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RESEARCH ARTICLE OPEN ACCESS

# Barriers and Enablers of Circular Economy in Electrical and Electronic Equipment: A Systematic Literature Review

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**Received:** 16 October 2025 | **Revised:** 19 December 2025 | **Accepted:** 2 January 2026

**Keywords:** barriers | circular economy | electrical and electronic equipment (EEE) | enablers | systematic literature review | waste electrical and electronic equipment (WEEE)

## ABSTRACT

Rapid technological change, shorter lifecycles and rising demand for electrical and electronic equipment (EEE) are increasing waste electrical and electronic equipment (WEEE) and emphasise the need for a circular economy. This paper identifies barriers and enablers of the circular transition in EEE and outlines interventions. Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), 161 papers (2015–2024) were systematically reviewed and thematically coded. Five themes emerged: policy and regulation, sustainable design, consumer knowledge and awareness, infrastructure and technology and economic and financial factors. Implications include harmonised and eco-modulated extended producer responsibility (EPR) with value-retention metrics; right to repair with access to parts and repair information; design rules for durability and disassembly; digital product passports with standardised data; and economic instruments such as reduced VAT and deposit–refunds. Future research should build product-specific evidence, compare across income contexts and examine tensions and trade-offs across value chain stages and recovery flows.

## 1 | Introduction

The global demand for electrical and electronic equipment (EEE) has experienced rapid growth in recent decades, driven by technological advancements, increasing consumer demand and shortening product lifecycles (Cheshmeh et al. 2023; Jaiswal and Mukti 2024; Sonego et al. 2022). As a result, waste electrical and electronic equipment (WEEE) generation continues to rise (de Oliveira Neto et al. 2023; Mohammadi et al. 2021; Sagnak et al. 2021). In 2022, around 62 million tonnes of WEEE were generated globally, yet less than a quarter was formally collected, resulting in a substantial loss of valuable materials worth an estimated 91 billion (Baldé et al. 2024). This makes WEEE one of the fastest-growing waste streams globally (Panchal et al. 2021). The remaining waste either ends up in a landfill or is incinerated, posing severe environmental and health risks due to hazardous material leakage (M. Chen and Ogunseitan 2021; Evans and Vermeulen 2021). In addition, large quantities of WEEE are exported illegally to low-income countries, where informal recycling practices expose workers and local communities to unsafe and toxic conditions (Neves, Marques, and de Sá Lopes 2024; Rudolf et al. 2022; Wibowo et al. 2021).

These environmental, economic and social issues are largely due to the linear economy dominating the EEE sector, which follows a 'take-make-dispose' approach (Ali and Shirazi 2023; Leitão et al. 2023). In such a system, resources are extracted, transformed into products and discarded at the end of life, which accelerates resource depletion, waste generation and environmental degradation (Xavier, Giese, et al. 2021). Therefore, transitioning towards a circular economy (CE) is a critical and urgent priority (Sagnak et al. 2021; Sharma et al. 2020). CE aims to maintain the value of products, resources and materials at their highest level for as long as possible (Ellen MacArthur Foundation 2019). It involves slowing, closing and narrowing material loops through strategies such as designing out waste and pollution, reducing resource use, extending product lifecycles, improving recycling and facilitating reuse, repair, refurbishment and remanufacturing (Geissdoerfer et al. 2017). CE strategies across the product life cycle are often summarised by the 10R framework: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover (Morseletto 2020; Potting et al. 2017). Implementing these strategies within the EEE sector can reduce waste, recover high-value materials and lower environmental and social impacts (Pan et al. 2022).

Policymakers and industry stakeholders are increasingly recognising the importance of this transition, and new policies and regulations are emerging globally to promote circularity in electronics (Grandhi et al. 2024). For example, extended producer responsibility (EPR) schemes for electronics require manufacturers to finance the take-back and recycling of WEEE (Compagnoni 2022; Corsini et al. 2017). Moreover, the EU Circular Economy Action Plan and the EcoDesign for Sustainable Products Regulation set out new requirements to improve durability, repairability and energy efficiency of EEE (McMahon et al. 2019; Sonego et al. 2022). Right-to-repair laws are expanding, requiring manufacturers to support longer product lifespans by making it easier for consumers and independent repairers to access spare parts and repair information (Ali and Shirazi 2023; Svensson-Hoglund et al. 2021). In response, the EEE sector is moving towards adopting circular business models such as product-as-a-service and take-back schemes to align with regulatory and market expectations (Cole et al. 2019b; Shi et al. 2023).

Research exploring the transition to a CE within the EEE sector has been growing rapidly in recent years. Existing literature often highlights that implementing circular practices in the EEE sector is a complex process. For example, Menon and Ravi (2021a) focused on sustainable supply chain management in the electronics industry, using interpretive structural modelling to map out barriers within the Indian context. Their analysis found that a lack of clear regulations and guidance from authorities is a primary barrier hindering efforts towards sustainability and circularity in the EEE supply chains. Moreover, Rizos and Bryhn (2022) investigated the adoption of CE business models in the EEE sector through an in-depth multicase study of European firms. Their findings highlight that, despite growing interest and supportive policy frameworks, companies still face persistent challenges, including insufficient supply chain transparency, weak enforcement of WEEE regulations and a lack of established CE standards. Furthermore, Svensson-Hoglund et al. (2021) reviewed the policy landscape for repair of consumer electronics in the EU and the United States. Their review revealed a wide range of legal and market barriers discouraging repair services, such as intellectual property restrictions and warranty terms that limit third-party repairs, consumer protection and contract laws, as well as product design features that make devices hard to repair. From a broader perspective, recent literature reviews have mapped the research landscape on the CE in the EEE sector. For instance, Pan et al. (2022) conducted a systematic review and citation network analysis to identify the main research domains and emerging themes in the field. Similarly, Bressanelli et al. (2020) reviewed the literature on CE in the EEE sector, emphasising persistent gaps in the literature such as the lack of system-level frameworks for implementing CE strategies in EEE and sector-specific guidance.

Despite these valuable contributions, research gaps remain. Specifically, there is a notable gap in translating identified barriers and enablers into actionable, practical interventions for stakeholders, hindering the practical implementation of research findings (Kumar et al. 2022; Pan et al. 2022; Rizos and Bryhn 2022). To address this gap, this study draws on 161 peer-reviewed papers published between 2015 and 2024, with almost 60% published after 2021, to conduct an updated and comprehensive systematic literature review (SLR). The review consolidates emerging insights and establishes a clearer research agenda by identifying key barriers and enablers influencing the circular transition in the EEE sector and by mapping how these variables relate to recovery flows and value chain stages. Building on this analysis, the study further develops actionable recommendations and interventions intended to support industry stakeholders, policymakers, industry actors and practitioners.

This study is guided by the following key research questions:

**RQ1**. What are the key barriers and enablers influencing the transition to a circular economy in the EEE sector?

**RQ2**. What actionable interventions can support stakeholders in overcoming key barriers and enabling the circular transition in the EEE sector?

The remainder of the paper is structured as follows: Section 2 outlines the research methodology, explaining the PRISMA process and the MAXQDA thematic coding approach. Section 3 presents the results of the review, including descriptive statistics of the literature and a meta-analysis of research trends, as well as the findings on key barriers and enablers. Section 4 discusses key insights regarding the identified barriers, enablers, tensions and trade-offs, offering practical recommendations. Finally, Section 5 concludes the paper by summarising contributions, addressing limitations and suggesting areas for future research on CE in the EEE sector.esearch on.

## 2 | Methodology

### 2.1 | Rationale for SLR and Methodological Approach

This study adopts a SLR methodology to identify barriers and enablers for the transition to a CE in the EEE sector. Given the rapidly evolving research landscape and the involvement of multiple disciplines in CE studies, a systematic approach was chosen to ensure the process of identifying, selecting and synthesising evidence was transparent, rigorous and reliable. Several SLR methodologies were considered during the research design stage, including scoping reviews, meta-analyses and rapid reviews. Scoping reviews are valuable for mapping broad research fields but do not provide the same depth of synthesis or risk of bias assessment as SLRs (Munn et al. 2018). Meta-analyses are quantitative in nature and typically focus on summarising results from studies with compatible statistical outcomes, which is less applicable given the qualitative and conceptual focus of this review (Siddaway et al. 2019). Rapid reviews provide timely syntheses but often do so at the expense of comprehensiveness and depth (Garritty et al. 2021; Hamel et al. 2021), which is critical for a complex, policy-relevant field such as CE research in EEE. Among SLR frameworks, PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was selected as the most appropriate for this study, which modifies PRISMA 2009, first proposed by Moher et al. (2009). PRISMA is widely recognised for its structured approach, comprehensive checklist and clear flowchart, supporting detailed and transparent reporting throughout the review process (Page et al. 2021). Its broad adoption across social, environmental and engineering disciplines and its adaptability to different review questions and study types (Siddaway et al. 2019) further support its selection.

This methodological choice is grounded in an interpretivist research philosophy, recognising that multiple perspectives and types of evidence (qualitative and quantitative) are necessary to understand the complexity of CE transitions (Bell et al. 2019). The research adopts an inductive approach, aiming to generate new insights from the literature rather than test predefined hypotheses (Saunders et al. 2019). A systematic and thematic coding was used to ensure comprehensive and rigorous analysis. Although the review is primarily qualitative, it also incorporates quantitative elements, such as mapping publication trends and analysing code frequencies. The use of qualitative data analysis software, MAXQDA, further strengthens the transparency and rigour of the analysis process.

## 2.2 | PRISMA Process

This review followed the three main PRISMA phases: identification, screening and inclusion. The review process and record flow are shown in Figure 1.

### 2.2.1 | Identification

To ensure comprehensive coverage, the initial search was conducted using the Scopus database. Scopus was selected because of its status as one of the most comprehensive and reliable bibliographic databases, offering extensive multidisciplinary coverage and high-quality indexing, particularly in engineering, environmental science and management research. Other

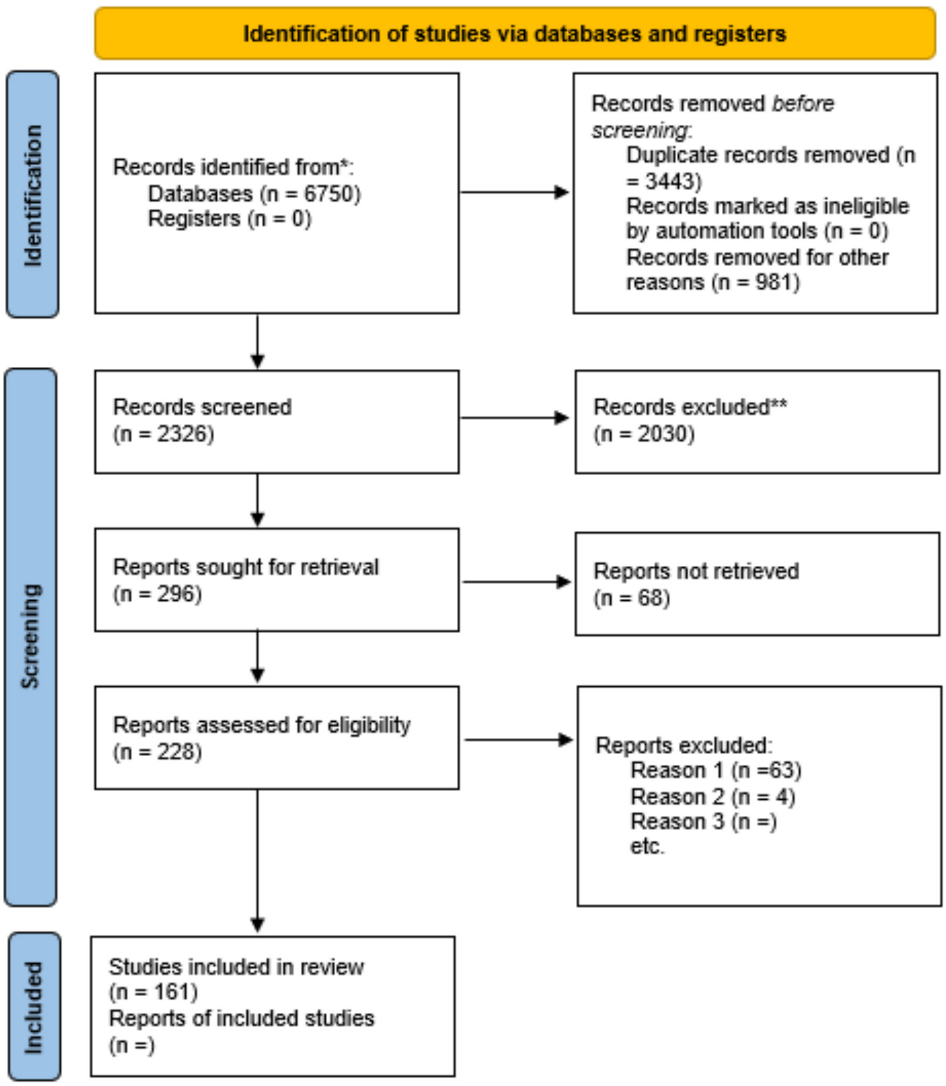


**FIGURE 1** | PRISMA 2020 flow diagram. Literature selection process following the three PRISMA phases: identification, screening, and inclusion.

databases, such as Web of Science and Google Scholar, were also considered. However, initial tests showed that Scopus offered the broadest and most relevant coverage for this topic, with fewer duplicates and higher-quality records.

