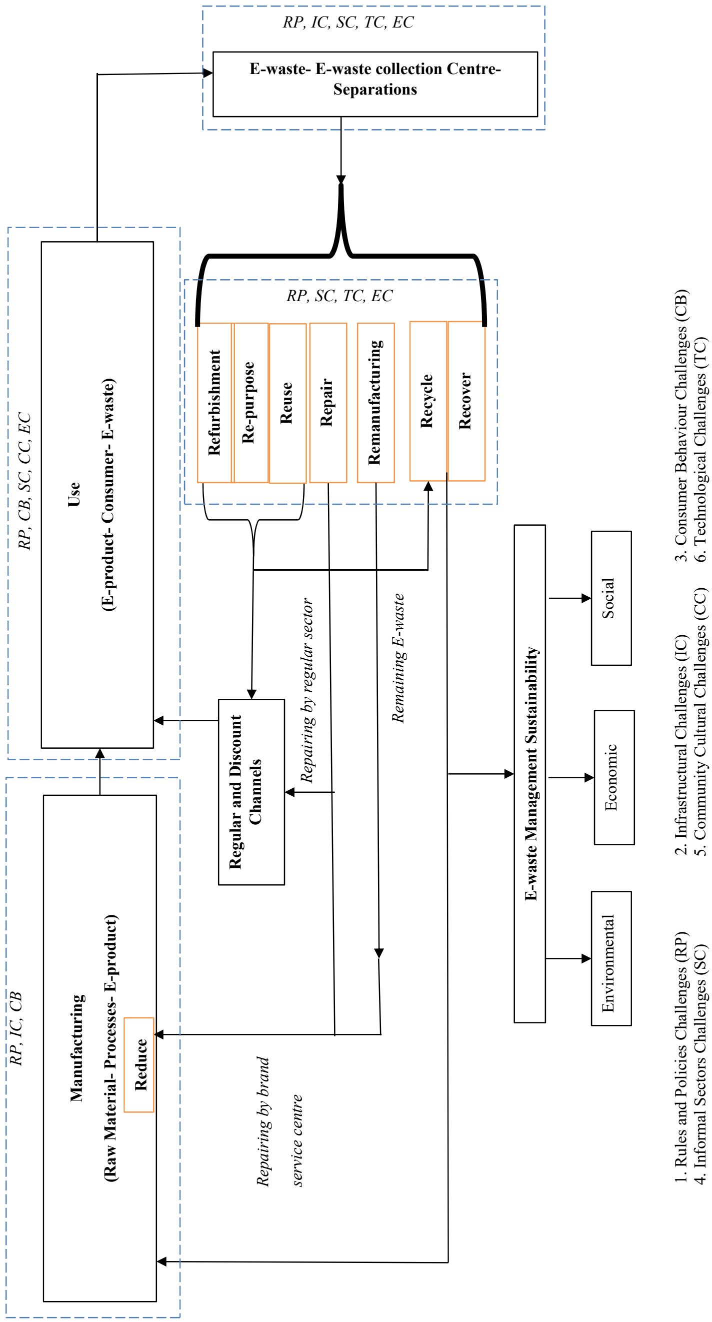
Five challenges – rules and policies challenges (e.g. E-waste laws enforcement), consumer behaviour challenges (e.g. lack of knowledge about sustainable products, lack of take-back programme), informal sector challenges, community-cultural challenges (e.g. backyard recycling) and economic challenges (lack of incentives to consumers for sustainable practice) – are usually faced during the use phase.

The government could enforce E-waste rules for each stakeholder like consumers. Awareness about green products, tack-back programmes, the harmful impact of backyard

**Table 1.**
Framework proposed for EWM

| Reference | Circular economy practice | | | | | | | | Challenges | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reuse | Recycle | Refurbishment | Recover | Repair | Remanufacturing | Reduce | Re-purpose | RP | IC | CB | SC | CC | TC | EC | Sustainability |
| Borthakur and Govind (2018) | | ✓ | ✓ | | ✓ | | | | | | ✓ | | ✓ | | | |
| Abdulrahman *et al.* (2014) | | ✓ | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Anyango Tocho and Mwololo Waema (2013) | | ✓ | ✓ | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | |
| Bhatia and Srivastava (2018) | | | | | | ✓ | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Borthakur (2015) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ | | | ✓ |
| Bouzon *et al.* (2016) | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Chaudhary *et al.* (2017) | | ✓ | ✓ | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chen *et al.* (2020) | | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Dutta *et al.* (2021) | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Kazançoglu *et al.* (2020) | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| Mhatre *et al.* (2023) | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Our Contribution | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

