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A global review of consumer behavior towards e-waste and implications for the circular economy

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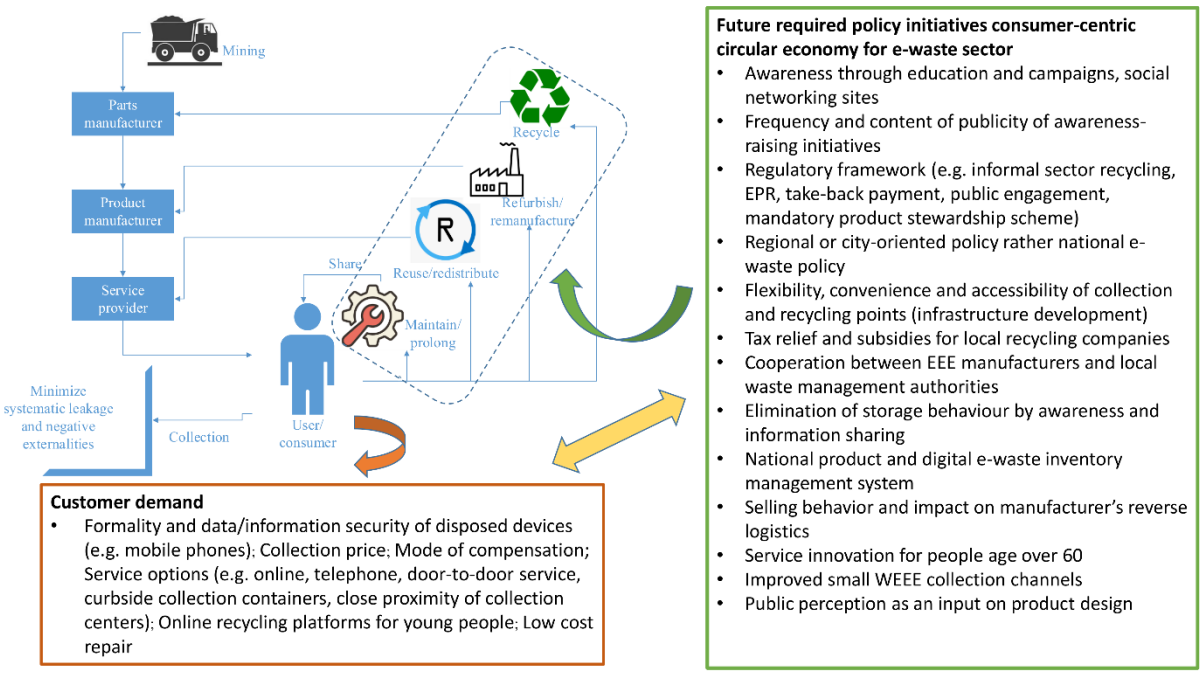
Highlights

- Reviewed 109 scientific articles on consumers' behavior focusing on e-waste.
- Content analysis is implemented to ensure scientific rigor of this review.
- Policy initiatives and potential innovations in business model are discussed
- Research gaps are identified showing future research directions.
- A consumer-centric circular economy framework is illustrated.

Graphical abstract



Abstract

To tackle the alarming increase in e-waste or end-of-life (EoL) electronic products, consumer behavior towards the end of their useful life needs to be thoroughly studied. End users or consumers are the starting point where e-waste starts its journey into several paths within the circular economy (CE), such as repair, reuse, remanufacturing, and recycling. However, e-waste often ends up in landfill due to improper disposal of e-waste with household waste by consumers. Studying consumer behavior allows for the identification of appropriate approaches to achieve CE. Numerous academic journal papers have been published concerning consumers' e-waste-related knowledge and awareness, and behavior on consumption, disposal, storage, recycling, and repair. However, a substantial knowledge gap exists around how understandings of consumer behavior around e-waste may be integrated into the CE model. This article aims to reduce this gap by reviewing 109 research papers published in international peer-reviewed journals identified in the Web of Science (WoS) core collection database, using content analysis methodology to analyze and review the articles. The study aims to provide invaluable input for developing a more consumer-centric CE framework for both policymakers and researchers seeking to advance knowledge and implementation strategies around e-waste. This is the first systematic review of studies on consumer behavior around e-waste, to the best of the authors' knowledge. The study results show that consumers' disposal and recycling behaviors are the two main areas of research interest in the studies reviewed. In contrast, reuse and repair behavior were investigated to a lesser extent. In this study, several research gaps and areas for future research are identified, along with suggestions for a CE framework focusing on the e-waste sector that, encompasses policy initiatives and business model innovations. The identified studies presented here offer a valuable starting point for researchers who are starting to work on consumer behavior-related e-waste research.

Keywords: Consumer behavior, Waste Electrical and Electronic Equipment (WEEE), Sustainable production and consumption, disposal, recycling, literature review

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1. Introduction

1.1 E-waste and circular economy (CE)

The rapid technological revolution, coupled with increasing demand among consumers for high-tech products, has triggered unprecedented levels of electrical and electronic equipment (EEE) consumption. At this moment, there are approximately 900 different types of EEE found in the international market (Forti et al., 2018). However, the electronic waste (e-waste) or Waste Electrical and Electronic Equipment (WEEE) that EEE becomes at the end of its useful life poses a severe challenge to the environment as well as to human health due to the presence of highly toxic substances (Balde et al., 2017). E-waste management (EM) is one of the most pressing problems for today's modern society (Islam and Huda, 2019a), with around 53.6 million tons of e-waste generated worldwide in 2019 and levels escalating rapidly (Forti et al., 2020).

Aside from reducing negative impacts, improved management of e-waste streams represents a lucrative opportunity due to the various precious and rare earth elements it contains (Shumon et al., 2014). The starting point for e-waste is consumers, who determine its destination. As such, for e-waste management to improve, understanding consumers' behavior is central (Saphores et al., 2012).

Parajuly et al. (2019) identified that the consumer is one of the critical elements of the e-waste problem, with demand growth for EEE, consumers' environmental awareness, and behavior being key factors. From the CE perspective, four different paths are associated with consumers, which are (1) maintained/prolonged use, including sharing and repair; (2) reuse and distribution; (3) remanufacture/refurbishment; and (4) recycling (Fig. 1).

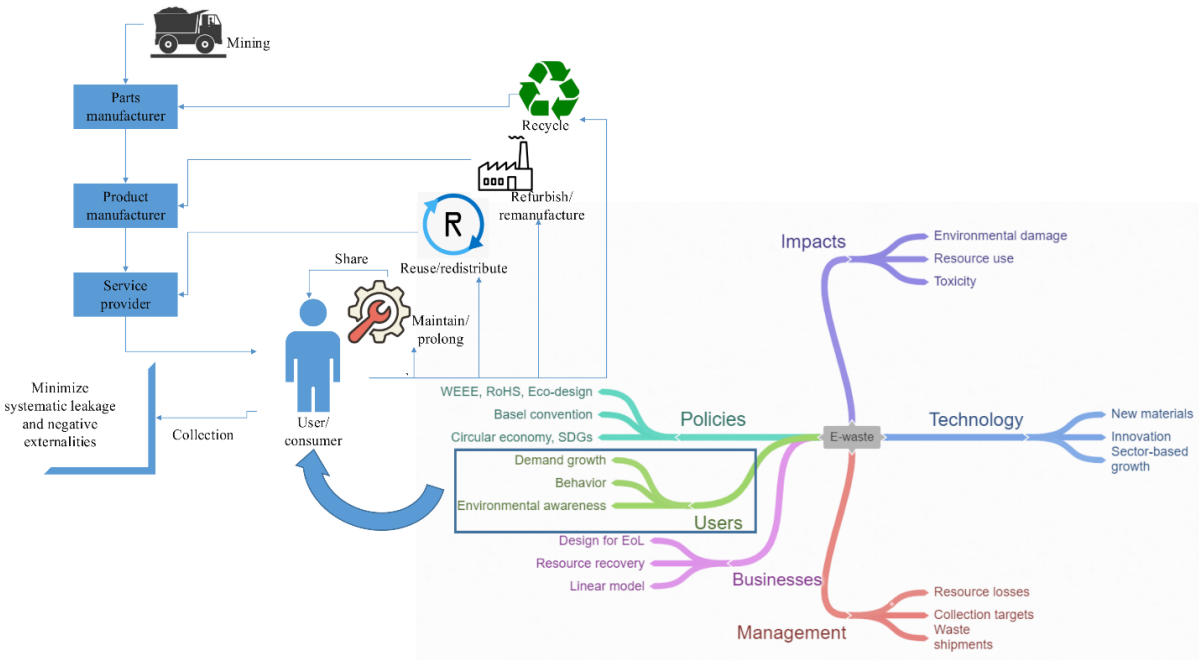

Fig. 1. E-waste, consumers and CE model, adapted from MacArthur (2013) and Parajuly et al. (2019)

CE is "an industrial economy that is restorative or regenerative by intention and design" (Ellen Macarthur Foundation, 2013). Reverse supply chain (RSC), product/service design, business models, EoL recovery, product/service use, and policy are the CE's building blocks (Ellen MacArthur Foundation, 2015). According to Lieder and Rashid (2016), "the definition is more comprehensive as it considers both the environmental and economic advantages simultaneously under the notion of regenerative performance" requiring novel business models that enable the high-quality circulation of technical material or nutrients and safe entry of bio-nutrients or regenerated materials into the biological sphere. Consumers, government, policymakers, charities, private sector investors, digital disruptors (at a multinational or entrepreneurial level), product manufacturers, parts manufacturers, service providers, and stakeholders of recycling industries are the main actors in CE (Ellen MacArthur Foundation, 2015, Infineo, 2020). Fig. 2 shows related factors (central inner circle) of a complex socio-economic system, and the building blocks of a CE. According to Alamerew and Brissaud (2020), the blocks and factors interact in a relatively complicated manner, requiring an interdisciplinary approach to solve problems. In this case, information on legal, economic, social, business, and environmental aspects are particularly critical (Brissaud and Zwolinski, 2017).

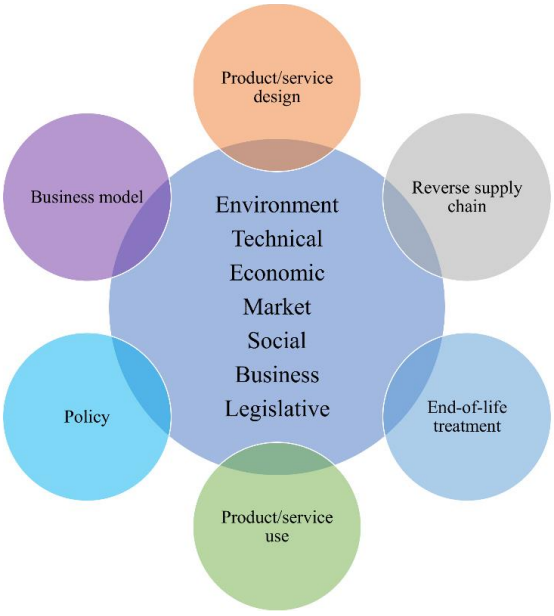

Fig. 2. Building blocks of CE (Alamerew and Brissaud, 2020)

In 1990, e-waste was first considered as a priority waste stream in Europe, and in 2002, the European Union (EU) WEEE Directive was published (Directive, EC 2012). Parajuly and Wenzel (2017) argued that the e-waste stream possesses a high possibility for reuse and valuable material recovery. The Directive imposes strict obligations on producers regarding waste management under the Extended Producer Responsibility (EPR) system (Horta Arduin et al., 2019). More recently, the EU CE action plan works towards "closing the loop" of product lifecycles through sustainable production and consumption and sound waste management (EU, 2019). Due to the diverse range of EEE products, the EU categorized e-waste items into six different segments. Table 1 shows the categories, sample products, and legislative provisions of recovery, reuse, and recycling for the member states.

Table 1. WEEE product categories with targets of EU WEEE Directive 2012/19/EU, adapted from Pérez-Belis, Victoria et al. (2015b), Islam and Huda (2018b) and (StEP, 2019)

Sl. No.	E-waste category	Sample e-waste product	Target	
			Recovered (%)	Prepared for re-use or recycled (%)
1	Temperature exchange equipment	Temperature exchange equipment, more commonly referred to as cooling and freezing equipment: refrigerators, freezers, air conditioners (ACs), heat pumps	85	80
2	Screens, monitors, equip. with surface screens >100 cm^2	Televisions, monitors, laptops, notebooks, and tablets	80	70
3	Lamps	Fluorescent lamps, high intensity discharge lamps, and light emitting diode (LED) lamps	-	80
4	Large equipment (LE)	Washing machines (WM), clothes dryers, dish-washing machines, electric stoves, large printing machines, copying equipment, and photovoltaic panels	85	80
5	Small equipment (SE)	Vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, electrical and electronic (EE) toys, small electrical and electronic (SEE) tools, small medical devices, small monitoring, and control instruments	75	55
6	Small IT and telecommunication equipment	Mobile phones (MPs), Global Positioning Systems (GPS), pocket calculators, routers, personal computers (PCs)/desktop computers (DCs), printers, telephones	75	55

1.2 Research motivation and research questions

In recent times, research related to consumers' awareness of e-waste, consumption, storage, disposal, and recycling behavior has been gaining attention among researchers worldwide. Broadly, consumer behavior

focusing on e-waste can be categorized into several areas: consumption, storage, repair and reuse (R&R), disposal, and recycling (Bovea, M.D. et al., 2018). Knowledge and awareness about the formal collection system among consumers are also critical aspects that determine the sustainability of the system in the socio-economic sphere. Several studies, such as the study by Islam et al. (2020a), Ramzan et al. (2019), Saphores et al. (2007) and others, emphasized the issue. Previously, Borthakur and Govind (2017) published a review article that focused only on consumers' disposal behavior and awareness regarding e-waste, in which other behaviors were not highlighted and reviewed. Thus, a significant knowledge gap exists in understanding a holistic picture of consumers' behavior around e-waste. To the best of the authors' knowledge, this is the first attempt at reviewing consumer awareness and behavior focused on e-waste, considering all the behavioral aspects.

The main research questions (RQs) of the article are:

RQ 1: How do the issues related to consumer awareness and behavior with a particular focus on the e-waste sector contribute to the essential operational framework in achieving a CE?