Keywords were chosen based on previous reviews and initial scoping and then combined in 21 different ways using 'AND' and 'OR' to ensure the search was both comprehensive and focused on the most relevant studies. The final set of 17 keywords included 'Electrical and Electronic Equipment', 'Electricals', 'Electrical Equipment', 'EEE', 'WEEE', 'E-waste', 'Circular Economy', 'Sustainability', 'Challenges', 'Barriers', 'Enablers', 'Opportunities', 'Repair', 'Remanufacture*', 'Reduc*', 'Reus*' and 'Recycl*'.

To ensure up-to-date coverage, database searches were conducted in January 2025, and eligibility was set for publications dated 2015 and later, up to the search point. Although 2025 was included in the search window, no papers beyond 2024 met the final eligibility criteria at the time of screening, meaning the reviewed dataset spans 2015–2024. This timeframe reflects the rapidly changing policy and industry landscape, allowing for a focused comparison of recent developments and trends. The search was further limited to English-language, open-access sources, ensuring accessibility and quality control. The initial search returned a total of 6750 records. All records from the 21 groupings were exported to Microsoft Excel for further processing. Duplicate records ($n = 3443$) were identified and removed. The dataset was further filtered to retain only journal articles, resulting in the removal of 981 additional records. This left a total of 2326 unique journal articles for further screening.

#### 2.2.2 | Screening

Screening was performed in two main steps to ensure only relevant and high-quality studies were included. First, titles and abstracts of the 2326 records were screened for relevance to the research aim. Therefore, papers had to focus explicitly on the CE or sustainability in the context of EEE, or on related barriers, enablers or interventions. This process excluded a further 2030 records because of a lack of relevance.

The remaining 296 records were subject to full-text screening, specifically assessing the introduction and conclusion sections for alignment with the inclusion criteria and research objectives. During this stage, a further 68 records were excluded, of which 63 records were not sufficiently relevant to the research question or context, and four were inaccessible (full text not available).

#### 2.2.3 | Inclusion

Following the multistage screening process, a total of 161 records met all inclusion criteria and were retained for full review and analysis. To visualise research activity and interest in this area, a graph was produced showing the annual number of included publications and their cumulative total over the 2015–2024 period, as no eligible 2025 publications appeared before the search cut-off in January 2025 (see Figure 2).

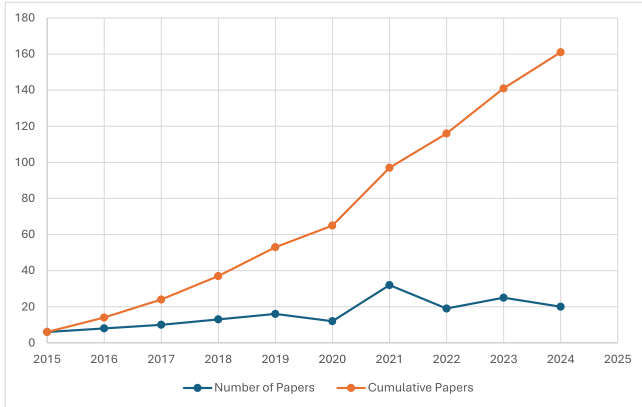


**FIGURE 2** | Publications per year and cumulative total. Annual number of publications included in the literature review (bars) and cumulative total over time (line).

### 2.3 | Thematic Coding

To synthesise the findings from the included studies, a thematic coding approach was adopted. Thematic analysis is well-suited and particularly effective for reviews with broad research questions and a diverse evidence base, as it allows for the identification and synthesis of recurring concepts and themes across multiple studies.

The coding process was conducted using MAXQDA, a qualitative data analysis software chosen for its user-friendly interface, powerful coding and categorisation tools and advanced features such as code relations browser and mapping functions. The software's ability to manage large datasets and visualise complex coding structures was especially useful for this review. Moreover, a mixed-methods orientation was adopted, combining qualitative thematic coding with quantitative code frequency analysis to identify dominant and emerging patterns.

#### 2.3.1 | Coding Process

The coding process unfolded in three iterative levels:

i. Level 1: Top-level categorisation

All extracted findings from the 161 included papers were initially coded as either barriers or enablers to the CE transition in the EEE sector. This distinction provided a broad yet structured foundation for further analysis, allowing for direct comparison and synthesis across studies.

ii. Level 2: Sustainability dimensions

Within each top-level code, findings were further classified into four main dimensions: economic, social, environmental and technical. This classification was informed by frameworks commonly used in sustainability and systems analysis and was iteratively refined through engagement with the literature. Each paper was reviewed in detail to ensure that findings were accurately coded to the most appropriate dimension(s).

iii. Level 3: Specific themes

Within each dimension, more specific subcodes were developed to capture recurring themes and particular issues found across the literature. For example, under the economic dimension, subcodes included 'economic and financial barriers/enablers' within the social dimension, and examples included 'consumer and behavioural barriers/ enablers', along with 'organisational and managerial barriers/enablers'. Technical subcodes covered areas such as 'technical and infrastructure barriers/enablers' and 'regulatory and policy barriers/enablers'. Environmental subcodes included 'environmental and health barriers' as well as 'environmental and resource management enablers'. As an example of a coded segment, 'Repair knowledge could lead to better purchases and better care since the customer is more aware of the product architecture and potential causes of failure, prolonging the product service life and, in the long run, the demand for higher quality products' (Sonego et al. 2022) was coded as Enablers > Social Enablers > Consumer and Behavioural Enablers > Increasing consumer knowledge and awareness.

Throughout the process, coding was not always straightforward, as several themes and findings were relevant to more than one dimension. For instance, an initial subcode for 'knowledge and awareness' was later separated into 'consumer knowledge and awareness' and 'organisational knowledge and awareness' to more accurately reflect the different actors involved. The naming and organisation of these subcodes were guided both by the existing literature and by new patterns that emerged during analysis.

Coding was conducted iteratively, with multiple review and refinement processes to ensure that codes were consistently applied and accurately reflected the literature. Therefore, First Cycle and Second Cycle coding principles were applied, as described by Saldaña (2021), to guide this iterative process. A double coding approach was also used, whereby 10% of the papers were independently recoded by the second author, and any differences in coding were reconciled through discussion, in line with Saldaña's (2021) emphasis on intercoder agreement and consensus. Any instances where codes could be interpreted in multiple ways, or where coding decisions were unclear, were carefully reviewed and resolved to maintain consistency across the dataset. The entire coding structure was reviewed and updated in response to new insights as the analysis progressed. Although the coding framework is described in three main levels, additional subcodes were also developed within MAXQDA to capture more detailed or specific themes as they appeared in the literature. This flexible structure enabled a thorough and comprehensive analysis, ensuring that all relevant aspects were systematically identified and categorised. In total, over 200 unique codes emerged from the review process, covering more than 6000 coded text segments. Additionally, MAXQDA features such as the code matrix browser were used to explore the frequency of codes across the dataset, and coded segments were exported to support organisation and further review of the material. Therefore, this extensive coding provided a rich, multidimensional dataset for subsequent synthesis and interpretation.

In summary, this review combines the strengths of the PRISMA systematic approach with in-depth qualitative analysis by adopting thematic coding. The three-level coding structure and use of advanced qualitative analysis software, MAXQDA, support a structured and transparent analysis of the literature, providing insights with practical and theoretical relevance for the CE transition in EEE. However, this methodology has some limitations. The search was limited to the Scopus database, open-access journal articles and studies published between 2015 and 2025. Although these criteria ensured quality and relevance, they may have excluded some relevant research, particularly studies published elsewhere. Furthermore, although the thematic coding process involved careful review and refinement, a degree of subjectivity is inherent in qualitative analysis. These limitations were taken into account when interpreting the findings.

## 3 | Results

### 3.1 | Publications Over Time

The dataset includes 161 peer-reviewed papers published between 2015 and 2024. Figure 2 presents both annual and cumulative publication trends to illustrate how research has evolved. The data reveal a notable increase in published research in this area, particularly from 2021 onwards. This upward trend can be linked to various factors, including increased policy attention, technological and infrastructure advancements and growing public awareness around WEEE and the CE. During this period, policy initiatives such as the recent EU Circular Economy Action Plan (2020), the introduction of right-to-repair legislation and the strengthening of EPR schemes, together with industry-led initiatives, including take-back schemes (Corsini et al. 2020), have further prompted research. This trend reinforces the importance of this study and the value of systematically examining the up-to-date barriers and enablers influencing the transition to a CE for EEE.

### 3.2 | Geographical Context

The reviewed literature covers a wide range of geographical contexts, but certain regions are featured more prominently than others (see Figure 3). General or global studies form the largest

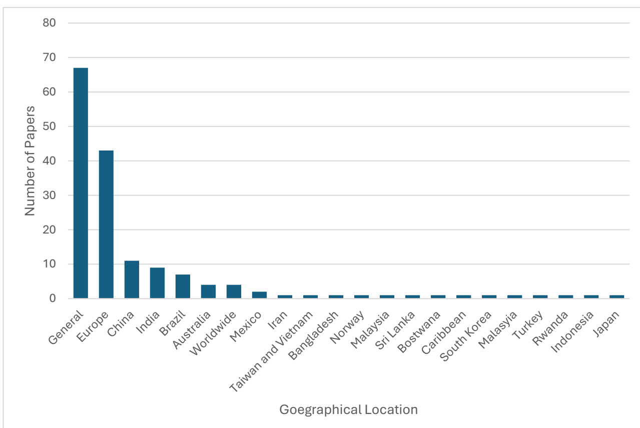


**FIGURE 3** | Number of papers by country/region. Geographical distribution of publications included in the dataset.

group, with 67 papers (41.6% of the dataset) that do not focus on a single country or region but instead address cross-country patterns or broader conceptual or policy frameworks.

Europe is the second most represented context, with 43 papers (26.7%). Within this group, several studies address Europe as a whole, whereas others focus on specific countries, most often the United Kingdom and Italy. Outside Europe, China, India and Brazil are the most frequently studied countries, whereas many others appear only once or twice. This indicates that, although the field is geographically diverse, the evidence base is shaped mainly by a relatively small number of countries. When grouped by World Bank income classifications (2025) (see Figure 4), high-income countries account for the majority of studies, followed by upper-middle- and lower-middle-income contexts. Low-income settings appear only once in the dataset. This suggests that existing research is shaped predominantly by higher-income regions, whereas lower-income contexts remain less explored.

### 3.3 | Product Types

Most of the papers in this review examine generic EEE product categories, rather than focusing on specific product categories. Out of the 161 papers, 132 (82%) are generic in scope, whereas only 29 (18%) focus on a particular product category. This shows that most research adopts a system-wide perspective, looking at overall WEEE flows, policy frameworks or sector-level recovery strategies rather than individual product types.

Among the product-specific studies, mobile phones are the most common focus, appearing in more than half of these papers, reflecting their short replacement cycles, high material value and the tendency for consumers to keep rather than discard them (Bigliardi et al. 2022; Chen et al. 2024; Islam et al. 2020). Other frequently studied ICT products include laptops, desktop computers, tablets and notebooks. Household appliances make up the next major group. These range from large items such as washing machines, refrigerators and air conditioners to small appliances, including kettles, coffee machines, vacuum cleaners, hair dryers, irons, juicers, toasters and hand blenders. Televisions and flat display panels also feature in several studies, often in relation to recycling challenges or eco-design requirements (Guo and Zhong 2021; Wagner et al. 2019).

A smaller number of papers focus on specialised products, such as professional and industrial equipment, such as programmable logic controllers and medical devices, as well as refurbished electronics such as speakers, earbuds and personal computers. Some studies use broader categories such as personal electronics, small WEEE (e.g., toys and household tools) or consumer electronics with a narrower focus, such as LCD TVs. The scope of these product-specific studies varies considerably. Some focus on technical aspects, such as how to recycle printed circuit boards or design products for easier disassembly. Others link these product-level issues to broader policy topics like eco-design standards, right-to-repair legislation and refurbishment regulations.