**Source(s):** Table created by authors




**Source(s):** Figure created by authors

**Figure 10.**
Framework for
E-waste management

recycling, formal recycling and ARF (advanced recycling fee) could be enhanced. By law, in Switzerland, shops must disclose to customers the final price of goods, which includes the ARF (Khetriwal *et al.*, 2009). Manufacturers and recyclers could give incentives and vouchers to consumers on return of E-waste. Besides, the government can ask consumers to give products only to formal sectors and could encourage formal sector collectors by providing tax refunds/relaxation and subsidies. Consumers (individual or bulk consumers such as schools, banks and universities) could conduct awareness programmes on a societal level so that more amount of E-waste can be collected, and more green products can be used by them for better EWM. For example, in 2014, the NS Raghavan Centre for Entrepreneurial Learning (NSRCEL) at IIM, Bangalore, fostered a start-up called "Binbag" for Indian Institute of Management Bangalore (IIMB). Three pillars – awareness (conducting awareness programme and collection drive), access and assets (in the form of physical infrastructure or recycling facilities) – are the foundation of Binbag's business strategy. Similarly, Wipro takes up a 'Tech Refreshing" approach every 3–4 years, where a lot of EEE are declared obsolete and thus are being disposed of in an eco-friendly manner (Borthakur and Govind, 2017).

*5.3 E-waste collection*

There are five challenges – rules and policies challenges (e.g. EPR implementation, E-waste laws enforcement), infrastructural challenges (e.g. lack of collection centres, storage and transportation, lack of collaboration among supply chain partners), informal sector challenges, technological challenges (lack of advanced technologies for sorting, lack of skilled workers) and economic challenges (lack of funds for collection centres) – usually faced during E-waste collection.

E-waste laws could be enforced on manufacturers to follow EPR effectively. Manufacturers could hire third-party organisation to collect E-waste from consumers to fulfil EPR. For instance, in India, manufacturers are hiring third-party organisations for E-waste collection and treatment (Arya and Kumar, 2020). This E-waste must be sent to formal recyclers. These practices could be monitored by the government. The government could give joint tax subsidies to collectors for better infrastructure facilities and advanced technologies for sorting and segregation of E-waste. Consumers can provide their E-waste to formal collectors. Manufacturers could provide details of E-waste to formal sectors so that more amount of E-waste can be collected and treated properly. The collectors can use the latest eco-friendly technologies and skilled workforce for better and more effective results. The informal sector needs to be regulated and controlled by converting them into formal collection centres. Likewise, it is difficult for E-waste collectors to get certified due to long procedures, and hence the certification process needs to be simplified.

*5.4 Circular economy practice*

Four challenges – rules and policies challenges (e.g. E-waste laws enforcement, lack of rules and policies related to eco-friendly recycling), informal sector challenges, technological challenges (e.g. lack of advanced technologies for E-waste treatment, lack of skilled workforce) and economic challenges (lack of funds for advanced technologies and infrastructure facilities, high cost involved in the treatment of E-waste) – are usually faced during CE practices.

When E-waste goes for refurbishment, reuse and repurpose, informal sector challenges and technological challenges are encountered. For instance, there may be competition between formal and informal sectors, a limited skilled workforce and absence of green recycling practices for handling E-waste issues. Therefore, formal sectors should have a skilled workforce, advanced technologies for treatment and SOPs for green recycling practices. In several economies such as China, India, the US and UK, formal sectors have these facilities (Arya and Kumar, 2020; Awasthi *et al.*, 2018; Kumar and Dixit, 2018b). Government could provide tax relaxation, incentives and subsidies to such sectors. The repair approach can be done in two ways: first, by formal sectors and, second, by producers' service centres. Refurbished, reused, repurposed and repaired products could be sold through discount channels or regular channels. Discount channels sell products on a discount basis. Because of this facility, consumers have the choice to use assorted products at lower costs.

When E-waste cannot be refurbished, reused, repurposed and repaired, then remanufacturing is a good option. Remanufacturing is done by the product's manufacturer. For instance, "Dell Electronics" is selling remanufactured laptops (mentioned in section 4.2.8). Manufacturers should benefit from the government in terms of tax relaxation and subsidies. They should have the latest machinery and technologies that do not produce pollution or produce less pollution compared to traditional technologies. The remaining E-waste after remanufacturing goes for recovering and recycling.

The remaining E-waste from refurbishment, repair, reuse, repurpose and remanufacturing processes can be recycled and recovered. At this stage of recycling and recovery, informal sector challenges, economic challenges and technological challenges may be encountered. To avoid or reduce these challenges, recyclers should have biological and technological treatment technologies, a properly skilled workforce and green recycling machinery. The government should help recyclers by awarding them for using green practices. Aforementioned steps can make EWM effective. It gives three sustainable benefits, namely environmental, economic and social benefits.