RQ 2: How can the general understanding contribute to informing policymakers and researchers in identifying future policy measures to be taken and the necessity of performing research studies in the area?

After reviewing the articles on the issues, a consumer-centric CE framework is proposed with policy implications in Section 4. With this, RQ 1 was answered. Based on the in-depth literature review of the selected articles, research gaps were identified, proposing critical future research directions in Section 5, by which RQ 2 was addressed.

2. Research Methodology

According to Easterby-Smith et al. (2012) and Brocke et al. (2009), a literature review plays a critical role in understanding and exploring a specific research field's structure. New theory development and investigation scope could further progress the knowledge base by identifying a useful literature review (Machi and McEvoy, 2016). In this study, the four-steps systematic literature review technique proposed by Mayring (2001) under the qualitative content analysis method is utilized. Fig. 3 shows the four steps process model for the content analysis method consisting of material collection, descriptive analysis, category selection, and material evaluation. Mayring (2014) provided an extensive discussion on the method. Previously, several literature review articles have applied the research methodology to e-waste research (e.g., Wati and Koo (2010), Islam and Huda (2018b), Islam and Huda (2019b), Ismail and Hanafiah (2020), Ismail and Hanafiah (2019), Pérez-Belis, Victoria et al. (2015b)).

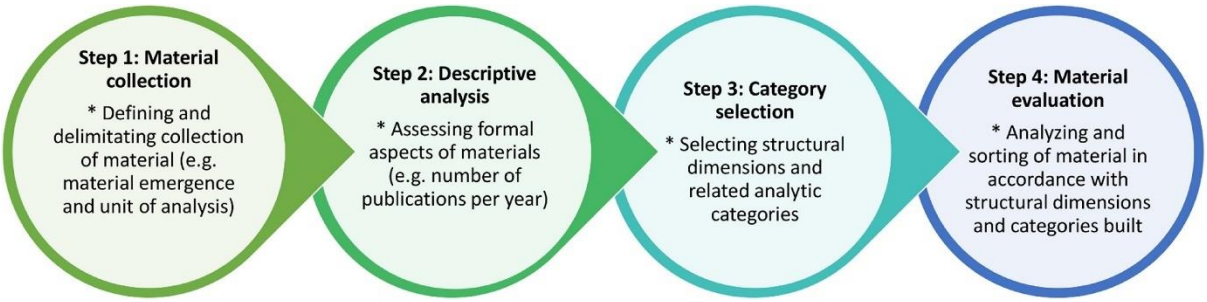

Fig. 3. Summary of the steps involved in qualitative content analysis, adapted from Mayring (2001) cited in Islam and Huda (2018b)

2.1 Material collection

To collect relevant articles that focused only on consumer behavior around e-waste, an extensive search was performed in the Web of Science (WoS) core collection database using "Advanced Search" window. The following keywords were used, which were previously utilized by Islam and Huda (2019a): *"TS=("waste electrical and electronic equipment*") OR TS=("e-waste") OR TS=("E-waste") OR TS=("WEEE") OR TS=("waste electronics*") OR TS=("waste-electronics*") OR TS=("electronic scrap") OR TS=("electronics waste") OR TS=("obsolete electronics*") OR TS=("electronic-waste*") OR TS=("electronic waste") OR TS=("electrical waste") OR TS=("electrical wastes") OR TS=("electronic wastes") OR TS=("waste electrical") OR TS=("wastes electrical") OR TS=("waste electronic") OR TS=("wastes electronic") OR TS=("electronic rubbish") OR TS=("electronic garbage") OR TS=("electrical rubbish") OR TS=("electrical garbage")".*

Here, TS refers to a topic utilized in the database. With these keywords, 4660 articles were found. In this stage, only "articles" (as a document category) and published in the "English" language were considered. Later, "public" OR "consumer*" OR "consumers*" OR "customer*" OR "household*" OR "resident*" OR "residents*" keywords were input in the refine search box of the database that retrieved a total of 907 articles. As the studies need to have a primary survey component as part of the methodology, the keyword "survey" was used in the refined search, which delivered 152 articles. The search was performed on 13 November 2020. Other criteria for selecting the articles were that the methodology section of the article must specify the sample size, sampling technique, and the number of the valid samples (of the participants).

In some cases, a few studies identified through the search involved surveyed stakeholders other than consumers, such as repair technicians, in the study by Sabbaghi et al. (2017). These were excluded from the selection, as the group does not represent consumers. Finally, 109 articles were found that only focused only on consumers' behavior around e-waste. The articles collected in the material-collection stage showed that authors had analyzed more than one issue in most cases. For example, Pérez-Belis et al. (2017) investigated the second-hand purchase and repair behavior of consumers focusing on small IT equipment in which they investigated consumption, R&R and disposal behavior altogether.

2.2 Descriptive analysis

2.2.1 Journal-wise distribution

The selected articles were published in thirty-six different journal outlets. From Fig. 4, it is evident that most of the papers were published in renowned journals such as the *Journal of Cleaner Production*, *Waste Management*, *Resources Conservation, and Recycling* and *Sustainability*. The diversity of the journal outlets publishing papers on consumer behavior related to e-waste shows the necessity of a multidisciplinary approach to analyzing specific behavior-related problems and solutions.

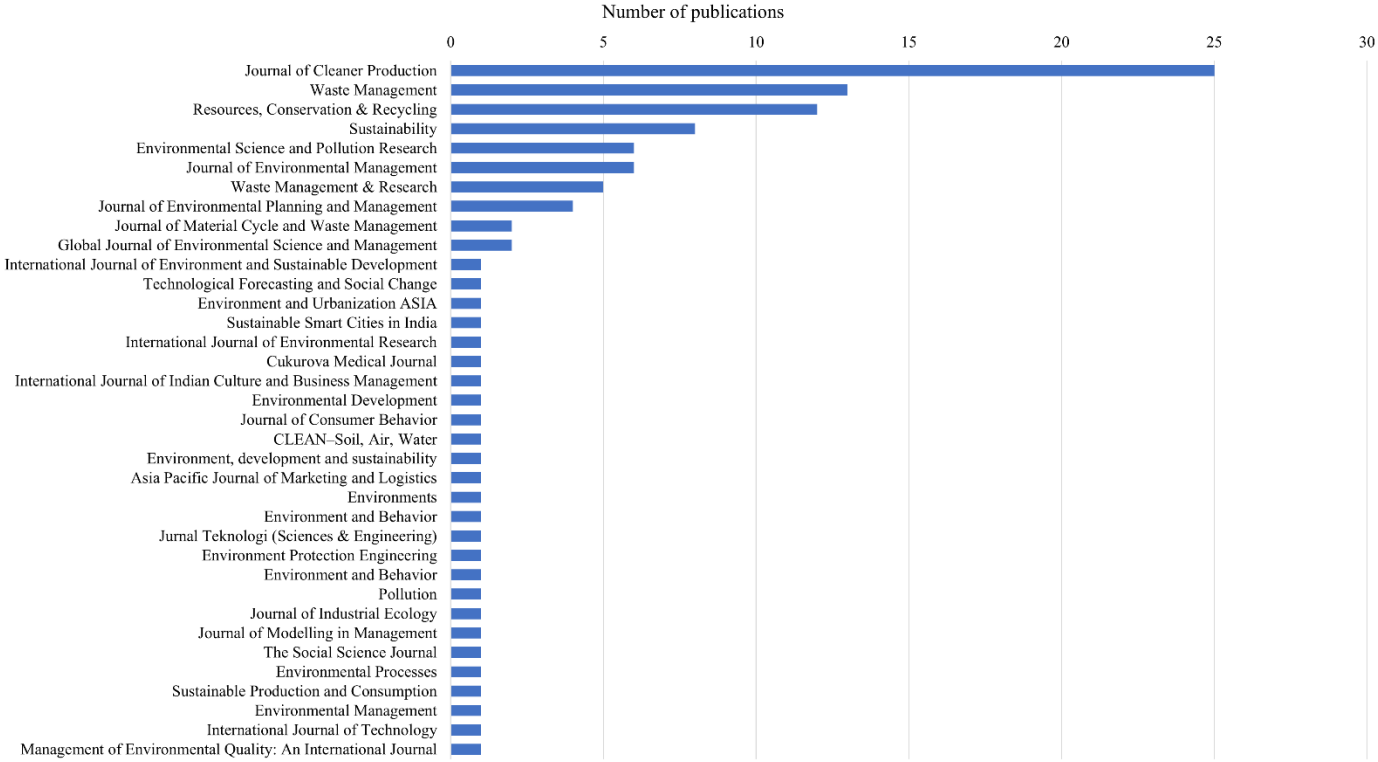

Fig. 4. Number of papers published in journals

2.2.2 Year-wise frequency of publications

Annual distribution of the articles published on the consumer behavior related issues focusing on e-waste from 2005 to 2020 (until 13 November) is shown in Fig. 5. Most of the papers are published in recent years (2017-2020). 40 papers out of 106 papers were published before 2016, while 70 papers from 2017 or later. The highest number of papers were published in 2019. However, it is expected that the trend will continue (due to the increasing interest in the topic), and more papers will be published in the future. One article had a publication year of 2021, as some journals publish online version first and volume and issue numbers are assigned in advance.

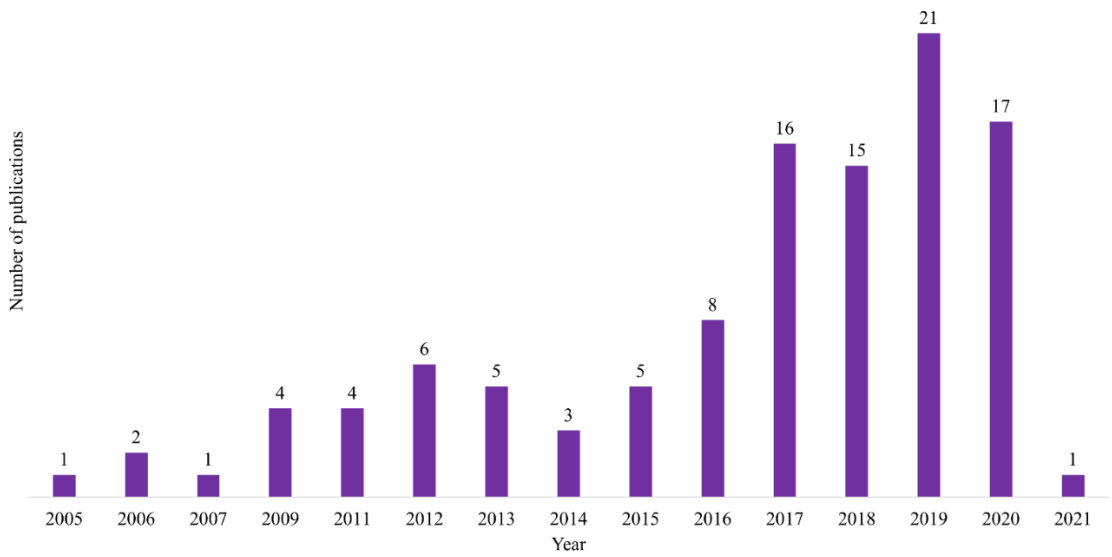

Fig. 5. Annual distribution of published papers (109 papers: 2005 – 2021)

2.2.3 Country-wise article production

Fig. 6 shows the geographical distribution of the studies, in terms of the number of publications focusing on a specific country. China, under the group of developing countries, produced the highest number of articles (26 papers until November 2020), and this number is higher than the number of papers published by some of the countries from developed nations such as the USA (10 articles) and Spain (6 articles). Malaysia (5 papers), India (9 papers), and Brazil (5 papers) were some of the other developing countries in which consumers' behavior was studied. Even though e-waste is a global environmental problem and consumer behavior is an important factor for e-waste impacts, surprisingly, consumer behavior was studied in relatively few countries. For instance, from Australia, there are only two academic papers published on the issue in 2020.

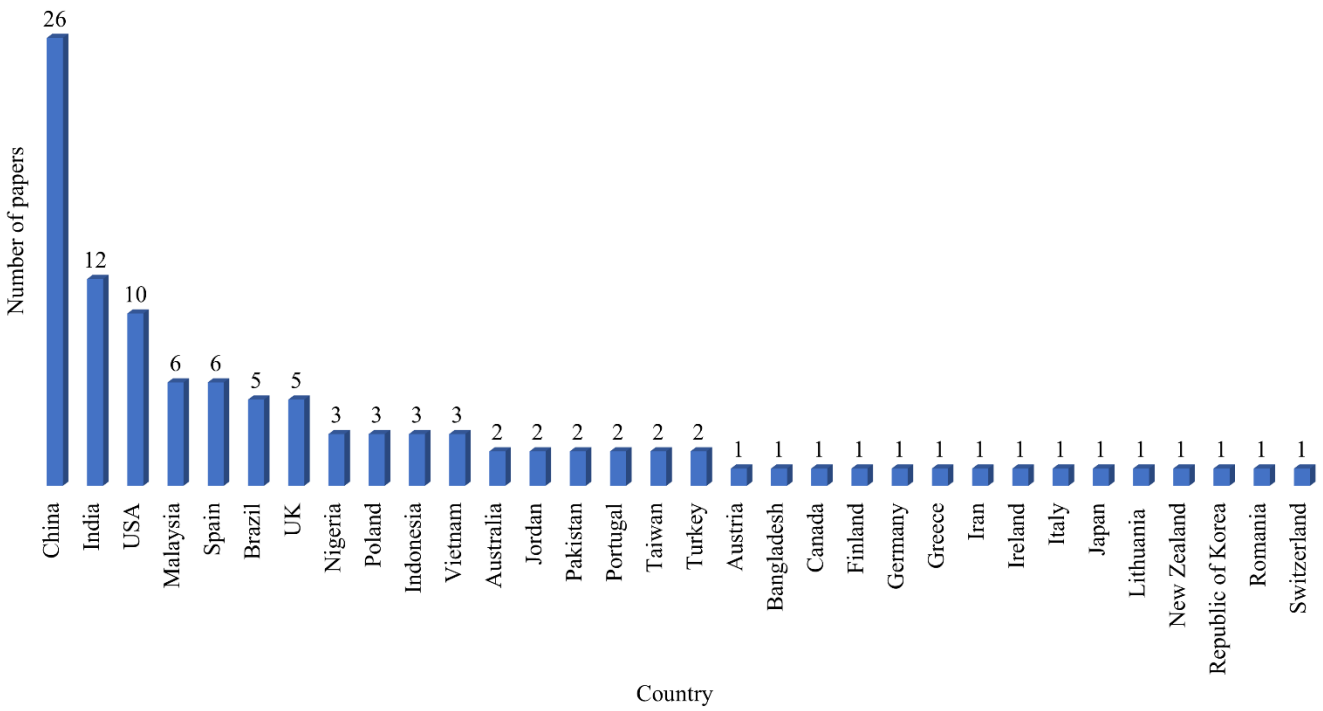

Fig. 6. Geographical distribution and number of articles published by the countries

2.2.4 Product diversity in papers

As consumer behavior varies substantially according to the categories of the products and specific product use, Fig. 7(A) shows the diversity of the products discussed in the selected articles. MPs (over 45%) were the most widely discussed topic in the consumer behavior related e-waste research (identified by analyzing the papers), followed by DCs (over 25%) and liquid crystalline displays (LCDs) (25%). In 24 papers, e-waste was not categorized; here, it is considered "e-waste in general," which is not shown in Fig. 7.