Overall, the dominance of generic studies highlights an ongoing gap in product-level understanding, especially for items with unique material composition, use patterns, or end-of-life challenges. More product-focused research could provide deeper insights into recovery potential, design barriers and material flows.

### 3.4 | Recovery Flows

The recovery flows addressed in the dataset are shown in Figure 5. Recycling is the most common, appearing in 160 papers (99.4%). Reduce follows closely with 156 papers (96.9%), and reuse and recovery each appear in 152 papers (94.4%). Reuse is often discussed together with other R strategies, especially repair or refurbishment. Repair itself appears in 109 papers (67.7%), refurbishment in 101 papers (62.7%) and remanufacturing in 91 papers (56.5%). Other recovery flows are far less common, with rethink in 37 papers (23%), repurpose in 28 (17.4%) and refuse in only 19 (11.8%).

Many studies address more than one recovery flow in the same analysis. The most frequent pairing is recycle with reduce (156 papers), followed by recycle with reuse (152 papers). Some papers approach recovery flows as a sequence, for example, evaluating whether repair is possible before moving on to recycling. Other studies look at flows side by side, for example, integrating remanufacturing with component reuse in the same system (Bridgens

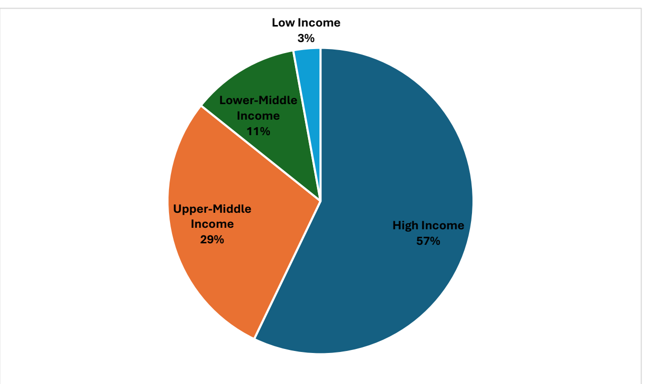


**FIGURE 4** | Distribution of country-specific studies. Country-specific studies in the dataset, grouped according to World Bank income classifications (2025).

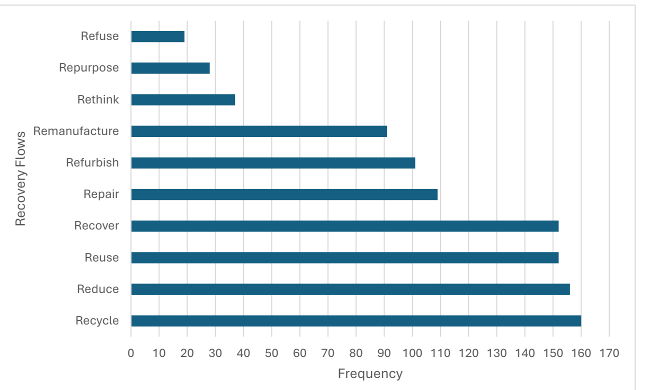


**FIGURE 5** | Frequency of recovery flows in the dataset. Frequency of all recovery flows covered in the dataset: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover.

et al. 2019). The data also show strong connections across flows. For instance, design choices that enable repair can also improve recyclability (Jayasiri et al. 2024), and reverse logistics can support both reuse and recycling (de Oliveira Neto et al. 2023).

These findings are consistent with the 10Rs framework, where strategies like reduce, reuse and repair sit higher in the waste hierarchy than recycling and recovery (Morseletto 2020; Potting et al. 2017). However, the strong presence of recycling across the dataset indicates that recycling still dominates the literature, highlighting a continued focus on lower R strategies despite the prioritisation of upstream approaches in CE frameworks.

### 3.5 | Value Chain Stages

Coverage of value chain stages across the dataset is shown in Figure 6. The most frequently addressed stages are collection (158 papers) and recovery (152 papers), both appearing in over 90% of the papers. These stages often appear together, reflecting a strong focus on downstream EEE management and the close operational and policy links between how products are collected and how they are treated. Product life extension studies, which track the movement of products and materials through the system, including reuse, repair and remanufacturing, are also common (138 papers). End of life appears in 133 papers. The use phase is covered in 83 papers, usually in the context of actively used and hoarded household and non-household products. Placed on market (POM) appears in 96 papers, generally referring to domestic production and imports, often linked to producer reporting requirements or estimates used to model future waste generation (de Waal 2023; Soesanto et al. 2023).

Most papers cover more than one value chain stage. The most common combinations involve collection and recovery, followed by connections between collection and product life extension, reflecting the operational link between take-back systems and strategies for retaining value. The use phase is commonly integrated into these analyses, particularly for estimating potential waste generation. POM data are sometimes

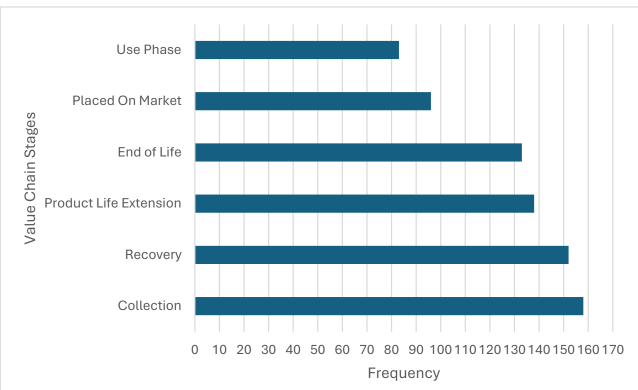


**FIGURE 6** | Frequency of value chain stages in the dataset. Frequency of all value chain stages represented in the dataset: placed on market (POM), use phase, end of life, product life extension, collection, and recovery.

linked to the use phase and collection to represent system inputs and estimate end-of-life volumes. Overall, focus remains heavily downstream, with comparatively limited attention to early-stage interventions at the point products enter the market.

### 3.6 | Overview of Sources

The complete meta-analysis of all 161 papers is presented in Appendix A. It shows methodology, country focus, product type, recovery flows and value chain stages for each study. Methodologies range from qualitative interviews and case studies to quantitative modelling, material flow analysis (MFA), life cycle assessment (LCA) and mixed methods designs. Literature reviews take a substantial portion of the dataset. Case studies dominate in single-country contexts, whereas statistical modelling, MFA and LCA are more common in studies examining flows at a regional or global scale.

### 3.7 | Key Themes of Barriers and Enablers

The coded barriers and enablers, along with their frequencies and ranks, are summarised in Tables 1 and 2. Across the dataset, five overarching themes emerge: policy and regulation, sustainable design, consumer knowledge and awareness, infrastructure and technology and economic and financial factors.

#### 3.7.1 | Policy and Regulation

Regulatory and policy factors emerge as the single most dominant theme in the dataset, across both enablers and barriers. On the enabler side, regulatory and policy factors appear most frequently ($n = 106$, rank 1), including core policy instruments such as EPR, EU WEEE directives, standardisation and certification schemes and global agreements such as the Basel Convention. Additional enablers emphasised include the Circular Economy Action Plan, the Ecodesign for Sustainable Products Regulation and emerging right-to-repair policies, reflecting regulatory initiatives aimed at improving durability, repairability and producer responsibility.

On the barrier side, weak enforcement of existing regulation is the most prevalent barrier ($n = 87$, rank 1), particularly in relation to collection and treatment systems. Illegal cross-border WEEE flows also appear strongly, pointing to persistent enforcement and monitoring gaps. Other issues include unclear or overlapping regulations, competition between formal and informal handlers and a lack of guidance for implementation. Together, these findings suggest that policy frameworks exist but do not always translate into effective practice, creating a significant implementation gap.

#### 3.7.2 | Sustainable Design

On the enabler side, sustainable design is a key theme ($n = 80$, rank 2) and is supported by a variety of design-focused strategies, such as product labelling, extending durability and lifespan, designing

**TABLE 1** | Key barriers coding system.

| Barriers | Code system | Frequency | Rank |
|---|---|---|---|
| **Regulatory and policy barriers** | **Regulatory and policy barriers** | | |
| | Weak enforcement of existing WEEE regulations | 87 | 1 |
| | Illegal cross-border trade of WEEE | 41 | 4 |
| | Competition of formal waste handlers | 19 | 19 |
| | Lack of standard guidelines and instructions | 16 | 21 |
| | Lack of integrated regulations | 15 | 23 |
| | Unclear and overlapping legislation for WEEE management | 14 | 26 |
| | Prioritisation of recycling over reduce and reuse | 14 | 26 |
| | Free riding | 7 | 35 |
| | Legislation misalignment with CE objectives | 6 | 37 |
| | Lack of clear responsibilities and roles | 3 | 45 |
| | Slow implementation or policies and regulations | 2 | 48 |
| **Environmental barriers** | **Lack of sustainable design** | 32 | 8 |
| | Short product lifecycle | 21 | 16 |
| **Social barriers** | **Lack of consumers knowledge and awareness** | 45 | 3 |
| | Increasing demand for electronics | 23 | 13 |
| | Household stockpiling of EEE | 21 | 16 |
| | Improper disposal of products | 20 | 18 |
| | Concerns over information and data security | 15 | 23 |
| | Consumer disinterest or resistance to circular products | 14 | 26 |
| | Frequent early replacement of electronics | 10 | 32 |
| | Attitude–behaviour gap | 9 | 33 |
| | Low perceived value | 7 | 35 |
| | Limited consumer engagement | 6 | 37 |
| | Psychological obsolescence | 5 | 41 |
| | Limited demand for sustainable and circular electronics | 5 | 41 |
| | Perceived risks | 3 | 45 |
| | Low adoption of green purchasing | 2 | 48 |
| | Subjective norms and values | 1 | 50 |
| | Low individual and social responsibilities for WEEE management | 1 | 50 |
| | Cultural challenges | 1 | 50 |
| | Irresponsible usage of shared resources | 1 | 50 |
| **Technical barriers** | **Limited infrastructure for WEEE management** | 29 | 10 |
| | Informal WEEE handling | 65 | 2 |
| | Limited accessibility and convenience of WEEE infrastructure | 25 | 12 |
| | Limited recycling infrastructure | 13 | 29 |
| | Fragmented and uncoordinated WEEE systems | 11 | 30 |
| | Low collection Rate | 8 | 34 |

(Continues)

TABLE 1 | (Continued)

| Barriers | Code system | Frequency | Rank |
|---|---|---|---|
| | Limited material segregation | 6 | 37 |
| | **Technological innovation issues** | | |
| | Limited availability and traceability of WEEE data | 40 | 5 |
| | Rapid Technological obsolescence | 39 | 6 |
| | Technological advancements without sustainability considerations | 33 | 7 |
| | Lack of adequate technologies for WEEE handling | 26 | 11 |
| | Fast-changing technological trends | 23 | 13 |
| | Limited measurability of CE aspects | 4 | 44 |
| **Economic barriers** | **Economic and financial barriers** | 30 | 9 |
| | Limited financial resources and support | 22 | 15 |
| | Economic growth-driven consumption | 18 | 20 |
| | Price and affordability | 16 | 21 |
| | Lack of incentives | 15 | 23 |
| | High cost | 11 | 30 |
| | Willingness to pay | 6 | 37 |
| | Lack of investment in research and development | 5 | 41 |
| | Hindering profitability | 3 | 45 |

for repair and disassembly, using recycled or safer materials and improving resource and energy efficiency. Circular business models also appeared within this theme, including product-as-a-service models, collaborative consumption and on-demand production. These strategies collectively demonstrate how design choices can directly influence downstream repairability, recyclability and overall material recovery.

On the barrier side, lack of sustainable design and short product lifecycles are recurring barriers, indicating that many products are still not built for longevity or ease of recovery. Therefore, sustainable design is a significant enabler, and its absence appears clearly as a barrier. This makes the design stage a key leverage point in the system, shaping outcomes all along the value chain. However, the short product lifespans and poorly designed products show that this potential is far from being achieved.

### 3.7.3 | Consumer Knowledge and Awareness

Consumer knowledge and awareness is another significant theme, ranking third for enablers ($n = 74$) and barriers ($n = 45$). On the enabler side, the most frequent factors include clear instructions and guidelines, followed by marketing and consumer engagement. Other enablers were less frequent but still noted in the dataset, including desire or willingness to participate in circular practices, perceived value of circular products and shifts towards adopting green purchasing behaviours.