## 6. Conclusion

E-waste contains toxic components that could be dangerous both to the environment and to human health. Hence, the implementation of effective EWM is the prime agenda for both developed and developing economies. CE practices are common practices in EWM that have a significant impact on sustainability. Several countries are adopting EWM to gain the benefits of sustainability, but they are still facing hurdles for effective EWM. The current study included an SLR of 169 articles to complete four main research objectives. This study identified eight common CE practices, namely recycling, reuse, recovery, repair, remanufacturing, refurbishment, repurpose and reduction used in literature for EWM (RO1). Recycling was the most cited CE practice in literature. Furthermore, we also identified how EWM can lead to sustainability in terms of environmental, economic and social goals (RO2). As an example, the E-waste stream exhibits significant recycling and recovery potential. This potential contributes to the reduction of virgin resource consumption, thereby diminishing ecological footprint and greenhouse gas emissions. In addition, EWM promotes the development of a new, more inventive and competitive industrial model, resulting in higher economic growth and employment opportunities. Likewise, reusing materials and products for manufacturing new products is more profitable than using virgin materials.

This study identifies seven major challenges to EWM, namlely rules and policy, infrastructural, consumer behaviour, informal sectors, community-cultural, technological and economic challenges (RO3). Based on the results of our review, technology challenges, infrastructural challenges and rules and policies challenges are the most cited challenges in the literature. Therefore, governments and manufacturers could focus more on these three challenges to effectively implement EWM. Additionally, the current study proposed a conceptual framework (RO4) consisting of the common challenges across the value chain and the proposed suggestions for overcoming those challenges. The framework is helpful for different stakeholders like government, manufacturers, EWM-facilitators, policymakers and consumers.

*6.1 Implications*

The current study provides theoretical, practical and policy implications which are discussed in the following sub-sections.

*6.1.1 Theoretical implications.* In this study, common circular economy practices have been identified, along with their alignment with various SDGs achievable through EWM. Additionally, seven major challenge categories, encompassing a total of 33 distinct challenges, have been meticulously classified. Notably, these challenges have been examined from diverse stakeholder perspectives, including government entities, manufacturers, consumers, collectors, recyclers, refurbishers, remanufacturers and disposers. To provide a comprehensive roadmap, a conceptual framework has been introduced, systematically addressing challenges spanning from the manufacturing phase to end-of-life treatment processes, such as reuse, recycling and disposal. This framework incorporates proposed solutions, supported by real-world examples, all of which contribute to the overarching goal of sustainability within the realm of EWM.

*6.1.2 Practical implications.* The present study offers valuable insights that can assist governments, industries and consumers in discerning optimal practices for EWM. Stakeholders across the board can leverage the proposed framework to pinpoint potential challenges and their specific locations in the EWM process. Notably, this framework not only identifies challenges but also provides practical solutions, emphasised by real-world examples of companies that have adeptly embraced CE practices. Manufacturers and formal sectors stand to gain inspiration from these contemporary examples, thereby adopting best practices aimed at achieving zero E-waste and supporting sustainability efforts. Furthermore, the study enhances comprehension of consumer behaviour challenges and presents viable solutions. For consumers, this research serves as a foundational resource to drive E-waste management initiatives at the societal level, contributing to a more sustainable future.

*6.1.3 Policy implications.* This study serves as a fundamental resource for governments in shaping policies that cater to diverse stakeholders. For instance, policy formulations can incorporate provisions for systematic, randomised monitoring of sustainable practices across stakeholder groups. Furthermore, policies can advocate for financial support to stakeholders actively contributing to sustainability efforts. In addition, the proposed framework offers valuable guidance for the development of effective policies. This includes integration of EWM courses into educational curricula, implementation of random audits and monitoring of sustainable practices among stakeholders, facilitation of synergy between formal and informal sectors and streamlining of regulations to facilitate the transition of informal sectors into the formal fold. These policy measures can collectively foster a more sustainable EWM ecosystem.

*6.2 Limitations and future work*

However, it is worth noting that our review is limited to studies indexed in Scopus database and published in the English language. It is possible that research studies in other languages or not indexed on Scopus may offer different perspectives on EWM. It is important to emphasise that the findings of this study are intended to be generalisable and not specific to any country.

Furthermore, this study serves as a foundational platform for future research endeavours. The proposed framework can be applied to explore a variety of topics, such as in-depth investigations into the reverse supply chain for specific products. Subsequent research efforts could delve into the integration of “digitalization” or “Industry 4.0” in the production of electronic goods and E-waste treatment. This may encompass areas like remote sensing of hazardous waste, the implementation of automated IoT E-waste monitoring systems, the utilisation of robotic processes for E-waste sorting and the integration of blockchain technology across the value chain.

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