Fig. 7(B) shows the distribution of the articles as per product categories presented in Table 1. SITTE (39%) products were most frequently considered, followed by SE (29%).

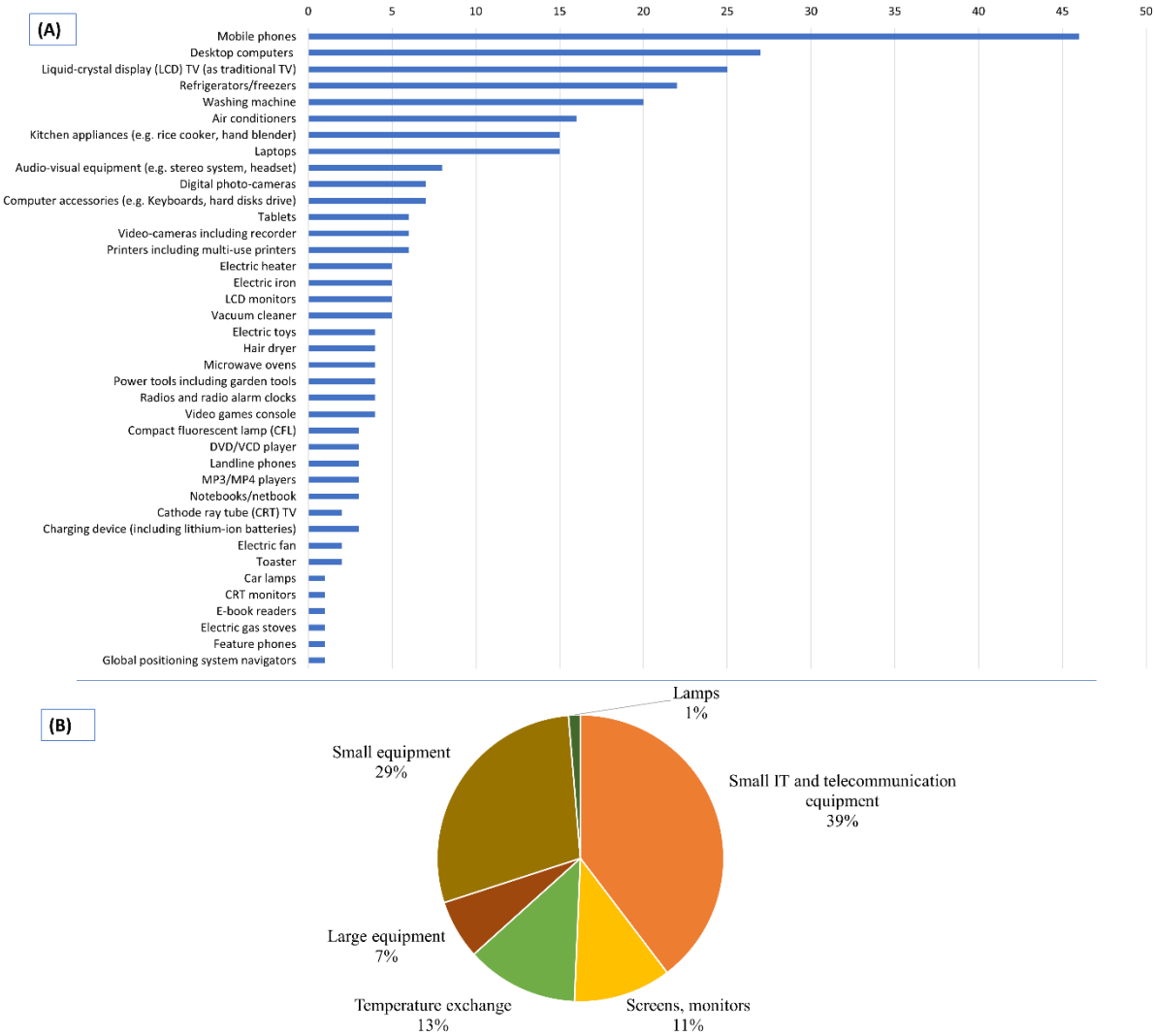

Fig. 7. Major e-waste considered in the papers (A) product (in %) and (B) category according to EU WEEE Directive (in %)

2.2.5 Distribution of research papers by methodology

In terms of research methodology (Fig. 8), the most frequent methodology was statistical (57%), followed by theoretical (17%), analytical (14%), survey (9%), and case study (3%). In Section S1 of the supplementary information (SI) of the article, details are given on utilized methodology. Although in this review article, articles that conducted surveys were selected, the "survey" as the research methodology category refers to the specific methodology that is directly connected with the data analysis technique. For example, the Contingent Valuation Method (CVM) is a survey-based economic technique (market research methodology) implemented mainly for assessing consumers' willingness to pay. Studies following this methodology are grouped under the survey category. Quasi-ethnographic approaches, direct waste analysis, and word of mouth research methodologies fall under the "case study" category.

Theory of Planned Behavior (TPB) is one of the dominant theories used in the analysis technique coupled with structural equation modeling (SEM). SEM is a combined statistical technique consisting of multiple regression, path analysis, and factor analysis. Ajzen (1991) first postulated the TPB, and later several extended versions of the theory have been implemented in marketing research. This evolved out of the "Theory of Reasoned Action," which states that intentions are the best predictors of behaviors. The central premise of TPB is that something is more likely to be done if there is a plan to do it. According to TPB, intentions are the product of three different processes, (1) behavioral attitudes, (2) subjective norms, and (3) perceived

behavioral control. Papers that applied TPB, particularly in e-waste-related consumer behavior research, are presented in the Appendix in Table A2, and the primary constructs and their interrelations are shown in Fig. A1.

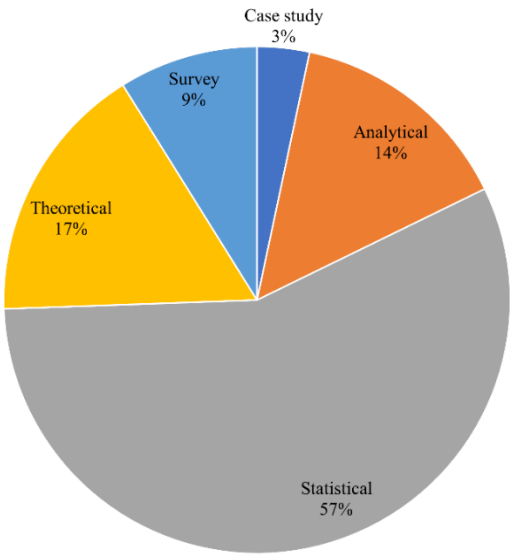

Fig. 8. Distribution of research methodologies of the selected articles

2.2.6 Primary data collection and analysis techniques

As mentioned earlier, in the selection criteria of the papers to be included in this article, a study must contain a survey component in its research methodology. After analyzing the data collection technique (DCT) of the papers (Fig. 9), it is found that face-to-face interviews (FTFI) were implemented by 24% of the articles, followed by paper-based surveys (PBS) (22%) and online surveys (21%). Approximately 13% of the articles mentioned that a survey was performed; but did not explicitly mention any specific DCTs. In some cases, multiple DCTs were also observed; for instance, around 6% of the articles used both PBSs and FTFIs.

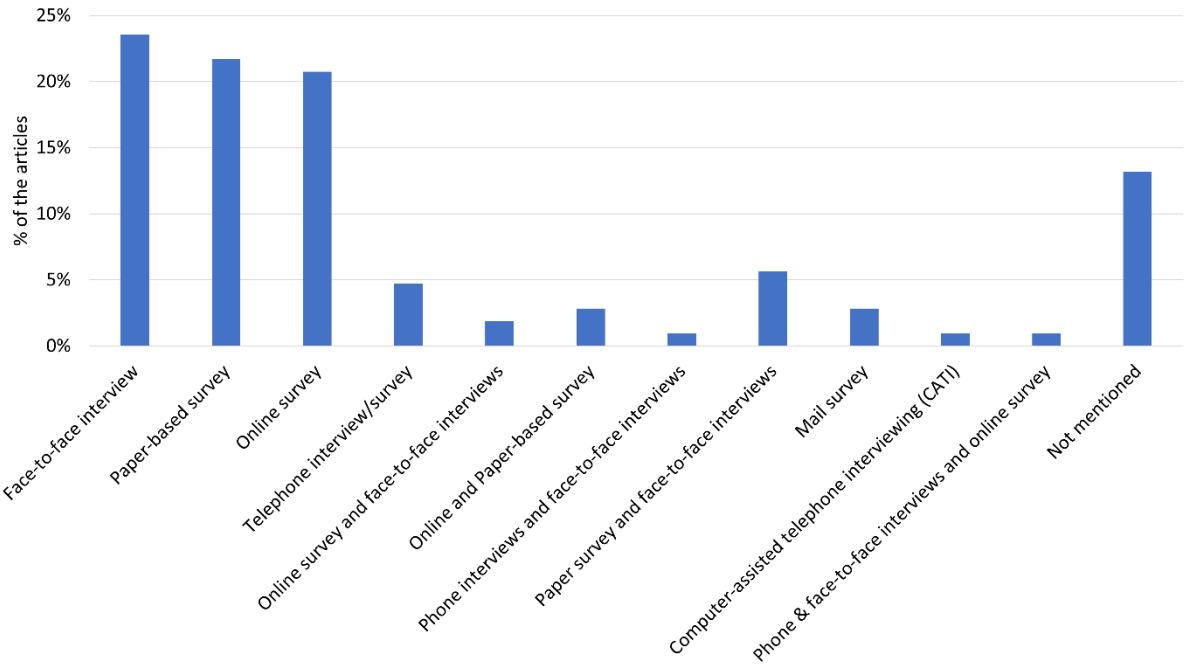

Fig. 9. Data collection techniques of the articles

2.3 Category selection

The main categorization of the content of this article and the research framework is presented in Fig. 10. As mentioned in the material collection section, the literature is classified into six major research types/categories. These six categories are (1) knowledge, awareness, and familiarity about formal e-waste collection and recycling systems; (2) consumption behavior (CB); (3) storage behavior (SB); (4) R&R behavior; (5) disposal behavior (DB); and (5) recycling behavior (RB).

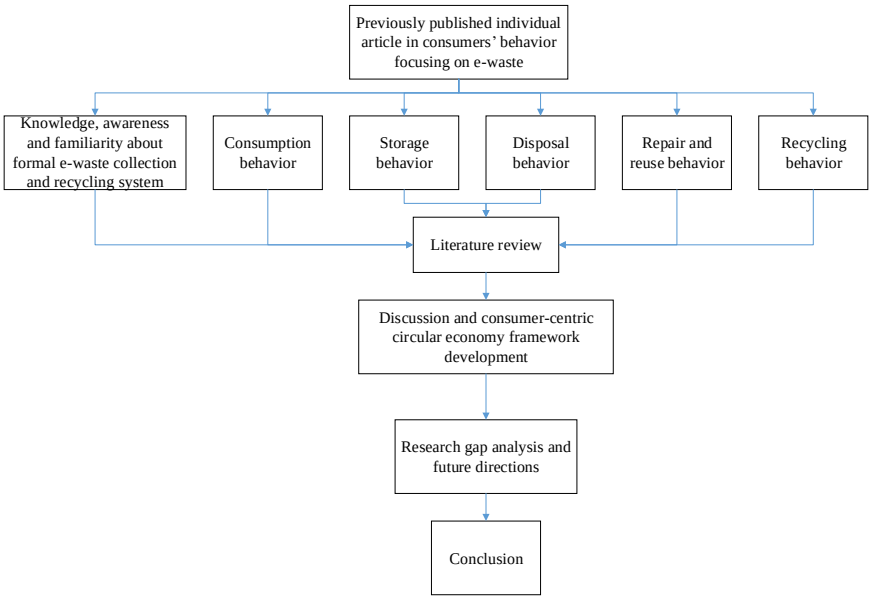

Fig. 10. Categorization and research framework of the studies

The distribution of the research articles for six different categories is shown in Fig. 11, with details of individual papers in Table S1 (in the SI). Disposal behavior was most commonly-assessed (26% of the publications), followed by consumption behavior (20%) and knowledge and awareness (19%). In contrast, recycling, storage, and repair /reuse behavior were less commonly studied, which illustrates the need for future exploration of these areas.