On the barrier side, increasing demand for electronics, household stockpiling and improper disposal were among the most commonly referenced challenges. Additional but less frequent barriers included concerns over information and data security, limited interest in circular products, early device replacement, low perceived value and the attitude–behaviour gap, which collectively reflect behavioural resistance to circular practices. There are other factors, each appearing once, such as subjective norms and values, low individual and social responsibility for WEEE management and cultural challenges.

### 3.7.4 | Infrastructure and Technology

The infrastructure and technology emerge as one of the most frequently discussed themes across both barriers and enablers. On the enabler side, improvements to collection infrastructure appear most frequently, along with advancements in reverse logistics, take-back systems and the strengthening of formal WEEE management structures. Integrated management systems and enabling technologies such as WEEE databases, reporting tools and Industry 4.0 applications are also emphasised, as they support traceability, monitoring and more efficient processing across the system. These infrastructure and technology improvements support both upstream collection and downstream material recovery.

On the barrier side, inadequate infrastructure remains a critical limitation, particularly where informal handling and fragmented systems reduce collection efficiency. Limited accessibility and convenience of formal channels and insufficient recycling capacity continue to weaken material recovery. Technological challenges sit alongside infrastructure issues, especially limited traceability of WEEE data, rapid

**TABLE 2** | Key enablers coding system.

| Enablers | Code system | Frequency | Rank |
|---|---|---|---|
| **Regulatory and policy enablers** | **Regulatory and policy enablers** | 106 | 1 |
| | EPR | 69 | 4 |
| | EU WEEE directives | 58 | 7 |
| | Country-specific regulations | 48 | 8 |
| | Standardisation of WEEE management and certification schemes | 39 | 12 |
| | Basel Convention | 29 | 18 |
| | Circular Economy Action Plan | 22 | 28 |
| | Imposing heavy tax/fines for non-compliance in WEEE management | 16 | 35 |
| | Right to repair | 13 | 38 |
| | Ecodesign for Sustainable Products Regulation (ESPR) | 12 | 42 |
| | Clear roles and responsibilities | 8 | 50 |
| | Reducing taxes for circular models | 5 | 56 |
| | Deposit refund scheme | 3 | 64 |
| | Health and safety standards | 2 | 67 |
| | Increasing costs of hazardous waste | 1 | 71 |
| | Data protection regulations | 1 | 71 |
| | Establishment of circularity and sustainability indicators | 1 | 71 |
| | Amendment of IP law | 1 | 71 |
| **Environmental enablers** | **Sustainable design** | 80 | 2 |
| | Product labelling | 37 | 13 |
| | Design for repair | 30 | 17 |
| | Design for recycling | 28 | 19 |
| | Product lifetime extension | 27 | 20 |
| | Design for durability | 27 | 20 |
| | Product-as-a-service (PSS) | 20 | 29 |
| | The use of safer materials and components | 20 | 29 |
| | Resource efficiency | 15 | 36 |
| | Energy efficiency | 13 | 38 |
| | Product type and quality | 12 | 42 |
| | Use of recycled content | 11 | 45 |
| | Disassembly process planning | 10 | 47 |
| | Size reduction | 8 | 50 |
| | Circular business models | 6 | 54 |
| | Eco-friendly material | 4 | 62 |
| | Collaborative consumption | 2 | 67 |
| | On-demand production | 1 | 71 |

(Continues)

**TABLE 2** | (Continued)

| Enablers | Code system | Frequency | Rank |
|---|---|---|---|
| **Social enablers** | **Increasing consumer knowledge and awareness** | 74 | 3 |
| | Clear instructions and guidelines | 27 | 20 |
| | Marketing | 17 | 32 |
| | Consumer engagement | 17 | 32 |
| | Desire or willingness | 13 | 38 |
| | Better understanding of consumer preferences | 13 | 38 |
| | Sustainable consumer behaviour | 9 | 49 |
| | Perceived value | 8 | 50 |
| | Increased adoption of green purchasing behaviour | 8 | 50 |
| | Emotional attachment | 5 | 56 |
| | Social and cultural norms | 5 | 56 |
| | Increased social responsibility | 1 | 71 |
| **Technical enablers** | **Improving infrastructure for WEEE management** | 25 | 25 |
| | Improved collection infrastructure | 59 | 6 |
| | Strengthening formal WEEE management systems | 41 | 11 |
| | Improving reverse logistics of WEEE | 36 | 14 |
| | Take-back systems | 27 | 20 |
| | Implementation of integrated WEEE management systems | 26 | 24 |
| | Advancing recycling infrastructure | 24 | 26 |
| | Optimised transportation and logistics | 11 | 45 |
| | Urban mining | 10 | 47 |
| | Improved recovery of valuable materials | 5 | 56 |
| | Accessibility and convenience of collection | 5 | 56 |
| | Improved supply chain | 5 | 56 |
| | Appropriate mapping of product characteristics | 3 | 64 |
| | Availability of product maintenance and repair services | 2 | 67 |
| | **Enabling technologies** | 33 | 15 |
| | Improved WEEE databases and reporting | 47 | 9 |
| | Industry 4.0 technologies | 32 | 16 |
| | Recycling technologies | 24 | 26 |
| | WEEE classification | 6 | 54 |
| | Good data protection | 4 | 62 |
| | Separation techniques | 3 | 64 |
| | Technologies enabling resource efficiency | 2 | 67 |
| **Economic enablers** | **Economic and financial enablers** | | |
| | Availability of financial support and subsidies | 64 | 5 |
| | Rewards and incentives | 44 | 10 |
| | Economic benefits/value capture | 18 | 31 |

(Continues)

**TABLE 2** | (Continued)

| Enablers | Code system | Frequency | Rank |
|---|---|---|---|
| | Increased Investment in research and development | 17 | 32 |
| | Increased employment opportunities | 15 | 36 |
| | Price and affordability | 12 | 42 |
| | Cost control measures | 1 | 71 |

technological obsolescence and the development of new technologies without sustainability considerations. These findings highlight a persistent implementation gap, where technology exists but is not yet sufficiently scaled or integrated to support circular outcomes.

#### 3.7.5 | Economic and Financial Factors

The economic and financial theme appears consistently across both enablers and barriers. On the enabler side, financial support plays an important enabling role. Subsidies, grants, rewards and incentive schemes encourage formal collection, reuse and adoption of circular business models. Investment in research and development, along with evidence of long-term economic value capture and employment creation, is also discussed as a driver that can strengthen CE system participation.

On the barrier side, the most common issues relate to limited financial resources, affordability challenges and insufficient incentives to participate in circular practices. High upfront costs for recycling, repair and collection services are widely reported, together with limited investment in research and development. These financial constraints reduce willingness to pay among consumers and weaken business motivation, particularly where profitability is uncertain.

### 3.8 | Link Between Key Themes and Value Chain Stages

The analysis of barriers and enablers across the value chain stages, shown in Table 3, reveals several important patterns. Barriers were most frequently associated with the collection stage, whereas enablers appeared more evenly distributed but also concentrated heavily at the collection and end of life. This shows the ongoing challenges in achieving effective WEEE recovery and also shows where interventions have been most actively discussed in the literature.

On the barriers side, regulatory and policy barriers were most commonly linked to collection ($n = 136$), highlighting persistent issues such as weak enforcement, fragmented regulations and inconsistent collection requirements and guidelines. These challenges also extend to product life extension ($n = 20$) and end of life ($n = 21$), which undermine proper treatment of WEEE. Barriers linked to sustainable design were less frequent overall but still present across several stages, most notably at collection ($n = 11$), end of life ($n = 7$) and product life extension ($n = 5$). These findings highlight that poor design for durability, repairability and disassembly continues to hinder circular strategies and increases WEEE. Limited infrastructure for WEEE management was another dominant barrier, again concentrated at collection ($n = 172$), reflecting insufficient formal collection systems, the continued dominance of informal channels in many countries and the limited accessibility and convenience of existing collection points for consumers. Technological innovation issues were most strongly linked to collection ($n = 66$), but they also showed the highest association with the end-of-life stage ($n = 24$). This reflects how limited availability and traceability of WEEE data, combined with rapid technological obsolescence, create barriers both at the point of collection and in later recovery stages. The absence of scalable and efficient technological solutions reduces the quality and consistency of collected materials and constrains downstream recovery processes, which makes it harder to close the loop across the EEE value chain. Consumer knowledge and awareness was another recurring barrier, most visible at collection ($n = 82$). This points to behavioural challenges, including household stockpiling and improper disposal, which weaken the effectiveness of formal collection and recovery systems. Finally, economic and financial barriers were less prominent but still notable at collection ($n = 48$), often linked to the high costs of formal collection compared with informal handling, and limited funding and weak financial incentives discourage both organisations and consumers from engaging in proper collection processes.

On the enablers' side, regulatory and policy enablers were strongly associated with collection ($n = 282$) and end of life ($n = 54$). This shows the significance of EPR schemes, take-back regulations and right-to-repair policies in strengthening circular practices. Infrastructure improvements were also strongly linked to collection ($n = 250$), underscoring the importance of strengthening formal handling systems. Additionally, a lot of emphasis was on expanding and improving reverse logistics and take-back mechanisms, as well as improving accessibility and convenience for consumers. Sustainable design enablers were most frequently linked to the collection stage ($n = 80$), but they were also associated with end of life ($n = 53$), product life extension ($n = 31$) and the point of being placed on the market ($n = 35$). This reflects how design choices that support durability, repair and disassembly can make it easier for consumers to return products, improve the management of product flows and enhance recovery processes at later stages. Technological enablers were most often linked to collection ($n = 106$) and product life extension ($n = 48$), showing how advances in sorting, recycling and digital tracking can strengthen collection systems and improve material recovery at later stages. Enablers related to consumer knowledge and awareness were most often linked

**TABLE 3** | Co-occurrence of key themes with value chain stages.

| Barriers code system | Collection | Use phase | Product life extension | End of life | Placed on market |
|---|---|---|---|---|---|
| Regulatory and policy barriers | 136 | 6 | 20 | 21 | 12 |
| Lack of sustainable design | 11 | 0 | 5 | 7 | 2 |
| Lack of consumers knowledge and awareness | 82 | 11 | 4 | 15 | 3 |
| Limited infrastructure for WEEE management | 172 | 9 | 27 | 20 | 3 |
| Technological innovation issues | 66 | 3 | 19 | 24 | 9 |
| Economic and financial barriers | 48 | 3 | 8 | 6 | 1 |
| **Enablers code system** | **Collection** | **Use phase** | **Product life extension** | **End of life** | **Placed on market** |
| Regulatory and policy enablers | 282 | 11 | 48 | 54 | 40 |
| Sustainable design | 80 | 19 | 31 | 53 | 35 |
| Increasing consumers knowledge and awareness | 144 | 14 | 12 | 15 | 8 |
| Improving infrastructure for WEEE management | 250 | 14 | 40 | 33 | 7 |
| Enabling technologies | 106 | 4 | 48 | 19 | 12 |
| Economic and financial enablers | 51 | 1 | 7 | 8 | 1 |

to collection ($n=144$), highlighting how awareness campaigns, incentives and behavioural change can encourage engagement in circular practices, proper disposal and reduce stockpiling. Economic and financial enablers appear less frequently overall but are most visible at collection ($n=51$), with additional mentions at end of life ($n=8$), mainly reflecting financial support, subsidies and reward schemes aimed at encouraging participation in formal systems.

### 3.9 | Link Between Key Themes and Recovery Flows

The analysis of barriers and enablers across the recovery flows, shown in Table 4, illustrates some important patterns. The most notable finding is the prominence of recycling, which emerged as the most frequently mentioned recovery flow across all themes. On the enablers side, regulatory and policy enablers ($n=391$), sustainable design ($n=327$) and infrastructure improvements ($n=233$) were most strongly connected here, pointing to how effective recycling relies on supportive policies, better product design and well-developed collection and processing systems. At the same time, barriers were also most frequently associated with recycling, particularly limited infrastructure ($n=226$) and regulatory and policy barriers ($n=220$). This highlights the continued bias in the literature towards recycling and comparatively limited focus on higher R strategies such as refuse and rethink.

Repair and reuse are also strongly connected with key themes. On the barriers side, technological innovation issues were closely linked to repair ($n=42$), whereas lack of consumer knowledge and awareness were associated with both repair ($n=36$) and reuse ($n=38$). This suggests that rapid technological change and consumer behaviour reduce the potential to extend product lifespans through repair and reuse. By contrast, sustainable design emerged as a powerful enabler, connected to both repair ($n=211$) and reuse ($n=215$). This shows that incorporating durability, modularity and ease of disassembly into product design directly increases the chances for repair and reuse, making design choices a crucial factor in extending product lifespans. Regulatory and policy enablers were also linked to both repair ($n=99$) and reuse ($n=144$), showing the importance of measures such as ESPR, right-to-repair and take-back schemes in supporting product life extension.