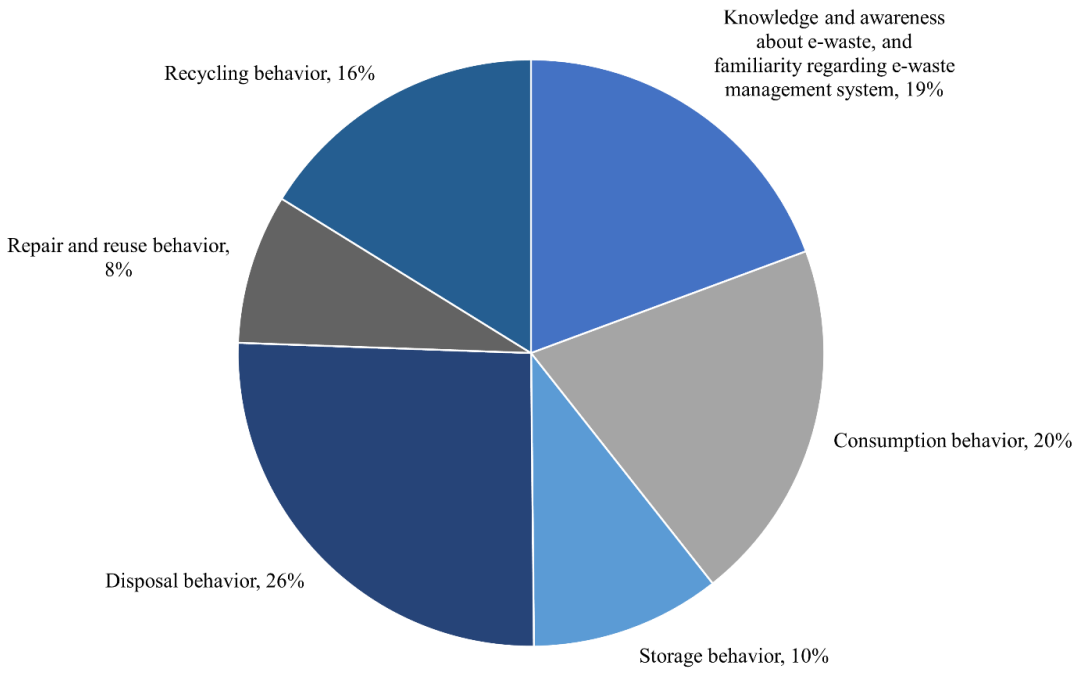

Fig. 11. Distribution of research articles for different categories

2.4 Material evaluation

Using inductive and deductive approaches simultaneously, two researchers performed a validity test as the last part of the content analysis process. The reliability of the content was measured by both intra-rater reliability and inter-rater reliability. After the material collection, all necessary data have been extracted as per categories and subcategories identified by the researchers and input in a Microsoft Excel™ spreadsheet to avoid repetition error. In the WoS database, the same keywords were utilized to search articles, producing similar results with the correct articles. This is how reliability was established. Over time, a few articles were added to the database. NVivo version 12 plus was utilized in some places, identifying specific content and subsequent analysis and for cross-referencing purposes. This is how the validity of the content has been achieved.

3. In-depth analysis of the literature

3.1 Consumers' knowledge and awareness regarding e-waste and familiarity of collection and recycling system

Response from the consumers regarding "what e-waste is" and "the negative health impact of e-waste" fell under the category of "general awareness," and these specific questions were investigated by around 19% of the articles. Rather than developed countries, this issue was mainly highlighted in the articles published from the developing countries. Associated issues that come under the category of consumers' knowledge and awareness are reviewed in the subsequent subsections.

3.1.1 Understanding and perceptions of e-waste

Generally, mature adult consumers consider e-waste to create negative environmental impacts (Afroz et al., 2013, Siringo et al., 2020, Tan et al., 2018), even young consumers (Islam et al., 2020b, Ramzan et al., 2019); however, some studies indicated that level of awareness related to this is still substantially low (Awasthi and

Li, 2018, Borthakur and Govind, 2019, Ravindra and Mor, 2019, Saritha et al., 2015), even sometimes people do not consider e-waste as dangerous and toxic (Pandebesie et al., 2019).

Lack of information related to e-waste was found to be one of the critical aspects that need to be disseminated (Gök et al., 2017), as often e-waste recycling-related activities and consumers' role is unclear (understood as complicated and time-demanding task). This scenario prevails both in developing and developed countries, for example, by Saphores et al. (2012) in the USA, where the authors found that consumers were unwilling to transfer the waste to proper recycling facilities. Limited e-waste toxicity knowledge often creates barriers adopting environment-friendly products. Darby and Obara (2005) mentioned that consumers demanded more information on where they can recycle their small WEEE instead why they should recycle. In an e-waste take-back system, lack of awareness, insufficient information, and socio-demographic factors (e.g., age, gender) significantly affect consumers' motivation to return e-waste (Botelho et al., 2016).

There are also other behavioral factors associated with the motivation to adopt environment-friendly practices, and Siringo et al. (2020) found that moral norms, environmental beliefs, and social pressure significantly affect performing (or willingness to perform) appropriate activities, such as recycling. Liu et al. (2019) even urged for a fundamental change in the environmental awareness and behavior. Environmental beliefs largely influence willingness to pay (WTP) to develop a sustainable EM system, even if recycling convenience is limited (Nixon et al., 2009). Nguyen et al. (2021) mentioned that end-user's willingness to participate in recycling programs, laws and regulations, inconvenience of recycling, and experience were four key factors that indicated WTP for e-waste recycling. Adequate environmental knowledge could lead to stronger environmental belief, and Saphores et al. (2007) found that environmental knowledge was a significant predictor of WTP for environmentally friendly products. Several authors suggested that consumers' awareness-raising programs should be organized (Saritha et al., 2015).

3.1.2 Lack of e-waste-related awareness – the consequences

Due to lack of knowledge, informal sector collectors and recyclers got an advantage and became more influential. For example, Islam et al. (2016) found that 30% of the households preferred to sell their e-waste items to local scrap collectors or even throwing e-waste with household waste, as indicated by Pasiecznik et al. (2017)'s study in which 12% of respondents (mostly young consumers) did so. For a formal system (developed and prepared as per environmental guidelines), 'weak environmental protection awareness' and limited knowledge of recycling channels results in a low collection rate, which is a loss in investment. Low-level of awareness could also influence personal beliefs. For example, Fraige et al. (2012) found that 11% of consumers believed that they could dispose of WEEE with household waste. Product-specific waste collection, for instance, in the case of waste mobile phone (WMP) recycling, low awareness levels, and inadequate recycling abilities were considered as main obstacles (Liu et al., 2019).

Furthermore, hibernating behavior (storing e-waste) could evolve due to little e-waste knowledge. Storing e-waste at home, a general practice (Borthakur and Govind, 2019), is nothing but stockpiling material resources in the whole supply chain or the built environment. Bai et al. (2018) particularly mentioned that perception regarding resource conservation effort (which was not well-recognized) needs to be more understood by the consumers.

3.1.3 Familiarity of collection and recycling programs

The familiarity of the formal collection and recycling system (C&RS) is critical for a system's overall long-term sustainability. Often such awareness, especially location of the nearest e-waste collection points, was found limited (Borthakur and Govind, 2019, Cao et al., 2018, Gu et al., 2017, Ravindra and Mor, 2019) or even any e-waste recovery programs in city area such as Bangalore, India (Awasthi and Li, 2018), Hong Kong, China (Deng et al., 2017), Sydney, Australia (Islam et al., 2020b), although in some cases, related e-waste knowledge was present. Environmental consciousness among young university students is expected to be higher than the general population, as seen by Dhingra and Maheshwari (2018) and Ramzan et al. (2019), and Islam et al. (2020b). Publicizing information regarding formal C&RSs was found to be critical in several studies (Cai et al., 2020, Park et al., 2019, Yin et al., 2014, Ylä-Mella et al., 2015), while Wang et al. (2018)

disagreed with that. Due to the lack of appropriate information regarding collection points, Colesca et al. (2014) found that 43.48% of the respondents dispose of their e-waste via other pathways such as landfills. Information dissemination on the collection schedule was also critical (Nowakowski, 2016). Miner et al. (2020) mentioned that community-based interventions to improve awareness levels have significance.

Dagiliūtė et al. (2019) mentioned that despite self-reported awareness, consumers were not familiar with the various classifications of e-waste (category of EEE) under the national EM of Lithuania. Among the various categories of e-waste, SE has a relatively shorter lifespan, and Echegaray (2016) found that the products' expected lifespan decreases with the electronic device's portability. Cao et al. (2016) concluded that most consumers could not differentiate between formal and informal sector e-waste collection channels. Chi et al. (2014) mentioned that despite the higher economic benefits of old-for-new (OFN) collection schemes, 60.7% of respondents in their survey did not know about the price differences with other collection channels. Martinho et al. (2017) mentioned that environmental consciousness existed among Portuguese consumers, however, due to a lack of knowledge about recycling campaigns/programs, such moderately familiar aspects failed to capitalize on the higher collection and recycling rate of waste tablets and MPs.

3.1.4 Impact of socio-economic factors on consumers' e-waste knowledge and awareness

In India, Singh et al. (2018) found that respondents with higher educational qualifications had higher awareness about e-waste. Similar results were also found by Shaikh et al. (2020) in Pakistan. Nowakowski (2019) identified the factor as influential in Poland. Islam et al. (2020a) found that age, household size, and income were significantly associated with recycling program familiarity, while Milovantseva and Saphores (2013a) found gender and age. Regional distribution of EEE use and gender are vital attributes to a successful e-waste management system (EMS). Bhatt et al. (2017) found that most women from Delhi and NOIDA were more cognizant of the environmental issues related to e-waste. However, Miner et al. (2020) mentioned that respondents' socio-demographic characteristics had no significant influence on the levels of awareness, knowledge, and willingness to participate in the EM programs and extended producer responsibility schemes.

3.1.5 Awareness improvement techniques

Arain et al. (2020) suggested that e-waste educational campaigns should inform consumers on what constitutes e-waste and why it is essential to ensure proper recycling. Saphores et al. (2006) mentioned that providing education to young people and making e-waste sites convenient (similar to the curbside collection program for other recyclable products) for older people were crucial aspects of participants' willingness to recycle. Song et al. (2012) mentioned that despite general hazard perceptions among consumers regarding e-waste, educational campaigns should be promulgated specifically for reuse and recycling. Environmental protection and resource conservation-related education should be given at an early stage, creating recycling habits.

Jafari et al. (2017) contend that the focus of awareness-raising campaigns should be on college students, higher-income households, and married residents. Young consumers in a developing country, such as China, believe that EM is a shared responsibility of different stakeholders, including consumers, the government, manufacturers, and sellers (Ramzan et al., 2019). Huang et al. (2006) also found that respondents are willing to share environmental responsibilities around e-waste in China and similar perceptions exist amongst Australian consumers (Islam et al., 2020b). Kumar (2019) mentioned an opportunity to influence and propagate pro-environment behavior amongst young adults through university programs. Table S2 presented in the SI shows various solution techniques proposed by the reviewed articles' authors improving consumer awareness.

3.2 Consumer behaviors

Various consumers' behaviors were analyzed in the selected articles. The articles were categorized into five different consumer behavior types, as shown in Fig. 11 (consumption, storage, disposal, repair/reuse and recycling), which are discussed in the following sub-sections.

3.2.1 Analyzing consumers' consumption behavior

"Consumption behavior" was one of the significant topical issues researched by over 20% of the selected articles. Measurements applied to understand behavior included the number of appliances in households, average ownership of household appliances, average lifespan of EEE, reasons for replacing EEE and, frequency of replacement. Factors affecting consumption behavior are discussed below, including growing device penetration rate, source of device acquisition, factors-related to purchase decision, device-specific product ownership, reasons and trend of device replacement, and product lifespan. A detailed summary table of the consumers' consumption-related studies is presented in Table S3 in the article's SI. In the last column of the table (category), articles were mapped according to their discussion area.

3.2.1.1 Growth of device penetration rate – the reasons

The consumption of AC is influenced by climatic conditions to a greater degree than other products such as PCs (including DCs and laptops), TV sets, refrigerators, and WMs (Cai et al., 2020, Chung et al., 2011, Song et al., 2012). During the Christmas season, consumption of electrical and electronic toys increases (Pérez-Belis, V. et al., 2015). On the other hand, new government initiatives in ICT knowledge and skill dissemination program showed a positive trend in higher device usage. Similarly, Rodrigues et al. (2020) identified that the government incentive program accelerated computers and printers' penetration rate. The major contributing factors to high penetration and replacement rates were the rapid economic growth of a country (Bhatt et al., 2017, Huang et al., 2006, Nguyen et al., 2009), the income of growing consumer segments, and the competitive market for electronic products (Arain et al., 2020, Cai et al., 2020, Shaikh et al., 2020), affordable fast-pace technological innovation and price (Afroz et al., 2012, Arain et al., 2020, Bhatt et al., 2017), local manufacturing base (Afroz et al., 2012), ever-increasing consumer demand (Cai et al., 2020), poor electronic repairability coupled with shorter product lifespan (Arain et al., 2020). High-tech device penetration, such as PCs, now becomes an indicator of a city's economic and cultural development (Li et al., 2012). Among large equipment, the most consumed products are washing machines, air conditioners and refrigerators (Cai et al., 2020, Nguyen et al., 2009). Chi et al. (2014) mentioned that, except for mobile phones, per capita consumption for large equipment was higher than small equipment such as camcorders and printers. On the other hand, a high device replacement rate indicates consumption patterns and future EG (Arain et al., 2020, Fraige et al., 2012).

3.2.1.2 Factors-related to purchase decision

Consumers prefer to buy cheap (nonbrand) electronics, despite a shorter lifespan (Othman et al., 2015). Comparative price (Afroz et al., 2012, Gök et al., 2017, Islam et al., 2016), warranty period, brands, and installment facilities were also found as critical criteria during product purchase (Islam et al., 2016). Recommendations from friends and, store promotion were some of the motivating factors behind purchasing decisions (Afroz et al., 2012), while Huang et al. (2006) found that "launching of new products with more powerful designs and extended capacity" and "the increasing purchasing power" were the main reasons for new product purchase.

Some studies introduced a hypothetical green product to assess consumers' WTP or willingness to buy (WTB). For example, Nnorom et al. (2009) and Milovantseva (2016) populated the concept of "green phones" that do not contain any hazardous substances and can be disposed of with regular household solid waste. The products' purchase and use intentions were found to be positive, despite discrepancies about extra money (Saphores et al., 2007). The primary enablers for green product purchase and WTP for such products were environmental attitude (improving local environment), resource (money or wealth), ease of use, and product eco-labeling (Huang et al., 2006, Nnorom et al., 2009, Sheoran and Kumar, 2020). Milovantseva (2016) found that consumers who had a positive attitude towards recycling small electronics had significant environmental beliefs. Importance of environmental product labeling was critical especially, for informed decision-making of the consumers (Bovea, M.D. et al., 2018, Huang et al., 2006).

Tu et al. (2018) found that brand recognition, service quality, usage period, and perceived prices are the most significant characteristics of "iPhone" as a MP brand. For purchase motivation, "recognition" and "brand advantage" were the factors. In contrast, "recognition," "brand advantage," and "service quality" were essential factors for brand loyalty, and "perceived price" was necessary for purchase intention. Authors also found that female respondents were more inclined towards "recognition," "brand advantage," and "perceived price" than their male counterparts. Simultaneously, the level of income was the critical socio-economic variable for the factor "perceived price." The factor also influenced the consumers' purchase intention. Bai et al. (2018) reported that consumers tended to purchase mobile phones more frequently, and the service life of mobile phones was decreasing dramatically, with phones most commonly purchased brand new through official channels.

Echegaray (2016) and Li et al. (2012) showed variable ownership levels for different appliances, with MPs having the highest per-capita consumption and, DCs the lowest. Similarly, Araujo et al. (2017) observed that mobile phone ownership was higher than other LE such as WMs, ACs, and SE such as tablets and DCs. In India, Borthakur and Govind (2019) that the number of the out-of-use mobile phone was equal to or higher than the number of in-use mobile phones. Bai et al. (2018) identified that more than two MPs were possessed by the majority of the consumers in China. Martinho et al. (2017) identified that smartphone usage is higher than tablets in Portugal. Consumers with high income and education tended to acquire more high-tech equipment, such as MPs, plasma TV sets, PCs, and ACs (Cao et al., 2016, Nguyen et al., 2009, Song et al., 2012) in China and Vietnam.

3.2.1.3 General product-focused trend

Rodrigues et al. (2020) found that the device acquisition (possession) period was higher for white goods but smaller for SE and screen categories. Zhang, L. et al. (2019) mentioned that product functionality is shifting towards more portable devices (e.g., DCs' functions could be replaced by tablets and laptops and digital cameras by mobile phone). A stationary device such as a PC requires fewer updates among the students. Borthakur and Govind (2019) identified that between computers and MPs, the latter is replaced more frequently than the first one among the Indian consumers. For example, within 2–3 years, MPs were replaced, and for computers, it was every 3–4 years. However, beyond four years, none of the devices were used.

3.2.1.4 Reasons for device replacement

The reasons for product replacement could be broadly categorized as malfunction, technological obsolesce, and, demand for additional features (Sabbaghi and Behdad, 2018). Consumers' perceived obsolescence is characterized by physical and technological obsolescence. The first two reasons were more evident in European developed countries, and the last one is seen from the developing country's context. Furthermore, due to demand for additional features, the product itself became obsolete and in that case, replacing a new item was the only option that consumers had. Wieser and Tröger (2018) revealed that perceived obsolescence is the primary motivation for mobile phone replacements and the defective device was the main reason for replacement. Perceived obsoleteness was the main reason for replacement rather than "desire for a new phone". Logics of technological change and fashion were the determinants of replacement.

Articles discussing for product replacement identified multiple reasons, which varied between products. The fast advancement of technology, function, and application availability was critical for MPs (Bai et al., 2018). Among the various reasons, "broken down"/malfunctioning device/damaged" was found as the main reason for device replacement regardless of the product types (Borthakur and Singh, 2020, Islam et al., 2020a, b, Martinho et al., 2017, Miner et al., 2020, Ongondo and Williams, 2011, Pérez-Belis et al., 2017, Rodrigues et al., 2020, Shaikh et al., 2020, Tan et al., 2018, Yin et al., 2014). Pandebesie et al. (2019) discovered that the unstable electrical voltage was the main reason for products malfunctioning in Indonesia. It is a common phenomenon in developing countries.

Among the other (secondary) reasons, lack of accessories of SE (Pérez-Belis et al., 2017), upgrade from network operator, longer battery life, fashionable, music storage, picture storage for MPs (Martinho et al.,

2017, Miner et al., 2020, Ongondo and Williams, 2011), new system requirements by software applications for DCs (Islam et al., 2016), old design and backdated functionalities (Afroz et al., 2012, Martinho et al., 2017, Shaikh et al., 2020, Yin et al., 2014), stolen (Liu et al., 2019, Miner et al., 2020, Shaikh et al., 2020), lost (Tan et al., 2018), completely destroyed (Tan et al., 2018), service lifetime exceeded (Tan et al., 2018), market introduction of newer designs (Miner et al., 2020), "influences by others (e.g., through advertisement, friends and trend)" (Afroz et al., 2012) were found critical among consumes. Distribution of the reasons for replacement is shown in Fig. 12.

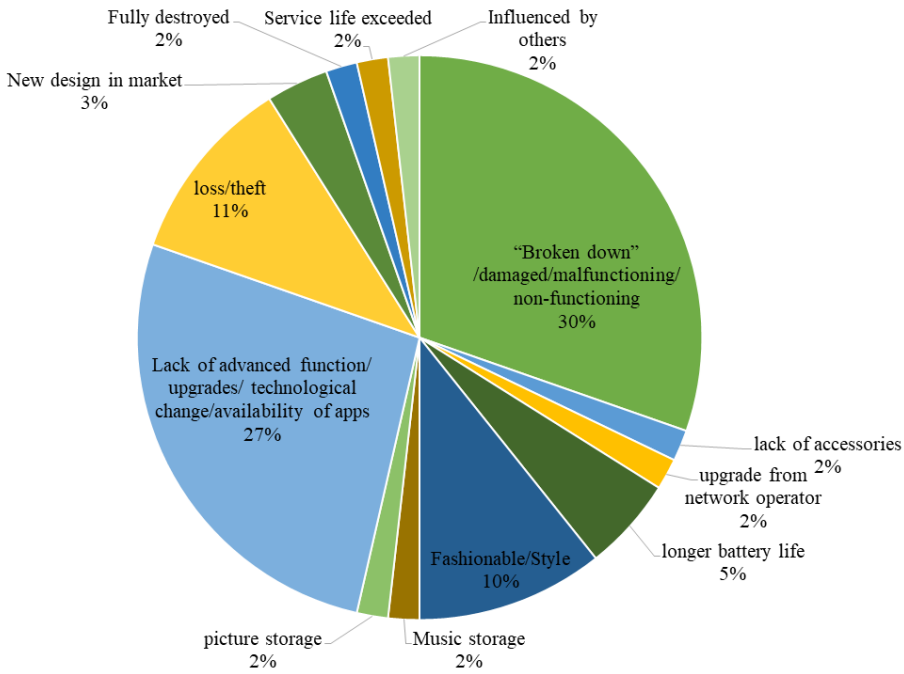

Fig. 12. Top reasons for device replacement

In some studies, fashion pursuit (Cao et al., 2016, Liu et al., 2019), "additional and more advance technological features" (Afroz et al., 2012, 2013) were selected as the main reason for device replacement. Borthakur and Singh (2020) found that consumers tended to buy new phones even though their old phone is still working, with fashion and status often driving such behavior around mobile phones (Shaikh et al., 2020, Yin et al., 2014) and small equipment such as MP3/MP4 players and notebooks (Cai et al., 2020, Rodrigues et al., 2020). Such high device replacement rates can indicate future EG (Arain et al., 2020, Fraige et al., 2012). On the other hand, Shaikh et al. (2020) mentioned that consumers from Pakistan tended to buy new EEE due to their needs, not for luxury, regardless of the new product introduction in the market.

3.2.1.5 Factors affecting device replacement

Ongondo and Williams (2011) found that among the various parts of a mobile phone, replacing batteries was the most frequent activity among students for which the device was replaced. New device purchases do not necessarily depend on products being malfunctioned; instead, consumers demand improved quality or capacity. Echegaray (2016) identified that "technical failure" serves as a proxy indicator for product obsolescence, and this is observed as a tangible reality for all individuals. Milovantseva and Saphores (2013a) found that getting a more recent model is their primary motivation for replacement in the case of MPs. However, replaced phones were still in working condition and hold economic value.

Nowakowski (2016) mentioned that the time to replace LE is higher than SE. Jayaraman et al. (2019) found that computer literacy had a significant moderation effect on laptop usage. If a user has a relatively high

knowledge of using laptops, then there is a high probability that device replacement would occur after active use.

3.2.1.6 Perspectives of young consumers

Ongondo and Williams (2011) identified that young consumers' age was not associated with the frequency of mobile phone replacing and the number of phones stockpiled by students. Islam et al. (2020b) found that the "number of items in use" laptops, television sets, and DCs were significantly associated with age, income, and household size of young consumers in Australia. Around 28% of the students changed their MPs every year. Besides device failure, mobile phone replacement because of the upgrades from network operators was dominant, and this should be considered the planned obsolescence. The young consumers' lifestyle was found responsible for the shorter lifespan of MPs (or the damage of the phones). Although limited, a small proportion of the students changed their MPs due to fashion pursuit. Wieser and Tröger (2018) found that the definition of "up-to-datedness" of a mobile phone varied. For example, old respondents perceived that their MPs were not technologically or aesthetically obsolete, opposite to the young.

3.2.1.7 Product-lifespan

Product lifespan-related articles are summarized in Table 2.

Table 2. Summary of product lifespan-related articles

Discussion focus	Reference	Summary
MPs	Abbondanza and Souza (2019)	• MPs are the fastest growing e-waste items than CRT monitors, refrigerators and freezers, and CRT TVs
	Cai et al. (2020)	• On average, consumers use MP for 6 hours per day
	Borthakur and Singh (2020)	• Although the potential life span of a mobile phone is around ten years, the present-day scenario is such that people will not use their phone longer.
	Bhatt et al. (2017)	• Consumers in different parts of India is also changing their MPs in 1-2 years.
	Thiébaud et al. (2018)	• MPs' service life is often connected to mobile phone contracts. Consumers' expected service life for MPs was four years, while, MPs became obsolete (no longer in use) after three years.
	Liu et al. (2019)	• The lifespan of MPs was considerably shorter than the technical life expectancy and reduced from 3 years to 1 year (within the analyzed period 2011-2018)
	Cai et al. (2020)	• MPs' service life is longer than the average life that included storage time
	Jayaraman et al. (2019)	• Modular repair work, for example, a broken screen of a mobile phone, could extend the product lifespan.
	Ongondo and Williams (2011)	• Network operators' motivations and management strategies were identified as one of the undiscovered investigations, with operator promoting a culture of quick new technology obsolescence and product upgrades, with this seen as necessary for network providers to retain consumers

Comparison between small and LE	Botelho et al. (2016), Cao et al. (2016), Chi et al. (2014), Echegaray and Hansstein (2017), Ravindra and Mor (2019)	• Small IT equipment such as MPs, digital camcorders has a shorter lifespan (consumers changed every 2-3 years) than screens and LE such as TV sets, WM, and refrigerators
	Nowakowski (2016)	• The average lifespan for refrigerators was higher than for TV sets and WMs.
	Islam et al. (2016)	• Frequent repairing for refrigerators and TV sets was an economic burden for consumers, but essential to reach consumers' expected product lifespan rather than extend product lifespan
		• most EEE used by the households were phased out within the product lifespan, and devices were updated within two-thirds of the products' designed lifespan. TV sets and computers were notable.
		• the average lifespan of devices was three years, and old portable electronic devices have been replaced three times within the device ownership period
Factors associated with product lifespan	Zhang, L. et al. (2019)	• The product lifespan of SE is shorter among university students than the general population
	Shaikh et al. (2020)	• Lifespan of flat panel television, routers and modems, laptops, notebooks, and tablets were higher among women.
	Echegaray (2016)	• Individuals' past experiences with products (falling short of a reasonable lifetime) should relate to the informed decision making of consumers' expectations and specific product durability
	Pandebesie et al. (2019)	• EEE's lifespan depends on the quality of the goods rather than the availability and quality of electricity.
Product lifespan – an indicator for future planning	Abbondanza and Souza (2019)	• Efficiency and efficacy of a take-back system largely depend on local data on product lifespan, required for future policy planning, especially location and capacity of WEEE dismantling units and WEEE collection routing.
	Chung et al. (2011)	• Regional data on product lifespan data is incredibly useful, and lifespan-related data collection methods should be more efficient and accurate
	Gök et al. (2017)	• Service life of product is inversely proportional to the quantity of EG
	Yin et al. (2014)	• Product service life is directly associated with energy and resource use

Overall, product lifespan is a critical parameter that is generally used to estimate EG. Furthermore, for a similar product, the reported value of product lifespan may provide a tentative international comparison for future studies and define that product's lifespan profile. Table 3 shows the lifespan of various e-waste items.

Table. 3 Reported product lifespans (in years) of various EEE (as e-waste)

Ref.	Country	Product lifespan (in years)																														
		CRT monitor	CRT TV	Traditional TV set	Washing machine	Air conditioner	Microwave ovens	Refrigerators and freezers	MP3/4 player	Video camera	Photo-cameras	Mobile phones (smartphones)	Feature phone	Tablets	E-book readers	Desktop computer	Laptops	Hard disks drive	Global positioning system navigators (GPS)	Radio alarm clocks (RAC).	Electrical toys	Iron	Fluorescent lamp	Heater	Toaster	Vacuum Cleaner	Sandwich makers	Kettles	Hair Dryer	Headset	Large loudspeakers	Rice cooker	DVD player
Abbondanza and Souza (2019)	Brazil	10	6.9					7.8																									
Bovea, M.D. et al. (2018)	Spain								3-6	>6	>6	1 - 3		1-3	1-3		3-6	>6	3-6	>6													
Chung et al. (2011)	China		8.5	5.1	7.1	7.8		8.1								4.4	4.6																
Pérez-Belis, Victoria et al. (2015a)	Spain																				2-3												
Gutiérrez et al. (2011)	Spain			12				11	10													5											
Liu et al. (2019)	China											2.21																					
Nowakowski (2016)	Poland			12.9	12.1			13.4																									
Wieser and Tröger (2018)	Austria											1.8																					
Zhang, L. et al. (2019)	China										2.5	1.6		1.7		3.5	2																
Tan et al. (2018)	China											1.57																					
Afroz et al. (2012)	Malaysia			>6	>6			>6			>6					2-4																	
Bai et al. (2018)	China											2.24																					
Borthakur and Govind (2019)	India											4				4																	
Cao et al. (2016)	China			8				9				3		3																			
Chi et al. (2014)	China			8.1	7.1			8.6		2-3		2-3																					
Botelho et al. (2016)	Portugal			>10	>10		>10	>10				3-5				3-5																	
Deng et al. (2017)	China											1.91																					
Echegaray (2016)	Brazil							6				2.6																					
Gök et al. (2017)	Turkey							4.7			0.5	0.3				1.8							0.5										
Huang et al. (2006)	China			8-10		8-10		13-16								6																	
Martinho et al. (2017)	Portugal											2.7		3										8	8	7	7	6	6				
Ravindra and Mor (2019)	India			11	10	8		11				4				7	7						4										
Sabbaghi and Behdad (2018)	USA											2.84																					
Saritha et al. (2015)	India											1-2																					
Thiébaud et al. (2018)	Switzerland		9									3																			9	9	

Yin et al. (2014)	China										< 3																			
Ylä-Mella et al. (2015)	Finland										2-3	4																		
Shaikh et al. (2020)	Pakistan	2-5									1-3					2-5														
Siringo et al. (2020)	Indonesia		6.84	5.39	4.14		6.08				3.58				5.27	4.6					5.47								5.81	5.28
Islam et al. (2020a)	Australia										3.17																			

3.2.2 Analyzing consumers' storage behavior

After useful life of an EEE, consumers tend to store the equipment at households before it reaches to collection points or the household bin, especially for small WEEE items such as MPs. Although this issue is crucial and considered a significant barrier for potential acquisition for collection and recycling (Nowakowski, 2019), very few studies focused on this specific topic (around 10% of the articles). The number of items stored at households, storage time before disposal, and reason for storage were critical aspects that were used by the articles identifying consumers' storage behavior. Summary of the storage behavior related studies is presented in Table S4 in SI of this article.