Recovery processes were less prominent overall and were often associated with barriers such as limited infrastructure ($n=72$), regulatory and policy barriers ($n=46$) and technological innovation issues ($n=31$). On the enabler side, recovery was linked with regulatory and policy frameworks ($n=136$), sustainable design ($n=111$) and infrastructure improvements ($n=104$). However, it is important to note that recovery sits lower in the waste hierarchy compared with other strategies and its prominence in the literature highlights the tendency to focus on downstream flows rather than upstream ones.

Higher R strategies, such as refuse and rethink, received very limited attention in the literature. On the barriers side, associations ranged only between $n=0$ and $n=2$ across themes. Similarly, enablers were rarely connected to these strategies, with refuse ($n=5$) and rethink ($n=4$) representing the lowest levels of association across all recovery flows. The findings

**TABLE 4** | Co-occurrence of key themes with recovery flows.

| Barriers code system | Refuse | Rethink | Reduce | Reuse | Repair | Refurbish | Remanufacture | Repurpose | Recycle | Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Regulatory and policy barriers | 0 | 1 | 38 | 85 | 41 | 30 | 10 | 1 | 220 | 46 |
| Lack of sustainable design | 0 | 0 | 12 | 14 | 14 | 5 | 2 | 0 | 24 | 14 |
| Lack of consumers knowledge and awareness | 2 | 1 | 23 | 38 | 36 | 18 | 10 | 2 | 106 | 23 |
| Limited infrastructure for WEEE management | 0 | 0 | 27 | 44 | 21 | 17 | 8 | 2 | 226 | 72 |
| Technological innovation issues | 2 | 2 | 27 | 36 | 42 | 19 | 10 | 2 | 91 | 31 |
| Economic and financial barriers | 0 | 0 | 34 | 25 | 25 | 8 | 5 | 1 | 107 | 26 |

| Enablers code system | Refuse | Rethink | Reduce | Reuse | Repair | Refurbish | Remanufacture | Repurpose | Recycle | Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Regulatory and policy enablers | 5 | 1 | 151 | 144 | 99 | 26 | 30 | 2 | 391 | 136 |
| Sustainable design | 0 | 4 | 217 | 215 | 211 | 71 | 70 | 18 | 327 | 111 |
| Increasing consumers knowledge and awareness | 1 | 2 | 64 | 45 | 49 | 31 | 23 | 1 | 166 | 27 |
| Improving infrastructure for WEEE management | 1 | 0 | 83 | 76 | 55 | 21 | 20 | 5 | 233 | 104 |
| Enabling technologies | 1 | 0 | 50 | 31 | 24 | 10 | 7 | 1 | 121 | 81 |
| Economic and financial enablers | 0 | 0 | 42 | 28 | 16 | 13 | 12 | 1 | 94 | 31 |

indicate that most of the research continues to focus on downstream strategies such as recycling and recovery, whereas upstream strategies that could prevent waste before it is generated remain underexplored. This imbalance risks overlooking opportunities for systemic change in production and consumption patterns, which are essential for transitioning to a CE.

## 4 | Discussion

This section interprets the literature review findings by examining the key drivers and barriers to the circular transition in the EEE sector and by outlining practical, actionable interventions identified in the literature (Table 5). The discussion is organised around the five themes that emerged from the coded review: policy and regulation, sustainable design, consumer knowledge and awareness, infrastructure and technology and economic and financial factors.

### 4.1 | Policy and Regulations

Policy frameworks are among the most influential factors shaping the circular transition in the EEE sector. The literature shows consistent links between strong, well-designed measures and improved collection and treatment outcomes, whereas weak enforcement and unclear guidance reduce effectiveness and leave room for informal waste handling (de Waal 2023; Evans and Vermeulen 2021; Grandhi et al. 2024). Additionally, policy focus strongly influences which recovery flows dominate. When policy focuses on end-of-life obligations and quantitative recycling targets, both research and practice tend to focus on recycling outcomes. Where regulations include durability requirements, repair information access or spare-part obligations, attention shifts towards repair and reuse. This pattern aligns with this review's findings, which show the strongest coverage at collection and end of life and far less attention to POM and product life extension phases.

EPR is the most frequently discussed regulatory approach in the literature and has strongly shaped recovery flows. Its emphasis on measurable collection and recycling targets has helped meet regulatory obligations, build formal collection systems and improve reported recovery rates (Favot et al. 2018; Panchal et al. 2021). However, performance is set and measured mainly by the volume of material collected and processed (Aminoff and Sundqvist-Andberg 2021; Shittu et al. 2021). This unintentionally reinforces recycling dominance, whereas higher R strategies, such as repair, reuse and remanufacture, have received less attention (Aminoff and Sundqvist-Andberg 2021; Evans and Vermeulen 2021). This review's finding that recycling is the most cited flow across themes is consistent with that measurement logic.

EU directives are identified as key regulatory enablers in the literature. The WEEE directive set the framework for collection and recycling. Additionally, the eco-design directive introduced product standards that now extend beyond energy efficiency to early requirements related to durability and reparability (Sonego et al. 2022; Svensson-Hoglund et al. 2021). More recently, right-to-repair measures have been linked to this framework, reflecting a broader policy focus on keeping products in use for longer and seeking to lower barriers to repair for consumers and independent service providers (Boniface et al. 2024; Nagase and Uehara 2024; Reynolds et al. 2024). However, their effect remains limited when not paired with obligations on part availability, repair information and fair pricing (Ali and Shirazi 2023; Cenci et al. 2022; Purkiss et al. 2024). Examples such as France's repairability index (Ali and Shirazi 2023; Boniface et al. 2024) and Sweden's reduced VAT for repair services (Rudolf et al. 2022; Xavier, Giese, et al. 2021) demonstrate how linking regulation with incentives can increase repair uptake in practice.

The literature points to several actions that could strengthen policy. Harmonising EPR schemes across countries would reduce compliance costs and give producers the certainty needed to invest in design and reverse logistics (Corsini et al. 2017; Guzzo et al. 2021). Design-focused policies should specify repairability, durability and modularity requirements as core criteria, not voluntary extensions (Sonego et al. 2022; Svensson-Hoglund et al. 2021). Right-to-repair measures should include enforceable access to spare parts and documentation, making repair commercially viable beyond warranty periods (Ali and Shirazi 2023; Cenci et al. 2022; Purkiss et al. 2024). Finally, performance monitoring systems should move beyond weight-based targets towards indicators that capture product lifetime, component recovery quality and reuse flows, which would shift incentives upstream (Aminoff and Sundqvist-Andberg 2021). These interventions suggest that regulatory impact is maximised when design requirements, economic incentives and enforcement mechanisms operate together rather than in isolation.

### 4.2 | Sustainable Design

The literature emphasises that the design stage largely determines a product's lifetime environmental impact (Berwald et al. 2021; Bressanelli et al. 2021; Karagiannopoulos et al. 2024). Choices about materials and components shape durability and repairability and influence recovery quality at the end of life (de Oliveira Neto et al. 2023; Islam and Huda 2018; McCulloch et al. 2023). In the coded results, sustainable design appears both as a high-ranking enabler and, when lacking, as a recurring barrier. The most frequent enablers include product labelling, design for repair and recycling, durability and life extension approaches.

The value-chain analysis demonstrates that sustainable design enablers are strongly associated with collection, yet among all themes, they are also the ones most often linked to POM, end-of-life and use phase. This is consistent with the idea that design decisions determine what happens later in the value chain (Bressanelli et al. 2021). At POM, specifications on durability, modularity and replaceable parts determine whether repair is feasible and affordable. At the end of life, design for disassembly and product labelling improve treatment quality and reduce material loss. Furthermore, the association with the use phase suggests longer in-use lifetimes and less hoarding when products remain repairable and supported. Therefore, sustainable design stands out as the only theme strongly linked to both early and late stages, highlighting its central role in circularity.

**TABLE 5** | Practical and actionable interventions identified in the literature.

| Dimension | Theme | Actionable interventions | Sources |
|---|---|---|---|
| Regulatory and policy | Policy and regulations | • Harmonise EPR schemes across countries<br>• Expand eco-design rules to cover durability and repairability<br>• Link right to repair with obligations on spare parts and repair information<br>• Move beyond weight-based targets towards lifetime/value-based indicators | (Ali and Shirazi 2023; Aminoff and Sundqvist-Andberg 2021; Cenci et al. 2022; Corsini et al. 2017; Guzzo et al. 2021; Purkiss et al. 2024; Sonego et al. 2022; Svensson-Hoglund et al. 2021) |
| Environmental | Sustainable design | • Access to failing parts with standard tools<br>• Set minimum standards for durability and repairability<br>• Provide spare parts and repair information<br>• Align warranties/software support with lifetime<br>• Extend labels and repairability scores<br>• Ensure clear end-of-life labelling<br>• Provide clear disassembly guidelines<br>• Prioritise high-volume or complex products | (Cenci et al. 2022; Cole et al. 2019a; Coughlan et al. 2018; Pan et al. 2022; Purkiss et al. 2024; Rudolf et al. 2022; Scruggs et al. 2016; Sonego et al. 2022; Svensson-Hoglund et al. 2021; Talens Peiró et al. 2017) |
| Social | Consumer knowledge and awareness | • Offer accessible and convenient collection and take-back options (postal/pick-up)<br>• Provide simple instructions and credible data security<br>• Strengthen reuse through warranties and certification schemes<br>• Incentivise repair (VAT, vouchers)<br>• Target marketing and engagement towards actionable interventions | (Boniface et al. 2024; Ibanescu et al. 2018; Kankanamge 2023; Nagase and Uehara 2024; Nowakowski 2019; Purkiss et al. 2024) |
| Technical | Infrastructure and technology | • Establish facilities for testing/sorting used EEE<br>• Ensure accessibility of digital product passports and sorting equipment<br>• Standardise/protected data with clear access rights<br>• Implement context-specific approaches (reuse and traceability in high-income, formalisation in low-income) | (Boniface et al. 2024; Coughlan et al. 2018; Shittu et al. 2021; Surange et al. 2024) |
| Economic | Economic and financial factors | • Narrow repair vs. replacement price gap (reduced VAT, vouchers)<br>• Make spare parts and service information affordable and accessible<br>• Invest earlier in the chain<br>• Fund testing at collection and reverse logistics<br>• Fund R&D on design for disassembly, repair, recovery, and digital tracking<br>• Support business models that retain value in use (PSS, leasing) | (Ali and Shirazi 2023; Anuardo et al. 2023; Cenci et al. 2022; Chersan et al. 2023; Cole et al. 2019b, 2019a; de Oliveira Neto et al. 2023; Kumar et al. 2022; Liu et al. 2016; Menon and Ravi 2022; Pan et al. 2022; Purkiss et al. 2024; Rizos and Bryhn 2022; Suppipat and Hu 2022; Svensson-Hoglund et al. 2021; Vishwakarma et al. 2022) |

The recovery-flow results demonstrate similar conclusions. Recycling remains the most cited flow, but sustainable design shows the highest associations with rethink, reduce, reuse, repair, refurbish, remanufacture and repurpose, positioning it as the most directly connected to higher R strategies. Across the reviewed studies, several patterns recur: durability and modular design extend product use (Cenci et al. 2022), access to spare parts and repair information supports repair (Sonego et al. 2022) and clear product labelling drives resource and energy efficiency (Purkiss et al. 2024). Therefore, sustainable design emerges as a direct route to shifting activity beyond recycling towards longer product lifetimes.

Several actionable interventions follow from these insights. Eco-design rules should require access to commonly failing parts with non-specialist tools, set minimum standards for durability and repairability and guarantee the availability of spare parts and repair information (Rudolf et al. 2022; Svensson-Hoglund et al. 2021). Moreover, warranty and software support should be aligned with expected physical product lifetimes to avoid early replacement and keep products usable for longer periods (Cenci et al. 2022; Scruggs et al. 2016; Svensson-Hoglund et al. 2021). Labels and repairability scores should be extended so design quality is visible in markets and procurement, and clear product labelling should support material separation at the end of life (Purkiss et al. 2024; Sonego et al. 2022). Additionally, providing clear disassembly documentation and guidelines can lower costs across the chain and minimise WEEE (Coughlan et al. 2018; Talens Peiró et al. 2017).

Finally, research and standards should prioritise high-volume or technically challenging product categories, such as small household appliances and IT and telecommunications equipment, to target categories with the greatest system impact (Cole et al. 2019b; Pan et al. 2022).