3.2.2.1 General trend of device storage

In Switzerland, Thiébaud et al. (2018) found similar storage behavior for almost all types of electronic products. The study also found that a vast amount of the products was stored and reused before reaching the collection scheme. In Lithuania, Dagiliūtė et al. (2019) found that approximately 31% of respondents stored obsolete EEE, which later transferred to the collection points. In Poland, Nowakowski (2019) found that computer accessories and other information technology equipment were frequently stored by households (by over 60% of the respondents). For MPs, this was found above 80%. Another study by Nowakowski (2016) identified that SE stored per household was 1.5, while medium-sized equipment was stored one item per two households. In Ireland, Casey et al. (2019) identified that small e-waste items are generally existing in less visible and more fluid states due to the understanding of "lying somewhere in the house" on shelves and in drawers, which resulted in addressing e-waste differently than other recyclable materials. Ongondo and Williams (2011) observed that there is at least one mobile phone stockpiled for every student working out the average in the UK. Martinho et al. (2017) addressed that smartphones have a higher reuse potential than tablets in the overall storage behavioral pattern of Portuguese consumers.

In China, Zhang, L. et al. (2019) found that students' storage behavior was predominant (58% of the respondents). Tan et al. (2018) found that 62.1% of residents stored their MPs among the participants, while only 4.7% disposed of their WMPs in the formal collection facilities. Bai et al. (2018) estimated that WMP stored at home was 1.79 per person, and over the years, and surprisingly, it was observed that consumers became conservative in giving out their used phones to the recycling channels.

In Brazil, Rodrigues et al. (2020) found that more than half of the respondents intended to maintain out-of-use EEE, where small EEE products were stored the most compared to large EEE, as limited space is required.

3.2.2.2 Dominant stored products

The top hibernated products were MPs (Blake et al., 2019, Nowakowski, 2016, Pandebesie et al., 2019, Ramzan et al., 2019, Shaikh et al., 2020, Singh et al., 2018) and laptops (Ramzan et al., 2019, Singh et al., 2018), followed by DC (Singh et al., 2018), mobile chargers (Bovea, M.D. et al., 2018, Nowakowski, 2016, Rodrigues et al., 2020), computer mouse (Shaikh et al., 2020), hairdryers (Pandebesie et al., 2019), digital cameras (Pandebesie et al., 2019, Rodrigues et al., 2020), refrigerators (Singh et al., 2018), DVD players (Singh et al., 2018), CRT TV sets (Singh et al., 2018).

3.2.2.3 Motivating factors behind storage behavior

Top cited reasons for storing old devices found in the studies are shown in Table 4. These include barriers to recycling, such as cost and inconvenience, as well as the benefits of keeping devices, such as spare parts, data retention or to give to other people.

Table 4. Top cited reasons for storing devices

		Blake et al. (2019)	Kurisu et al. (2020)	Bovea, M.D. et al. (2018)	Ongondo and Williams (2011)	Qu et al. (2019)	Wieser and Tröger (2018)	Liu et al. (2019)	Shaikh et al. (2020)	Zhang, L. et al. (2019)	Martinho et al. (2017)	Zhang, B. et al. (2019)
Benefits of retention	For spare parts	✓	✓	✓	✓	✓	✓					
	Information/data security	✓				✓		✓	✓	✓		
	Difficulties backing up data		✓					✓	✓			
	Emotional attachment			✓					✓			
	To give them to family/friends					✓					✓	
Barriers to recycling	Not knowing where to take devices				✓	✓		✓			✓	
	Inconvenient or bothersome to participate in recycling or disposal		✓			✓		✓		✓		✓
	High cost of recycling	✓	✓									
	Low collection price					✓		✓		✓		✓

Martinho et al. (2017) found that most respondents prefer to keep e-waste items (smartphones and tablets) at home instead of recycling. However, optimistic consumers' attitudes were identified for reusing the products. Islam et al. (2020a) concluded that the lack of familiarity with a recycling program is critical for the observed WMP storage behavior. Wieser and Tröger (2018) concluded that emotional attachment to the phones due to data and information and the phones' qualities made consumers not dispose of it in any other means. Besides, consumers thought their kept phone would be used by someone instead of deliberately delivering it to the recycling channel. In this process, reusing the phone with a regular interval was common. In a cross-cultural study, Miliute-Plepiene et al. (2016) found that social norms are the most crucial factor in storing e-waste in Lithuania's early-stage recycling system; this did not apply to the case of Sweden.

Information/data security was the principal reason for storing MPs. Blake et al. (2019) mentioned that consumers tended to keep their device as a spare/backup, as it may have a monetary value. Similar reason was identified by Shaikh et al. (2020). Bovea, M.D. et al. (2018) identified that e-book readers, GPS navigators, or radio alarm clocks were stored because they could be used in the future as spare parts. Singh et al. (2018) identified that consumers often do not have or do not know about the dumping or resale opportunities of the discarded EEEs, which triggered storage habits. Qu et al. (2019) mentioned that little knowledge on hazard and contamination of e-waste coupled with preserving memories motivated device hibernation behavior.

3.2.2.4 Mitigating measures against storage

Rodrigues et al. (2020) found that storage behavior could be changed by implementing recycling policies, reverse logistic systems, environmental education, and incentives for social participation. Casey et al. (2019) reported that charity campaigns and life transition circumstances (such as moving and renovation) could be internal and external triggers, respectively, against hibernating behavior.

Ongondo and Williams (2011) found that take-back services could encourage students not to hoard more than one extra phone, but some students may not participate even with knowledge of such schemes. Greater a awareness of the "environmental value" (the importance of recycling to reclaim the resources embedded) within the phone could increase participation. Arain et al. (2020) concluded that consumers' awareness of stewardship responsibilities and lowering the personal cost to recycle could be determining factors behind reducing storage habits. Zhang, L. et al. (2019) contend that university students stockpile large and increasing amount of personal electronics, unless economic incentives are given. Pierron et al. (2017) found that in a student accommodation setting, students were not interested storing as 1) there is limited space and 2) alternatives (recycling, discarding, reusing, selling) are now more readily available than previously. This finding is different from others, where, in most cases, consumers wanted to store their devices at home.

Nowakowski (2016) concluded that for developing countries, storing and later reusing is expected behavior. The situation becomes intensified when the purchase price of the product is significantly higher, such as smartphones. This overall scenario influences consumers' discarding decisions. Improvement of WEEE returns' convenient methods is a crucial factor enhancing the collection rate (for recycling) of stockpiled e-waste. Dagiliūtė et al. (2019) found that consumers tended to repair their MPs if they were malfunctioning and if the operation is economically feasible; otherwise, the phones were stored or to a limited extent threw with household municipal waste.

3.2.2.5 Storage period

Milovantseva and Saphores (2013b) found that storing waste TV sets for up to 5 years was evident in American households where the number of sets was one or more. Kurisu et al. (2020) determined that PCs were disposed of within one year of storage. However, 3.8% of PCs were hibernated for more than ten years. Islam et al. (2020a) found that the average storage time (0.57 to 1.17 years) for MPs is similar for Swiss and Australian consumers. Results on hibernating time showed that all types of personal electronics have been retained for less than 3 years, with the longest retaining time close to 3 years (for DCs) (Zhang, L. et al., 2019).

3.2.2.6 Socio economic factors

Milovantseva and Saphores (2013b) found that pro-environmental behavior in the past 12 months, age, education, household size, marital status, the gender of the head of household, type of dwelling, and geographic location was strongly associated with the junk TVs storage among American households. The authors also identified that larger households are more likely to have more junk TVs, while the converse was true when household income increases. Furthermore, the consumers' geographical locations impacted waste TV storage behavior, and in that case, the age of the sets was equal or greater than 16 years old. Dagiliūtė et al. (2019) indicated that age has a positive association with storage. For example, due to limited purchase power, students tended to use the products as spares. Another study by Saphores et al. (2009) identified that except for knowledge of e-waste and income, all other explanatory variables age, marital and employment status, ethnicity, household size, previous e-waste recycling behavior, and to some extent education, homeownership, and understanding the consequences of recycling were found significant indicators describing the households' e-waste storage behavior.

Pandebesie et al. (2019) found that storage behavior is affected by the consumers' residential conditions. Arain et al. (2020) mentioned that attaining a certain level of education alone is not sufficient to eliminate storage behavior and lack of knowledge among consumers regarding disposal options, such as the location of proper facilities and concerns regarding personal data security, the main reasons for storage. Qu et al. (2019) reported that 80% of all residents had more than one WMP stored at home, while 17% of them had more than four WMPs. One of the apparent reasons behind this was high disposable income. Martinho et al. (2017) found that consumers with large household sizes and high education levels were keener keeping broken smartphones in the home (in the absence of preferred discounts/cashback method).

3.2.2.7 Measurement perspective

Rodrigues et al. (2020) found that at the center of the EG estimation method, the portion related to storage or donation could often result in overestimations (due to incorrect idea of immediate substitution of product). Repressed demand is expected to implement reverse logistics systems, which is often hampered by the storage habit. Singh et al. (2018) mentioned that the storage of discarded EEEs is a problem in quantification and recycling. Casey et al. (2019) found that keeping household items can be divided into two main categories: 1) disused or broken and 2) abandoned. In both cases, over time, the value of stored items dissipates, which is often more troublesome than recycling or discarding it.

3.2.3 Analyzing consumers' disposal behavior

When consumers finally decide to dispose of unwanted EEE, many options are generally available to them. It could be formal disposal paths arranged and managed by government authorities or informal collection services managed by local scrap metal recyclers, paddlers, waste collectors, etc. The second practice is widely used in developing countries where recycling is done by a crude process such as acid leaching. Identifying "disposal pattern" is one of the significant issues of consumers' behavior that can provide valuable information on the existing e-waste collection system and opportunities to improve it. This issue was investigated in most of the articles (26% of the articles). In the following sub-sections, issues related to consumers' disposal behavior are reviewed. Table S5 (in the SI) provides in-depth details of each of the articles at the country level, highlighting the main research problems identified in the articles.

3.2.3.1 Mode of disposal

Fig. 13 shows the top disposal methods identified by the articles reviewed. Overall, "store at home" is the most common disposal method (Borthakur and Govind, 2019, Chi et al., 2014, Islam et al., 2020a, Martinho et al., 2017, Miner et al., 2020, Ongondo and Williams, 2011, Shaikh et al., 2020, Siringo et al., 2020, Wieser and Tröger, 2018, Zhang, L. et al., 2019), but is typically temporary, as discussed previously. The reason was identified by the 34% of the article.

Other notable methods of e-waste disposal include - "throwing e-waste with household solid waste/mixed waste" (Arain et al., 2020, Araujo et al., 2017, Blake et al., 2019, Borthakur and Govind, 2019, Bovea, M.D. et al., 2018, Chi et al., 2014, Fraige et al., 2012, Gök et al., 2017, Martinho et al., 2017, Pasiecznik et al., 2017, Rodrigues et al., 2020, Wieser and Tröger, 2018), "donate to others" (Abbondanza and Souza, 2019, Araujo et al., 2017, Borthakur and Govind, 2019, Cao et al., 2016, Colesca et al., 2014, Echegaray, 2016, Fraige et al., 2012, Hamdan and Saidan, 2020, Martinho et al., 2017, Rodrigues et al., 2020), "drop it to council collection centers/recycling centers" (Araujo et al., 2017, Borthakur and Govind, 2019, Chi et al., 2014, Fraige et al., 2012, Islam et al., 2020a, Martinho et al., 2017, Rodrigues et al., 2020, Wieser and Tröger, 2018), "selling" (Cai et al., 2020, Cao et al., 2016, Chi et al., 2014, Echegaray, 2016, Fraige et al., 2012, Hamdan and Saidan, 2020, Islam et al., 2020a, Nguyen et al., 2009, Ongondo and Williams, 2011, Ravindra and Mor, 2019, Rodrigues et al., 2020, Shaikh et al., 2020, Siringo et al., 2020), "forwarding it to recycling companies for environmentally friendly recycling" (Hamdan and Saidan, 2020, Islam et al., 2020a, Ongondo and Williams, 2011), "wait for the door-to door recovery" (Cai et al., 2020), "trade in OFN" (Cai et al., 2020), old-for new/discount (Bovea, M.D. et al., 2018, Cao et al., 2016, Colesca et al., 2014, Ongondo and Williams, 2011), "deliver to point purchase" (Martinho et al., 2017) and "leave it at the store during new purchase" (Borthakur and Govind, 2019).