## 4.3 | Consumer Knowledge and Awareness

The results position consumer knowledge and awareness as a major theme for both enablers and barriers. Household stockpiling, rising demand and early replacement appear frequently, alongside improper disposal and concerns about data security, which reflect the attitude–behaviour gap, where intended consumer attitudes and support for circularity fail to translate to actual circular behaviour (Corsini et al. 2017; Reynolds et al. 2024). The mobile phone case studies further underline this point, as phones are small, high-value items often kept in drawers for long periods, delaying collection and reducing resale value (Guzzo et al. 2021; Islam et al. 2020; Shittu et al. 2021).

The value chain links in the results reinforce these patterns. Most consumer-related barriers and enablers are concentrated at the collection stage, where decisions are made about product return and data wiping. The recovery-flow analysis shows that consumer barriers are most often linked to recycling, whereas enablers appear first in recycling and then extend to reduce, repair and reuse. This pattern is expected since recycling is familiar and supported by more accessible and convenient return routes. By contrast, shifting from recycling to higher R strategies such as reuse and repair requires more than awareness. It depends on accessible and convenient services, clear quality assurances, affordable repair, perceived value and price (Svensson-Hoglund et al. 2021; Tansel 2017).

The literature emphasises that information alone rarely changes behaviour. Campaigns can raise awareness, but participation depends on accessibility, convenience and perceived value (Svensson-Hoglund et al. 2021; Tansel 2017). Certifications and warranties on refurbished goods, and clear data-wipe guarantees, reduce perceived risk and make second-life options credible (Mugge et al. 2018). Repair must be affordable and accessible, and recent literature treats right to repair as an important policy approach to achieve this. However, impact remains limited if spare parts are costly or hard to obtain, products are not standardised, or repair information is not accessible, or when repair services have long turnaround times (Cenci et al. 2022). Therefore, coordinating consumer rights with guaranteed access to parts, repair information and timely service is more effective because it addresses several barriers at once.

Actionable interventions follow from these findings. Interventions are most effective at the point of collection, with visible and convenient return and take-back options, postal or pick-up services and simple instructions to explain the process and what happens next (Ibanescu et al. 2018; Nowakowski 2019; Purkiss et al. 2024). These should be paired with credible data security assurances, including certified data-wipe and proof of destruction for sensitive storage components (Boniface et al. 2024; Kankanamge 2023). Reuse can be strengthened through warranties of meaningful length and certification schemes that set quality standards and protect data. Repair becomes a realistic choice when right to repair is supported with incentives such as reduced VAT on repair and vouchers (Nagase and Uehara 2024). Therefore, marketing and engagement should focus less on generic awareness and more on promoting these specific service-based interventions, since behaviour change occurs when options are visible, convenient and low-risk.

## 4.4 | Infrastructure and Technology

Infrastructure and technology emerge as high-ranking themes in this review. Most coded associations occur at collection and end of life, indicating limited infrastructure, the dominance of informal handlers in some contexts and the need for improved reverse logistics and integrated systems. Existing literature emphasises the significance of infrastructure for formal WEEE management and for scaling circular practices (Mmereki et al. 2015; Shittu et al. 2021). The literature also highlights technological constraints, including rapid product turnover, technological obsolescence, limited availability and traceability of WEEE data, advances that outpace serviceability and inadequate treatment technologies. Controversy, the literature identifies several technological enablers. Industry 4.0 applications, such as Internet of Things (IoT), Big Data and Analytics, 3D Printing, Cloud and Blockchain, help improve monitoring and reporting on WEEE data while increasing the efficiency of WEEE management (M. Chen and Ogunseitan 2021; Sagnak et al. 2021; Soesanto et al. 2023). Moreover, digital product passports are increasingly proposed to provide access to design information, repair guidelines, energy labelling and material or chemical composition throughout a product's life, supporting legal requirements, decision making and circular supply chain management (de Waal 2023; Purkiss et al. 2024). The results also highlight the need for better WEEE databases and reporting, including the POM, stock and end-of-life data to improve forecasting and system planning.

Existing research suggests that infrastructure and technology are still organised around recycling, which aligns with the dominance of recycling in policy and monitoring. In this review, links were strongest to collection when mapped to value chain stages and to recycling when mapped to recovery flows. This pattern implies systems are built to aggregate volume and move it quickly to treatment, with limited capacity to assess condition or keep product fit for higher-value routes.

The practical implication is to establish facilities that test, sort and categorise used EEE products and validate suitability for different circular routes such as remanufacturing, repurposing and refurbishing (Coughlan et al. 2018; Shittu et al. 2021). Moreover, technology needs to be accessible, since digital product passports and new sorting equipment are only helpful if stakeholders throughout the chain can use them (Surange et al. 2024). This requires data standardisation and protection, and clarity on access rights, to enable secure and reliable multistage processes (Boniface et al. 2024). Interventions should be context specific. In high-income settings, the priority may be to expand reuse capacity and embed digital traceability. In lower-income settings, the priority may be to formalise and upgrade existing networks through safe collection hubs, training and take-back schemes that integrate informal actors rather than displace them. Good practice examples in the literature highlight voucher-based take-back schemes, shared testing hubs and repair centres as scalable models when supported by policy, logistics and finance.

### 4.5 | Economic and Financial Factors

Economic and financial factors support the other themes. Many options that are technically feasible do not scale because costs and benefits are misaligned across stakeholders in the chain (Pollard et al. 2021; Sundar et al. 2023). In the reviewed studies, the main barriers are limited financial resources and support, economically driven consumption, price and affordability and limited incentives. Limited financial resources and support restrict investment in formal collection, testing and upgrading capacity, design improvements, reverse logistics and data systems, making it harder to direct products to high R strategies (Gaur et al. 2024; Yang et al. 2021). Price and affordability encourage replacement because new devices are often priced low relative to labour-based services, such as repair (Islam et al. 2020; Svensson-Hoglund et al. 2021). Economic growth-driven consumption normalises frequent upgrades, shortens replacement cycles and narrows the window in which value can be recovered (Ghimire and Ariya 2020; Karagiannopoulos et al. 2024; Neves, Marques, and Silva 2024). Incentives are weak for both consumers and organisations. Consumers have received no or limited rewards and have limited incentives to return devices, choose repair or buy refurbished products with confidence (Govindan et al. 2024; Jabbour et al. 2023; Mmereki et al. 2015). Similarly, organisations operate within target structures and economic models that prioritise new product sales over longer use, limiting investment in higher R strategies such as reuse, repair, remanufacturing and refurbishment (Cole et al. 2019b; Svensson-Hoglund et al. 2021).

On the enabler side, availability of financial support and subsidies, rewards and incentives and mechanisms for economic benefits or value capture can change these dynamics, but only when they align with other parts of the system, such as accessible service, parts and information and clear data and policy measures. In practice, financial support and subsidies support return and service options, and incentives at return reduce stockpiling and direct products into formal channels (Leitão et al. 2023; Reynolds et al. 2024; Shevchenko et al. 2021). Additionally, EEE products contain valuable materials and components. Therefore, value-capture tools such as EPR fees, buy-back and deposit–refund schemes allow stakeholders to retain part of that value and make investment in life extension commercially viable and economically beneficial (Cheshmeh et al. 2023; Kumar et al. 2022; Sharma et al. 2020).

The association patterns in this review help explain these effects. For value chain stages, both barriers and enablers concentrate on collection. This is where costs are immediate, and routing choices are made. If return routes are inconvenient or expensive, or if collection systems cannot assess condition and separate items suitable for reuse, products are sent directly to recycling or other end-of-life processing. In recovery flows, links are strongest to recycling, with fewer links to higher R strategies. This reflects the dominance of measurable targets and compliance reporting, which draw finance and infrastructure to recycling rather than to strategies that keep products in use (de Waal 2023; Favot et al. 2016; Purkiss et al. 2024). Although economic and financial enablers would be expected to link more strongly to higher R strategies such as reuse, repair and remanufacture, their weaker links in this review suggest that instruments still focus on easily measured and reported outcomes. The result is a system organised for volume rather than value retention, even when higher R strategies are technically feasible (Aminoff and Sundqvist-Andberg 2021).

Several interventions follow from these insights. The literature underlines that linear options remain cheaper, so the economics of circular practices need to be more predictable and attractive (Cole et al. 2019b; Liu et al. 2016; Vishwakarma et al. 2022). The price gap between repair and replacement can be narrowed through reduced VAT on repairs and on refurbished products, or vouchers (Purkiss et al. 2024; Svensson-Hoglund et al. 2021). Right-to-repair measures should include pricing and availability for parts and service information, so repair is a practical choice at the point of decision (Ali and Shirazi 2023; Cenci et al. 2022). Investments should also move earlier in the value chain. Funding for testing at collection and for reverse logistics that keep products separate enables product life extension through higher R strategies such as repair and reuse (de Oliveira Neto et al. 2023; Menon and Ravi 2022a; Pan et al. 2022). Additionally, targeted research and development can lower costs in practice, including work on the development of innovative and efficient technologies to improve capture quality, as well as design for disassembly, recovery of critical materials, repair methods and data systems that track product condition across uses (Anuardo et al. 2023; Kumar et al. 2022; Rizos and Bryhn 2022). Moreover, business models that keep value in use should be supported since leasing and product–service systems create incentives to design for durability and longevity because revenue depends on performance rather than new product sales (Chersan et al. 2023; Cole et al. 2019b; Suppipat and Hu 2022). A number of studies highlight deposit–refund schemes as promising good-practice examples that directly increase return rates and create predictable material flows for reuse and refurbishment.

## 5 | Conclusion

This paper aims to identify the main barriers and enablers of the circular transition in the EEE sector and to draw out actionable interventions from the literature. A structured review of 161 peer-reviewed papers published between 2015 and 2024 was completed and coded using MAXQDA. Five themes emerged from the coding of the literature: policy and regulation, sustainable design, consumer knowledge and awareness, infrastructure and technology and economic and financial factors. The five themes were also linked to value-chain stages and recovery flows.

The findings suggest that research and practice remain largely focused on downstream activities, particularly recycling, reflecting how policy and monitoring structures currently assess performance. Decisions at collection often determine whether products move to repair and reuse or go straight to treatment, whereas choices made at market entry through design and pricing set the conditions for what is feasible later in the chain. Sustainable design therefore emerges as a critical leverage point because durability, modularity, repairability and labelling shape the feasibility of higher R strategies long before products enter the waste stream.

Interventions emerging from the literature appear most effective when implemented together rather than in isolation. Regulatory efforts such as EPR and right to repair have a greater impact when supported through design standards, availability of parts, consumer-facing repair options and infrastructure capable of separating reusable items. Likewise, behavioural change is more successful when awareness is matched with accessibility, convenience and economic incentives. Financial mechanisms help close the gap between repair and replacement, whereas technology such as digital product passports strengthens traceability and improves routing decisions across the chain.

The overall implication is that progress depends less on identifying barriers and enablers individually and more on how they interact in practice. Policy, design, consumer behaviour, infrastructure and finance reinforce one another, and circular outcomes are shaped by the alignment of these elements rather than by single themes or measures alone. A more systemic approach that considers how decisions at one stage influence outcomes in others is therefore necessary for moving further up the waste hierarchy.

Despite its contributions, this review has several limitations that should be acknowledged. The literature reviewed is not distributed evenly across geographical contexts and products. Most studies focus on Europe and other high-income regions, with far fewer from contexts where informal waste handling is common. Many papers treat EEE generically rather than examining product-specific categories, where design and safety constraints differ. These limitations point to clear directions for future research. First, widen geographical coverage and integrate analysis of informal actors where relevant. Second, product-specific studies are needed to identify the enablers and barriers for each category, with attention to design choices, durability, repairability, repeated use and recovery of critical materials. Third, track outcomes before and after policy or market changes to test their effects. Fourth, explore the trade-offs and tensions among different circular strategies across various product categories. Finally, adopt a systems perspective that maps how the five themes connect to one another and how these links shape outcomes across value-chain stages and recovery flows.

### Author Contributions

**Aya Abdelmeguid:** conceptualisation, validation, formal analysis, investigation, data curation, writing – original draft, writing – review and editing, visualisation. **Lucia Corsini:** conceptualisation, validation, supervision, writing – review and editing, project administration, funding acquisition.

### Acknowledgements

This research is funded by UKRI Future Leaders Fellowship Tackling Waste Electrical and Electronic Equipment (WEEE) MR/X036081/2.

### Funding

This work was supported by the UK Research and Innovation (MR/X036081/2).

### Conflicts of Interest

The authors declare no conflicts of interest.

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## Appendix

| No. | Source | Methodology | Country | Product type: Generic | Specific | Specific product(s) | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| 1 | Ádám et al. (2021) | Literature review | General | X | | | Recycle, recover | Collection, end of life |
| 2 | Ali and Shirazi 2023 | Literature review, case study | General | X | | | Reuse, repair, recycle, recover | Collection, product life extension, end of life |
| 3 | Gebregiorgis Ambaye et al. (2020) | Literature review | General | X | | | Recover, recycle | End of life, collection, product life extension |
| 4 | Aminoff and Sundqvist-Andberg (2021) | Case study, interviews | Europe (Finland) | X | | | Recycle | Collection, product life extension, end of life |
| 5 | Anandh et al. (2021) | Systematic literature review | General | X | | | Reuse, recycle | Use phase, collection, product life extension, end of life |
| 6 | Anuardo et al. (2023) | Content analysis | General | X | | | Recycle, reuse, repair, refurbish, reduce | Use phase, collection, product life extension, end of life |
| 7 | Bakhiyi et al. (2018) | Literature review | General | X | | | Recycle, reuse | Use phase, collection, end of life |
| 8 | Baxter and Gram-Hanssen (2016) | Literature review, behavioural study | Norway | | X | Mobile phones | Reuse, recycle | Use phase, collection, end of life |
| 9 | Bernardes et al. (2024) | Action research | Brazil | X | | | Recycle, repair, reuse | Stock, collection, product life extension |
| 10 | Berwald et al. (2021) | Interviews, framework development | General | X | | | Rethink, reuse, recycle | Placed on market, end of life |
| 11 | Bhattacharjee et al. (2023) | Literature review, interviews | Bangladesh | X | | | Reuse, recycle | Use phase, collection, product life extension, end of life |
| 12 | Bigliardi et al. (2022) | Survey | General | | X | Mobile phones | Reuse, refurbish, repair, remanufacture | Use phase, product life extension, end of life |
| 13 | Boniface et al. (2024) | Literature review | Europe (United Kingdom) | X | | | Repair, repurpose, reuse, recycle | Use phase, collection, product life extension, end of life |
| 14 | Borland et al. (2019) | Case study, interviews | Europe (United Kingdom) | X | | | Reuse, recycle, repair | Use phase, collection, product life extension, end of life |
| 15 | Botelho et al. (2016) | Survey | Europe (Portugal) | X | | | Reuse, recycle | Collection, end of life |
| 16 | Bovea and Pérez-Belis (2018) | Literature review | General | | X | Heater, vacuum cleaners, hand blenders, juicers, sandwich makers, toasters, irons, hair dryer, coffee maker, kettle | Repair, reuse, recycle | Use phase, product life extension |
| 17 | Bracquené et al. (2021) | Literature review, field study | General | | X | Washing machines | Repair | Product life extension, end of life |

| No. | Source | Methodology | Country | Product type: Generic | Specific | Specific product(s) | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| 18 | Bressanelli et al. (2021) | Literature review | General | X | | | Refurbish, remanufacture, reuse | Use phase, collection, product life extension |
| 19 | Bressanelli et al. (2020) | Literature review | General | X | | | Reuse, remanufacture, recycle | Use phase, product life extension, end of life |
| 20 | Bridgens et al. (2019) | Life cycle assessment | General | | X | Mobile phones | Reuse, remanufacture, recycle, reduce | Use phase, collection, product life extension, end of life |
| 21 | Cenci et al. (2022) | Literature review | General | X | | | Reduce, reuse, recycle | Placed on market, end of life |
| 22 | Cesaro et al. (2018) | Literature review | General | X | | | Recycle, recover | Use phase, collection, product life extension, end of life |
| 23 | M. Chen and Ogunseitan (2021) | Literature review | General | X | | | Recycle, recover | Collection, product life extension, end of life |
| 24 | W. Chen et al. (2024) | Modelling | China | | X | Mobile phones | Recycle, repair, refurbish | Use phase, collection, product life extension, end of life |
| 25 | Chersan et al. (2023) | Mixed methods | Europe | X | | | Reuse, recycle, repair, refurbish | Placed on market, collection, end of life |
| 26 | Cheshmeh et al. (2023) | Literature review | General | X | | | Reduce, reuse, repair, refurbish, recycle | Use phase, collection, product life extension, end of life |
| 27 | Cole et al. (2019a) | Interviews | Europe (United Kingdom) | X | | | Reuse, recycle, recover | Collection, product life extension, end of life |
| 28 | Cole et al. (2019b) | Interviews | Europe (United Kingdom) | X | | | Reuse, repair | Use phase, collection, product life extension |
| 29 | Compagnoni (2022) | Literature review | General | X | | | Recycle, recover | Use phase, collection, end of life |
| 30 | Cordova-Pizarro et al. (2019) | Survey, material product life extension analysis | Mexico | X | | | Repair, recycle, reuse | Collection, product life extension, end of life |
| 31 | Corsini et al. (2020) | Literature review | General | X | | | Repair, reuse, recycle | Use phase, collection, product life extension, end of life |
| 32 | Corsini et al. (2017) | Latent class analysis | Europe | X | | | Recycle, recover | Collection, end of life |
| 33 | Coughlan et al. (2018) | Experimental study | General | | X | Notebook computers | Reuse, repurpose, recycle | Collection, product life extension, end of life |
| 34 | Cruz-Sotelo et al. (2017) | Literature review | Mexico | X | | | Reuse, recycle, recover | Use phase, collection, product life extension, end of life |
| 35 | Cucchiella et al. (2015) | Literature review | Europe | X | | | Recycle, reuse, repair, refurbish, reduce | Use phase, collection, product life extension |
| 36 | de Oliveira Neto et al. (2023) | Life cycle assessment | General | X | | | Reuse, recycle | Collection, recovery, end of life |

| No. | Source | Methodology | Country | Product type: Generic | Specific | Specific product(s) | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| 37 | de Souza et al. (2016) | Life cycle assessment | Brazil | X | | | Recycle, recover | Collection, end of life |
| 38 | de Waal (2023) | Literature review, interviews | Europe (Netherlands) | X | | | Reuse, recycle, recovery | Placed on market, use phase, collection, product life extension, end of life |
| 39 | Echegaray (2016) | Survey, behavioural analysis | Brazil | | X | Computer, mobile, washing machine, printer, TV, DVD/Blu-Ray, oven, fridge/freezer, camera, microwave | Reuse, recycle | Use phase, end of life |
| 40 | Evans and Vermeulen (2021) | Meta-evaluation | General | X | | | Recycle, recover, reuse | Placed on market, collection, recovery, end of life |
| 41 | Favot and Grassetti (2017) | Modelling | Europe (Italy) | X | | | Recycle, recover | Collection, flows |
| 42 | Favot et al. (2022) | Econometric analysis | Europe | X | | | Recycle | Collection, flow, end of life |
| 43 | Favot et al. (2018) | Literature review | General | X | | | Recycle, recover | Collection, product life extension, end of life |
| 44 | Favot et al. (2016) | System-level analysis | Italy | X | | | Recycle, recover | Collection, product life extension, end of life |
| 45 | Fernandes et al. (2023) | Literature review | China | X | | | Reuse, recycle, remanufacture, recover | Use phase, collection, flow, end of life |
| 46 | Fetanat et al. (2021) | Literature review | General | X | | | Recycle, recover, repair, remanufacture | Use phase, collection, flow, end of life |
| 47 | Gaur et al. (2024) | Literature review | General | X | | | Reuse, recycle, remanufacture, refurbish, repair, reduce, recover, repurpose | Placed on market, collection, product life extension, end of life |
| 48 | Ghimire and Ariya (2020) | Literature review | General | X | | | Reduce, recycle, recover | Use phase, end of life |
| 49 | Ghisellini et al. (2023) | Interviews | Europe (Italy) | X | | | Recycle, reuse | Use phase, collection, flow |
| 50 | Ghisolfi et al. (2017) | Modelling | Brazil | | X | Desktop, laptop | Reuse, refurbish, recycle | Use phase, collection, end of life |
| 51 | Ghulam and Abushammala (2023) | Literature review | General | X | | | Reuse, recycle, reduce | Use phase, end of life |
| 52 | Govindan et al. (2024) | Modelling | Iran | | X | Mobile phones, laptops, tablets | Recycle, repair, reuse | Use phase, collection, flow, end of life |
| 53 | Grandhi et al. (2024) | Literature review, policy analysis | General | X | | | Reuse, repair, recycle, recover, refurbish | Placed on market, collection, recovery |
| 54 | Gu et al. (2017) | Model-based analysis | China | X | | | Recycle, recover | Product life extension, end of life |
| 55 | Guo and Zhong (2021) | Model-based analysis | Taiwan, Vietnam | | X | TVs, washing machine, air conditioner, refrigerator | Recycle, recovery | Collection, product life extension, end of life |

| No. | Source | Methodology | Country | Product type |  |  | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Generic | Specific | Specific product(s) |  |  |
| 56 | Guzzo et al. (2021) | Modelling | Brazil |  | X | Flat display panel TV | Recycle, remanufacture, recover | Use phase, collection, flow, end of life |
| 57 | Guzzo et al. (2022) | Modelling | General |  | X | Mobile phones | Recycle, recover, reuse | Placed on market, collection, recovery |
| 58 | Hischier and Böni (2021) | Life cycle analysis, total cost of ownership | Europe (Switzerland) |  | X | Washing machines, refrigerators, televisions, laptop computers, mobile phones | Reuse, recycle | Use phase, flow, end of life |
| 59 | E. Hsu et al. (2019) | Literature review | General | X |  |  | Recycle, reuse, repair, refurbish, reduce | Use phase, collection, flow, end of life |
| 60 | J. Hsu et al. (2024) | Literature review | General | X |  |  | Reduce, reuse, recycle | Placed on market, collection, recovery, end of life |
| 61 | Ibanescu et al. (2018) | Mixed methods | Europe | X |  |  | Recycle, recover | Collection, product life extension, end of life |
| 62 | Isernia et al. (2019) | Performance analysis | Europe (Italy) | X |  |  | Recycle, reuse, recover | Collection, flow, end of life |
| 63 | Işıldar et al. (2018) | Literature review | General | X |  |  | Recycle, recover | Collection, flow, end of life |
| 64 | Islam et al. (2020) | Survey | General |  | X | Mobile phones | Reuse, recycle | Use phase, collection, end of life |
| 65 | Islam and Huda (2020) | Multicriteria analysis | Australia | X |  |  | Recycle, repair, reuse | Use phase, collection, end of life |
| 66 | Islam and Huda (2018) | Literature review, content analysis | General | X |  |  | Recycle, reuse, repair, remanufacture, reduce | Use phase, collection, product life extension, end of life |
| 67 | Islam and Huda (2019a) | Modelling | Australia | X |  |  | Recycle, recover | Use phase, collection, flow |
| 68 | Islam and Huda (2019b) | Literature review | Australia | X |  |  | Recycle, remanufacture | Collection, flow, end of life |
| 69 | Islam et al. (2021) | Literature review, survey, content analysis | Worldwide | X |  |  | Recycle, reuse | Collection, end of life |
| 70 | Ismail and Hanafiah (2020) | Systematic literature review, content analysis | General | X |  |  | Recycle | Placed on market, collection, product life extension |
| 71 | Jabbour et al. (2023) | Survey | General | X |  |  | Reuse, recycle | Use phase, collection, end of life |
| 72 | Jaiswal and Mukti (2024) | Literature review, interviews | India | X |  |  | Reuse, recycle, recovery | Placed on market, collection, product life extension, end of life |
| 73 | Jayasiri et al. (2024) | Survey, material flow analysis | Australia |  | X | Small WEEE (toys, food preparation equipment, vacuum cleaners, household tools) | Reuse, repair, recycle | Placed on market, use phase, recovery, collection |