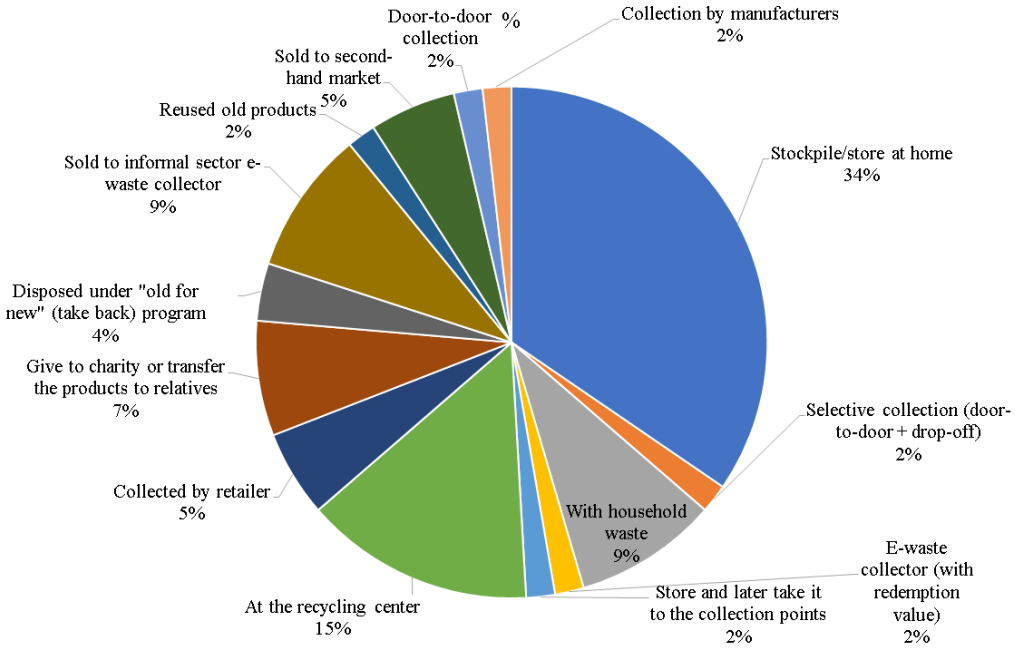

Fig. 13. Top disposal methods of e-waste

Depending upon the types and socio-economic conditions of consumers, e-waste flows at different channels. For example, Song et al. (2012) mentioned that people from less developed areas preferred to give MPs to friends, relatives, and other organizations while waste ACs and PCs were sent to manufacturers. On the other hand, Bovea, M.D. et al. (2018) found that "I threw it in the trash" and "I replaced it with another type of appliance" were the primary method and reasons for disposal, respectively for SE. For DCs, "collection by manufacturers" and "at electronic retail stores" were standard practices in Japan (Kurisu et al., 2020).

Delivering e-waste to various recycling channels existed a practice among consumers. For example, Wang et al. (2011) mentioned that 41.79% of residents used various recycling channels, 36.79% discarded e-waste with municipal waste, while 21.62% stored e-waste at home. Although there was a high percentage of users using recycling channels, it is believed that informal sector e-waste collectors are one of them. For example, Ongondo and Williams (2011) found that selling is happening among consumers, companies, or individuals. Singh et al. (2018) found that most consumers disposed of their e-waste to informal e-waste collectors and recyclers. Chi et al. (2014) in China found the same. Informal sector e-waste disposal practice was considered as loss of energy and resources due to its unfriendly recycling nature (Ramzan et al., 2019). Despite the fact, Borthakur and Govind (2019) found, "I sell them to the scrap dealers" or 'kawariwalas' as one of the disposal paths from where consumers got benefits. A similar result was found by Abbondanza and Souza (2019).

Donation is often considered as a gift from the donors (Ongondo and Williams, 2011). It is a product lifespan extension process that reduces EG (Rodrigues et al., 2020). Lau et al. (2013) mentioned the entity of donation as "donated to non-profit making organizations."

Pérez-Belis, V. et al. (2015) concluded that besides the consumers who donate used toys to family or charities, around 67.1% of the consumers dispose of their fractions of waste toys in domestic bins, while 32.9% of the respondents used recycling points. Nowakowski (2016) mentioned that improper disposal practices existed among residents', and many of the residents disposed of e-waste with household solid waste and selling the item to local scrappers. In Malaysia, Othman et al. (2015) while approximately 14% of the E-waste generated by low-income residents would go through landfill sites. Among the young consumers, this practice also prevails. For example, Pasiecznik et al. (2017) found that 12% of the respondents, mostly young people, threw their e-waste in regular household bins.

Cai et al. (2020) identified that “sell to second-hand market” and “sell to the qualified enterprise” are the two variations of selling items to others. Gök et al. (2017) found the first one as the preferred method by the consumers. The authors also mentioned that “wait for the door-to-door recovery” was widely used for ACs, WMs, and refrigerators and also for products that consumers perceived requiring “high repair cost or cannot be repaired.” Ravindra and Mor (2019) specifically mentioned “selling it to the second-hand dealer.” Self-disassembly and second-hand use were found by Chi et al. (2014). Wieser and Tröger (2018) identified that trading-in or selling MPs was performed for younger aged MPs to make a new mobile phone purchase. Kumar (2017) mentioned that company-owned showrooms, authorized dealers, and distributors as organized channels and second-hand goods shops and repair shops as unorganized channels were the two primary paths for mobile waste disposal.

3.2.3.2 Main disposed items – the product flow

Casey et al. (2019) mentioned that e-waste type typically has gone through 4 different stages, including 1) inactive EEE, 2) critical moment, 3) transition from EEE to WEEE, and 4) divestment. Consumers' disposal practices largely determine the final routes of e-waste (Chung et al., 2011). Dindarian et al. (2012) postulated that the product was discarded by customers' choice, not for the latest technology. On the other hand, Wieser and Tröger (2018) mentioned that the mode of disposal varies depending on the replaced device's age. When consumers understand their mobile phone has some value, it was preferred to reuse rather than other channels.

Before reaching a final disposal point, products are hibernated. For example, Dagiliūtė et al. (2019) found that "Store and later take it to the collection points" was the disposal method, and MPs were disposed of the most. Afroz et al. (2012) identified that more than one-third of the respondents sent their unused EEE to charities and gave it to relatives when they could not repair it. As there is no specific collection scheme available in the country, the authors found that little fraction of e-waste went to recycling facilities. "Self-disassembly and keep the useful parts" were the most common disposal practice for desktop and laptop computers (Lau et al., 2013). Apart from storing WMPs at home, they were donated to relatives, friends, and charities (Tan et al., 2018).

For second-hand use, consumers wanted to deliver used DCs, WMs, and laptops (Chi et al., 2014). Thiébaud et al. (2018) identified that firsthand users disposed of CRT TVs and DVD players directly (at point of disposal), while FDP TVs and monitors were sent for second-hand use. A higher disposal rate was found for headsets and small loudspeakers and was directly disposed of with general waste and after storage. In India, Singh et al. (2018) found that MPs, laptops, cameras, WMs, ACs, heaters, geysers, LED, and LCD televisions were the major disposed e-waste items among the participants. Huang et al. (2006) mentioned that "selling to waste collection centers was the main method to dispose of waste TV sets, refrigerators, and ACs, and selling in the second-hand markets was the key method to deal with waste PCs."

Typically, in Brazilian households, MPs were kept at home, and audio-video equipment was sold mainly or passed along among relatives, friends, or charity groups (Echegaray, 2016). Nguyen et al. (2009) indicated that selling or giving the appliances to other users were primarily adopted TVs, refrigerators, WMs, and PCs. As per a study by Bovea, M.D. et al. (2018), MPs, cameras, and radio alarm clocks were disposed of by the Spanish households. Abbondanza and Souza (2019) found that smartphones, refrigerators, or freezers, and WMs were the most discarded items by Brazil's households. Despite being a developing country, Islam et al. (2016) found that MPs and PC were the dominant WEEE categories in Bangladeshi households.

3.2.3.3 Norms and perceived behavioral control

Nduneseokwu et al. (2017) identified that infrastructure moderated the relationship between two influencing factors (attitude and subjective norm) and intention. Consumers who did not recycle or recycled infrequently tended to dispose of small WEEE in the general household refuse (Darby and Obara, 2005). Recycling behavior reflected in practice is somewhat related to the economic status of participants. Those who already

had a recycling habit do not have an interest in incentives (Botelho et al., 2016). However, Pandebesie et al. (2019) showed that willingness to separate e-waste among consumers was relatively high, and they were aware of the importance of separated waste.

Echegaray and Hansstein (2017) mentioned that "product disposal practices remain hardly influenced by favorable views towards the environment". On the other hand, education had an impact on disposal behavior. For example, Saritha et al. (2015) found in their survey that 41.2% of the respondents would consider disposing of old products in an eco-friendly manner, while 94% agreed to return it to the manufacturer for free if the latter claimed to recycle products in an eco-friendly manner. Technical knowledge of product use also influences an individual's perception regarding disposal. For example, Jayaraman et al. (2019) showed that social consequences and the conviction of individuals' laptop disposal practices strongly depend on knowledge of computer literacy.

3.2.3.4 Influencing factors-associated with disposal decision

Infrastructural factors were some of the critical factors that determined willingness and positive behavior and attitude towards e-waste recycling and selecting disposal routes. These include availability and convenient access to recycling facilities and service (Arain et al., 2020, Araujo et al., 2017, Casey et al., 2019, Nixon et al., 2009, Wang et al., 2011, Zhang, L. et al., 2019), availability of information regarding formal collection channels rate (Arain et al., 2020, Borthakur and Singh, 2020), socio-economic condition, for example, residential condition (Wang et al., 2011), pro-environmental behavior, for instance, recycling habit and practice (Casey et al., 2019, Wang et al., 2011), information security (mainly for IT-related equipment, such as MPs and DCs) (Bai et al., 2018, Milovantseva and Saphores, 2013b, Zhang, L. et al., 2019), lack of product-related information (Arain et al., 2020), environmental concerns (Araujo et al., 2017) economic benefits (in terms of getting reward for e-waste delivery to the channel) (Wang et al., 2011, Zhang, L. et al., 2019), cost of disposal (in other words free access to disposal) (Arain et al., 2020, Kurisu et al., 2020, Nixon et al., 2009), and e-waste collector's capacity (Araujo et al., 2017).

The reasonable distance was critical for recycling infrastructure (Arain et al., 2020). In developing countries, the informal sector e-waste collection is generally expected. Consumers preferred to deliver e-waste to the channel due to economic benefits (Chung et al., 2011), as e-waste is considered a valuable commodity (Borthakur and Singh, 2020). Central processing units (CPUs) of DCs, computer monitors, keyboards, mice, printers, cellular phones, and landline telephones were considered valuable e-waste (Rodrigues et al., 2020). Furthermore, if e-waste is not repaired, it is thrown away; buying a new one is a common trend (Shaikh et al., 2020). On the other hand, Blake et al. (2019) found that design (built-in obsolescence), marketing and fashion trends, or the speed of technology advancement were the main factors for high disposal.

Tan et al. (2018) found that consumers expect to receive specific revenue for various disposal modes. "The difference between the high expectations of obsolete MPs and the actual collection price was also an important factor leading to a high ratio of MPs stored at home." Similarly, Deng et al. (2017) found that consumers kept the phones due to the low price for second-hand phones in the second-hand market. Identifying "best exchange offer and price" is the most critical factor for product return (Chi et al., 2014, Dwivedy and Mittal, 2013). In that case, Kumar (2017) argued that organized channels could provide incentives to consumers under the buyback scheme.

In terms of the e-waste collection method, Chi et al. (2014) found that consumers demanded to "collect other municipal wastes," "free door-to-door collection," "collect during a non-working time," "easy access to collectors," "provide repairing and cleaning service." The influence of online internet-based collection systems is gaining popularity; however, understanding consumers' preferences regarding modes (online and offline) of collecting e-waste (mainly obsolete MPs) was found paramount (Liu et al., 2019).

Product use could also be an indicator of the e-waste disposal trend. For example, Li et al. (2012) indicated that respondents with high income or good education possessed most high-tech household appliances advanced in technology and had the flexibility to use.

3.2.3.5 Impact of socio-economic variables in disposal behavior

Several studies applied statistical methods. Several independent socioeconomic variables were found significant; however, it is often hard to generalize the predictability of behavior indicators, mainly because of externalities (economic growth, local manufacturing, public policy, and others). For example, Abbondanza and Souza (2019) found that regional variation (pace of development across a country's regions) influenced disposal behavior. However, common variables that impacted disposal behavior were family size (Pérez-Belis, V. et al., 2015), age (mainly "method of disposal.") (Islam et al., 2020a, Nowakowski, 2019), income (Abbondanza and Souza, 2019, Darby and Obara, 2005, Islam et al., 2016, Othman et al., 2015), gender (Dagiliūtė et al., 2019, Darby and Obara, 2005, Nowakowski, 2019, Ongondo and Williams, 2011), education (Nowakowski, 2019, Zhang, B. et al., 2019), occupation (Zhang, B. et al. (2019), and types of residence (Dagiliūtė et al., 2019, Nowakowski, 2019).

Botelho et al. (2016) found that 'exchange for money' (mainly demanded by males) was the expected incentive in Portugal, followed by 'exchange for new EEE,' 'discount coupons on services' (females and consumers with a high level of education), 'collection of EEE at home' (females). Income and occupation, mainly in the environmental sector, influenced factors using e-commerce and professional recycling sites (Zhang, B. et al., 2019).

Othman et al. (2015) found that approximately 86% of the e-waste generated by low-income residents would go through four options of a waste management system, i.e., reuse, repair, remanufacturing, and recycling. On the other hand, Song et al. (2012) concluded that Macau residents did not consider the small financial benefit of selling discarded electronic products, which was different from mainland Chinese residents. In terms of e-waste sorting, Dagiliūtė et al. (2019) found that females preferred to do. For product-focused disposal behavior, Dwivedy and Mittal (2013) found that in India, the age of waste microwave ovens was relatively shorter, and consumers who were between 35 and 60 years old, owned cars, and were of middle to high income discarded most of the ovens.