| No. | Source | Methodology | Country | Product type: Generic | Product type: Specific | Product type: Specific product(s) | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| 74 | Kama (2015) | Literature review, policy analysis | Europe | X | | | Recycle, recover | Placed on market, collection, product life extension, end of life |
| 75 | Kang et al. (2020) | Prototype development | Malaysia | X | | | Recycle | Collection, product life extension |
| 76 | Kankanamge (2023) | Survey | Sri Lanka | | X | Personal electronics | Repair, reuse, recycle | Stock, collection, end of life |
| 77 | Karagiannopoulos et al. (2024) | Literature review | General | X | | | Reduce, reuse, recycle, remanufacture | Placed on market, collection, end of life |
| 78 | Khanal et al. (2024) | Literature review | General | X | | | Reduce, reuse, recycle | Placed on market, collection, recovery |
| 79 | Kumar et al. (2022) | Multicriteria analysis | General | X | | | Reuse, remanufacture, recycle, recover | Use phase, collection, flow, end of life |
| 80 | Laurenti et al. (2015) | Literature review | General | X | | | Refurbish, remanufacture | Use phase, flow |
| 81 | Leitão et al. (2023) | Literature review | Brazil | X | | | Recycle, reuse, repair, refurbish, reduce | Stock, flow, end of life |
| 82 | Liu et al. (2016) | Modelling | General | X | | | Recycle, reuse | Collection, flow, end of life |
| 83 | Lu et al. (2015) | Case study | China | X | | | Recycle, reuse | Use phase, collection, end of life |
| 84 | Lynch and Cabrera Serrenho (2023) | Scenario-based modelling | Europe (United Kingdom) | X | | | Reduce, reuse, repair, refurbish | Placed on market, use phase, end of life |
| 85 | Magrini et al. (2021) | Case study, interviews | Europe (Italy) | | X | Professional EEE | Reuse, repair, recycle | Use phase, collection, flow |
| 86 | Makov et al. (2019) | Regression analysis | General | X | | | Reuse, repair | Use phase, product life extension, end of life |
| 87 | Mansuy et al. (2020) | Conjoint analysis | Europe (Brussels) | | X | Mobile phones, coffee machines, washing machines | Reuse, repair, recycle | Collection, flow, end of life |
| 88 | Marke et al. (2020) | Literature review, interviews | China | | X | Mobile electronics | Reduce, reuse, recycle, recover | Use phase, collection, flow, end of life |
| 89 | Mazahir et al. (2019) | Policy modelling | Europe | X | | | Reuse, repair, recycle | Collection, flow, end of life |
| 90 | McCulloch et al. (2023) | Literature review | Europe (Italy) | X | | | Rethink, reduce, recycle | Placed on market, end of life |
| 91 | McMahon et al. (2019) | Literature review, interviews | Europe (Ireland) | X | | | Reuse | Use phase, collection, flow |
| 92 | Menon and Ravi (2021a) | Literature review, modelling | India | X | | | Recycle, repair, reuse | Use phase, collection, recovery, end of life |
| 93 | Menon and Ravi (2022) | Literature review, interviews | India | X | | | Reduce, reuse, recycle | Use phase, collection, flow, end of life |
| 94 | Menon and Ravi (2021b) | Literature review, interviews | India | X | | | Reuse, remanufacture, recycle | Use phase, collection, flow |

| No. | Source | Methodology | Country | Product type | | | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| | | | | Generic | Specific | Specific product(s) | | |
| 95 | Mmereki et al. (2015) | Policy analysis | Botswana | X | | | Recycle, recover | Use phase, collection, end of life |
| 96 | Mohammadi et al. (2021) | Material flow analysis | Caribbean | X | | | Recycle, reuse, repair | Use phase, collection, flow, end of life |
| 97 | Moradi et al. (2024) | Literature review | Europe (United Kingdom) | X | | | Reuse, recycle, remanufacture, refurbish | Placed on market, use phase, collection, product life extension, end of life |
| 98 | Mugge et al. (2018) | Survey, experimental study | General | | X | Refurbished electronics | Reuse, refurbish | Use phase, collection, end of life |
| 99 | Murthy and Ramakrishna (2022) | Literature review | Worldwide | X | | | Recycle, recover | Collection, flow, end of life |
| 100 | Nagase and Uehara 2024 | Modelling | Europe (United Kingdom) | X | | | Repair, reduce, reuse, recycle | Use phase, collection, product life extension, end of life |
| 101 | Naik and Satya Eswari (2022) | Literature review | General | X | | | Recycle, reuse | Collection, end of life |
| 102 | Neves, Marques, and de Sá Lopes (2024) | Panel data analysis | Europe | X | | | Reuse, recycling | Placed on market, collection, product life extension, end of life |
| 103 | Neves, Marques, and Silva (2024) | Panel data analysis | Europe | X | | | Recycle | Use phase, collection, flow, end of life |
| 104 | Nithya et al. (2021) | Literature review | General | X | | | Recycle, recover | Collection, flow, end of life |
| 105 | Nowakowski (2019) | Survey | Europe (Poland) | X | | | Reuse, repair | Use phase, collection |
| 106 | Nowakowski and Mrówczyńska (2018) | Optimisation modelling | General | X | | | Recycle | Collection, product life extension |
| 107 | Pan et al. (2022) | Literature review | General | X | | | Reduce, reuse, repair, remanufacture, recycle | Use phase, flow, end of life |
| 108 | Panchal et al. (2021) | Economic modelling | India | X | | | Recycle, recover | Collection, recovery, end of life |
| 109 | Parajuly et al. (2020) | Literature review | General | X | | | Reuse, repair | Collection, end of life |
| 110 | Parajuly and Wenzel (2017b) | Literature review | Europe (Denmark) | X | | | Reuse, repair, recycle | Collection, flow |
| 111 | Parajuly and Wenzel (2017a) | Empirical study | Europe | X | | | Reuse, repair, recycle | Use phase, collection, flow |
| 112 | Park et al. (2022) | Survey, modelling | South Korea | X | | | Recycle, recover, reuse | Use phase, collection, flow, end of life |
| 113 | Pathak et al. (2017) | Literature review, case study, modelling | India | X | | | Recycle, repair | Collection, flow, end of life |

| No. | Source | Methodology | Country | Product type: Generic | Product type: Specific | Product type: Specific product(s) | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| 114 | Pérez-Martínez et al. (2021) | Life cycle assessment | General | | X | Programmable logic controller, perimeter security system | Reuse, repurpose, recycle | Use phase, collection, flow, end of life |
| 115 | Pollard et al. (2021) | Qualitative study | General | X | | | Recycle, remanufacture | Use phase, collection, flow, end of life |
| 116 | Pollard et al. (2023) | Case study | General | X | | | Repair, remanufacture, recycle, reuse | Use phase, flow, end of life |
| 117 | Pouyamanesh et al. (2023) | Literature review | General | X | | | Reuse, recycle, repair, reduce | Collection, flow, end of life |
| 118 | Purkiss et al. (2024) | Workshops, interviews | Europe (United Kingdom) | X | | | Repair, reuse, refurbish | Placed on market, use phase, product life extension, recovery |
| 119 | Razip et al. (2022) | Case study, interviews | Malaysia | X | | | Recycle, reuse | Use phase, collection, end of life |
| 120 | Reynolds et al. (2024) | Qualitative study | Europe (United Kingdom) | | X | Household appliances | Repair, reuse | Use phase, end of life |
| 121 | Rizos and Bryhn (2022) | Case study, interviews | Europe | X | | | Reuse, refurbish, recycle | Use phase, collection, flow, end of life |
| 122 | Rosa et al. (2019) | Literature review, interviews, case study | General | X | | | Reuse, repair, refurbish, recycle | Flow, end of life |
| 123 | Rudolf et al. (2022) | Empirical study, survey | Europe (Germany) | X | | | Repair, reuse | Use phase, collection, flow |
| 124 | Sagnak et al. (2021) | Literature review, modelling | Turkey | X | | | Recycle, recover | Collection, product life extension |
| 125 | Sandez et al. (2023) | Survey | Europe (Spain) | | X | Kettles | Repair, reuse | Collection, flow, end of life |
| 126 | Scruggs et al. (2016) | Case study, interviews | General | X | | | Recycle, recover | Collection, end of life |
| 127 | Seif et al. (2024) | Literature review | General | X | | | Recycle, recover | Collection, flow, end of life |
| 128 | Shahabuddin et al. (2023) | Literature review | Worldwide | X | | | Recycle, reuse | Use phase, collection, flow |
| 129 | Sharma et al. (2021) | Literature review, interviews | India | X | | | Repair, reuse, recycle | Use phase, collection, flow, end of life |
| 130 | Sharma et al. (2020) | Literature review, interviews | India | X | | | Recycle, reuse, remanufacture | Collection, flow, end of life |
| 131 | Shevchenko et al. (2021) | Literature review, case study | Europe (Ukraine) | | | | Recycle, reuse | Collection, flow, end of life |
| 132 | Shi et al. (2023) | Modelling, regression analysis | General | X | | | Recycle, recover | Placed on market, collection |
| 133 | Shittu et al. (2021) | Literature review | General | X | | | Recycle, reuse, refurbish | Use phase, collection, flow, end of life |

| No. | Source | Methodology | Country | Product type | | | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| | | | | Generic | Specific | Specific product(s) | | |
| 134 | Singhal et al. (2019) | Literature review, survey, interviews, modelling | India | X | | | Remanufacture, repair, reuse | Use phase, collection, flow, end of life |
| 135 | Soesanto et al. (2023) | Literature review, coding | General | X | | | Reuse, recycle, recover | Placed on market, collection, recovery, end of life |
| 136 | Sonego et al. (2022) | Literature review | General | X | | | Repair | Flow, end of life |
| 137 | Srivastav et al. (2023) | Literature review | General | X | | | Recycle, recover | End of life |
| 138 | Su et al. (2018) | Literature review, case study | General | X | | | Reuse, repair, refurbish, remanufacture, recycle | Collection, flow, end of life |
| 139 | Sundar et al. (2023) | Literature review, interviews | Europe (United Kingdom) | X | | | Reuse, repair, recycle, recover | Use phase, collection, flow, end of life |
| 140 | Suppipat and Hu (2022) | Literature review | General | X | | | Reuse, repair, remanufacture | Use phase, collection, flow, end of life |
| 141 | Surange et al. (2024) | Literature review, interviews, modelling | General | X | | | Recycle, remanufacture, reuse, repair, refurbish | Placed on market, collection, product life extension, end of life |
| 142 | Svensson-Hoglund et al. (2021) | Literature review | Europe, US | X | | | Repair, reuse | Flow, end of life |
| 143 | Talens Peiró et al. (2017) | Case study | Europe | | X | PC-tablets, subnotebooks | Reuse, repair, recycle | Placed on market, end of life |
| 144 | Tansel (2017). | Literature review | Worldwide | X | | | Recycle, reduce, repair, reuse | Use phase, collection, flow, end of life |
| 145 | Tian et al. (2022) | Life cycle analysis, modelling | China | X | | | Recycle | Use phase, collection, flow, end of life |
| 146 | Tong et al. (2018) | Modelling | China | X | | | Recycle, recover | Collection, flow |
| 147 | Torrubia et al. (2023) | Material flow analysis | Europe (Spain) | X | | | Recycle, recover, reuse | Use phase, collection, flow, end of life |
| 148 | Twagirayezu et al. (2023) | Literature review | Rwanda | X | | | Recycle, repair, reuse | Use phase, collection, flow, end of life |
| 149 | Vadoudi et al. (2015) | Material flow analysis | Europe (France) | X | | | Recycle, reuse | Collection, flow, end of life |
| 150 | Vishwakarma et al. (2022) | Framework development | General | X | | | Reuse, recycle, recover | Collection, flow, end of life |
| 151 | Wagner et al. (2019) | Scenario-based assessment | General | | X | Consumer electronics (only LCD TVs) | Recycle, recover | Collection, product life extension, end of life |
| 152 | Wallner et al. (2024) | Survey | General | | X | Refurbished speakers and earbuds | Refurbish, reuse | Stock, collection, end of life |
| 153 | Wang et al. (2018) | Framework evaluation | China | X | | | Recycle, recover | Product life extension, end of life |

| No. | Source | Methodology | Country | Product type | | | Recovery flows | Value chain stages |
|---|---|---|---|---|---|---|---|---|
| | | | | Generic | Specific | Specific product(s) | | |
| 154 | Wibowo et al. (2021) | SWOT, stakeholder analysis | Indonesia | X | | | Recycle, recover | Collection, product life extension, end of life |
| 155 | Xavier, Giese, et al. (2021) | Literature review | General | X | | | Recycle, reuse | Collection, flow, end of life |
| 156 | Xavier, Ottoni, and Lepawsky (2021) | Literature review, material flow analysis | Brazil | X | | | Recycle, reuse | Collection, flow, end of life |
| 157 | Xu et al. (2021) | Literature review | China | X | | | Recycle, repair, recover | Collection, flow, end of life |
| 158 | Yamamoto and Murakami (2022) | Survey | Japan | | X | Personal computers | Reduce, reuse | Stock, end of life |
| 159 | Yang et al. (2021) | Empirical evaluation, interviews | China | X | | | Recycle, recover | Collection, product life extension, end of life |
| 160 | Zeng et al. (2016) | Material flow analysis, sensitivity analysis | China | X | | | Recycle, reuse, repair, remanufacture | Use phase, collection, flow, end of life |
| 161 | Zlamparet et al. (2018) | Case study | China, Europe | | X | Medical devices, servers | Reuse, remanufacture | Collection, flow, end of life |