3.2.3.6 Barriers associated to disposal

Ardi et al. (2020) found that consumers' disposal behavior was primarily influenced by lacking well-established collection systems. Siringo et al. (2020) found that only 2% of respondents voluntarily participated in formal e-waste recycling. Disposal using municipal waste was also a popular choice due to the unavailability of appropriate options (Shaikh et al., 2020). High repair cost/cannot also be repaired found to be the critical barrier for which e-waste is stored or unrepaired (Blake et al., 2019). Cao et al. (2016) indicated that due to "OFN," LE was going to formal channels; however, small-sized mobiles and cameras were stored at home and remained idle without incentives.

3.2.3.7 Collection system/online recycling platforms

3.2.3.7.1 Reverse logistics

As seen earlier, infrastructural factors, such as availability and convenient (access to) recycling facilities, were one of the critical components of an efficient collection system (Nduneseokwu et al., 2017) and Dagiliūtė et al. (2019) indicated that consumer demanded more collection points/containers. Convenience appears to matter, as the number of consumers decreases with the increase of recycling centers distance (Darby and Obara, 2005, Saphores et al., 2012). Favot and Grassetti (2017) found that population density is negatively correlated with the kg of e-waste collected. The number of collection points, % of female, % of waste separately collected were positively correlated with kg of E-waste collected. Rodrigues et al. (2020) identified that the number of discarded units and the number of households were two critical parameters for RL system

design. Convenient transport facilities were also critical, especially for SE disposal for low-income residents (Darby and Obara, 2005). Darby and Obara (2005) also found that consumers needed information on how to dispose of WEEE and where it should be put for recycling for LE category. It is not clear under what circumstances consumers disposed of their items with household refuse or in the general waste at civic amenity (CA) sites for SE. This problem is also identified by Botelho et al. (2016) in Portugal. Sorting should be considered an essential task at the initial stage of RL system development; however, this issue is less concerned. Although, Gök et al. (2017) found that sorting e-waste from other types of waste was performed by 28% of the participants, mostly YUSs.

For young consumers, multiple options should be provided. Ongondo and Williams (2011) concluded that students' union facilities and libraries were the preferred central locations for disposal. Zhang, L. et al. (2019) mentioned that "university students intend to choose online recycling platforms to dispose of obsolete electronics." Regarding online collection platforms, perceived usefulness, perceived ease of use, attitude, subjective norms, and perceived behavioral control have a positive impact, while perceived risk has a negative impact on the behavioral intentions of Chinese millennials on the adoption of online e-waste collection platforms (Ramzan et al., 2020).

3.2.3.7.2 Key attributes - Provision of incentives

Cost of delivery (by consumers) to the collection system and receiving incentives were the two significant attributes of a successful system. Blake et al. (2019) found that consumers preferred to disposal cost to be collected at the product purchase point. Offering discounts/cashback during new product purchases could be significant for greater participation (Martinho et al., 2017). Nixon et al. (2009) conclude that California households preferred a combined service provision - "drop-off recycling at regional centers," with "curbside recycling" including other options such as Pay-As-You-Throw (PAYT), deposit-refund program at retail locations.

Park et al. (2019) found that a "free of charge door-to-door collection system" was preferred by most of the respondents, and in that case, public relation activities should be increased. There is a need for direct communication and booking channel with visiting engineers at the e-waste collection facility (and as a free service), which the consumers preferred. Due to the absence of a door-to-door collection system and incentive options, often there is a high chance that consumers deliver e-waste to the informal sector (Lau et al., 2013). Selling waste EEE items to local small scrap dealers to get economic benefits was the most preferred choice (Islam et al., 2016). Miner et al. (2020) identified that due to the lack of a door-to-door collection program, e-waste storage behavior was accelerated. In this regard, Pierron et al. (2017) mentioned that the stockpiled small e-waste category represented a vital source of revenue.

Cao et al. (2018) mentioned that different economic and internet penetration levels were the two main factors for developing efficient collection channels within a region. "Third-party integrated network platform integrate online, and offline resources were predicted to be widespread under the rapid development of IT and e-commerce. On the other hand, Yin et al. (2014) mentioned that consumers demanded official channel incentives. For WMPs, door-to-door collection services were not preferred. However, Zhang, B. et al. (2019) indicated that peddlers' on-site collection was still the dominant way of e-waste disposal and e-commerce and professional recycling site were far less competitive. The authors also found that the e-waste disposal rate among low income (<250 RMB/month) consumers were less while consumers with income > 10,000 RMB/month preferred e-waste collection by peddlers, e-commerce. Young consumers (<30 years old) preferred to use e-commerce sites for e-waste disposal, while older people did not.

3.2.3.7.3 Policy-oriented regulatory intervention and actors' involvement

Convenience and policy effectiveness influenced the youth e-waste disposal intention (Shaharudin et al., 2020). At the product-level, Tan et al. (2018) mentioned that WEEE-related regulation is expected to affect

mobile phone collection positively. However, Chung et al. (2011) found that despite the absence of a producer responsibility scheme (PRS) in the current EMS, customers still disposed of their e-waste in the appropriate channels (around 17%).

Trust and quality of e-waste collection service (especially who and how involved in the system) were found to be significant factors among consumers. Consumers' trust is critical for market competitiveness for the recycling industry, and involvement and endorsement of the recycling industry and government were imperative (Bai et al., 2018). For example, Song et al. (2012) indicated that consumers demanded government departments or other organizations to be involved in the e-waste disposal, mostly a well-developed collection system that included a component "telephone reservation." In China, the "Green Box Program" and "OFN activity" (without incentives) were the two official disposal channels that consumers utilized (Yin et al., 2014). On the other hand, Liu et al. (2019) concluded that consumers preferred government-operated facilities or through the collection by communications operators and retailers.

Furthermore, Martinho et al. (2017) mentioned that producer responsibility organizations (PROs), private entities (including non-government organizations (NGOs)) could be potential places for sustainable disposal locations; however, a lack of knowledge regarding such available options was evident. Kumar (2017) argued that multinational mobile manufacturing companies had collection points in India, while local companies had no take-back mechanisms, and more than half failed to provide information on physical collection points. Araujo et al. (2017) found that consumers preferred to have e-waste collection by manufacturer or seller. Second-hand retail shops should also be responsible, as Cao et al. (2016) found that "sell to second-hand stores" and "sell to after-sales repair stations" were the two dominant choices.

Echegaray and Hansstein (2017) mentioned that the government should take advantage of municipal garbage collection systems (that may include a segregated solid waste collection) and manufacturers' or retailers' point of disposal of e-waste to enforce current regulations. Awasthi and Li (2018) argued that non-government organizations (NGOs) could play a vital role in mediating consumers' improper disposal behavior where socio-cultural circumstances, lack of advanced technology and infrastructure, and environmental considerations are limited. Besides, manufacturers and municipalities should be more active and involved in collection activities (Deniz et al., 2019). It is necessary to promote legal ways of disposal or prepare scrapyards for large e-waste equipment (Nowakowski, 2016).

3.2.3.7.4 Impact of awareness and perception on disposal decision

Environmental awareness was cited in the literature as a key factor influencing disposal behavior (Ardi et al., 2020). Jayaraman et al. (2019) mentioned that individual awareness had a positive impact on laptop disposal behavior. Giving information about e-waste and its environmental risks would significantly increase proper disposal behavior (Gök et al., 2017), as a significant number of consumers did not have information about where to dispose of the e-waste (Dindarian et al., 2012). Gilal et al. (2019) mentioned that WOM significantly impacted consumers' e-waste disposal behavior, which also motivated acting to recycle appropriately. Furthermore, well-designed and door-stepping delivery of the campaigns could potentially shape consumers' disposal behavior for the items. Botelho et al. (2016) found that lack of awareness of consumers, delivery of e-waste-related information, and the consumers' socio-demographic factors significantly affected consumers' motivation to return e-waste.

3.2.4 Analyzing consumers' R&R behavior

In the light of the CE principle, R&R is the first step of the entire closed-loop chain that extends the product lifespan and reclaim the value of used EEE. However, the researchers have not investigated this issue extensively; only 8% of the articles (mostly from developed countries) discussed this specific consumer behavior.

3.2.4.1 Product design perspectives

Chuang and Liao (2018) examined consumer-driven innovation in green product designing, considering Taiwanese residents focusing on the digital camera. Using conjoint analysis, the authors found that consumers' innovative design ideas could significantly improve product design, and this issue should be considered in designing energy-related products. Pérez-Belis et al. (2017) showed that 9.56% of the consumers had never repaired any products that fall under the small e-waste category, while 0.75% of the participants bought second-hand small EEE. The study results also revealed that consumers demanded product information (in terms of design and labeling) and the products' durability. On the other hand, 83.7 % of the respondents of Dagiliūtė et al. (2019) 's survey repaired MPs when it was malfunctioning. Central problems of MPs were with the battery, software, button/buttons stop functioning, malfunctioning during power on/off (Borthakur and Singh, 2020). However, Wieser and Tröger (2018) stated that MPs' perceived speed of obsolescence was vital for repair and reuse. Chi et al. (2014) mentioned that cell phones, TVs, laptops, and refrigerators are the major products, which have significant room for recirculation by repairing. Othman et al. (2015) mentioned that manufacturers should design products that are easily repairable and incorporate recycled content and remanufactured components.

3.2.4.2 Barriers to repair and reuse

Bhatt et al. (2017) found that respondents preferred to buy new MPs instead of repairing and reusing them due to the higher repair cost. It was also found valid for other types of electronic products (Pandebesie et al., 2019). The same reason identified by Echegaray (2016) and the author mentioned that the product-repair market remains underdeveloped due to manufacturers' intention for higher returns selling new products. This reason is not only prevalent in a developing country but also in developed countries. Consumers from the developed country can buy a new EEE product instead of repairing as there is hardly any cost difference. This contributes to increased EG, with Blake et al. (2019) finding that 'lack of ability to repair/the cost to repair' was one of the significant drivers for EG.

Sabbaghi and Behdad (2018) found that consumers have robust repair behavior for products, but that the cost of manufacturers' repair service can be a significant inhibitor, resulting in losses for both consumers and manufacturers. The authors also estimated that WTP for repairing decreased at an annual rate of 6.7%. Ylä-Mella et al. (2015) found that reliability, perceived shorter product lifespan due to fast technical progress, and the existence of new budget models were the main reasons not to purchase used phones.

Another perspective of R&R is the second-hand market of the reusable product. Dindarian et al. (2012) found that current product design and the lack of market for second-hand items are significant barriers to product reuse. Bovea et al. (2017) showed that except for minor repairs of heaters, toasters, and vacuum cleaners, most SE category products were not repaired. Availability of cheap spare parts and difficulties during the disassembly process were the main constraints for repairing. The study also found that only 9.6% of respondents repaired their small-EEE, while less than 1% bought second-hand products from the repair shop. The reasons are also found valid for components (e.g., battery) of MPs and computers and accessories (Saritha et al., 2015). Lack of knowledge about repair and waiting periods were also critical for repair activities (Pérez-Belis et al., 2017).

3.2.4.3 Environmentally sustainable products

Bovea, M. et al. (2018) inspected consumers' preferences in product design and labeling that can contribute to the CE, considering durability, repair-ability, recycled material content, low environmental impact, fair working conditions, and origin. They found that Spanish consumers were concerned about fair working conditions and durability of products. Kumar (2017) mentioned that the repair-related secondary market is mostly dominated by the informal sector, which has a relatively low-performance recirculating product in an environmentally friendly manner. The authors mentioned that extending lifespan is also an indicator of environmental products. Pérez-Belis et al. (2017) found that respondents who repaired appliances (e.g., vacuum cleaners, juicers, and toasters) were using the products for more than four years. On the other hand, for cheaper electronics, the cost of repair is generally found high. Thiébaud et al. (2018) mentioned that after repair products' average service life is extended by at least 30%.

3.2.4.4 Secondhand product purchase

Second-hand product purchase is a relatively common practice in developing countries; for example, Abbondanza and Souza (2019) mentioned second-hand product acquisition from donations and directly from past users.

Bovea, M.D. et al. (2018) found that more than half of the participants (65.5%) never repaired broken e-waste items, while 87.6% of the respondents never bought second-hand EEE items. Similar results were found by Pérez-Belis, V. et al. (2015) for electronic toys in Spain. Chung et al. (2011) found that consumers would buy second-hand products if the reconditioned product's price is substantially lower than new products, durability and performance of the reconditioned product is guaranteed, and finally, the warranty level is similar to that of new products. The authors also mentioned that there should be an authoritative quality assurance scheme that might take responsibility for reconditioned products. Lacking the factors mentioned above in repaired products, 88% of the respondents of Fraige et al. (2012) 's study were not interested in purchasing second-hand products. Even though people bought the products, that was mainly due to economic reasons and for temporary use. These factors were also mentioned by Ylä-Mella et al. (2015) and Rodrigues et al. (2020).

Environmental education largely influences environmental behavior, specifically on second-hand product purchases (Pérez-Belis, V. et al., 2015). A higher percentage of households reused their old cell phones than TV sets (Milovantseva and Saphores, 2013a). Borthakur and Govind (2019) found that instead of repairing, consumers tended to purchase a new phone due to repair cost, which was the primary reason for new product purchase, followed by new product features, status symbol, and the ripple effect of other people purchasing new products.

Borthakur and Singh (2020) found that un-repairability was the main reason for purchasing a new phone while repairing was an alternative reason. The authors also mentioned that repair shop owners also discourage consumers from repairing, as there are insignificant differences between repair costs and new product purchases. The repair shops are also acting as a selling point for second-hand items. As consumers have less intention to buy second-hand products, the shops might hold their repaired items for longer, an indirect economic loss involved in the process.

Echegaray (2016) mentioned that consumers believed that their e-waste was beyond repair in most cases, although deliberate lifespan curtailment by producers or consumers directly influenced this perspective. In that case, symbolic and planned obsolescence was both critical and existed. Consumers experience a technology-driven push (purchase new EEE) and barriers in extending product lifespan, which was often a difficult choice assessing cost and benefits (of product repairing).

Rodrigues et al. (2020) identified those vacuum cleaners, radio receivers, CRT displays, and freezers were some of the devices that had the opportunity for reuse. Second-hand items as gifts from others were not expected for printers, sandwich toasters, grills, and electric toasters. Notebooks, CRT displays, radio receivers, and computers could be considered during second-hand purchases. The authors also found that the main reasons for not buying second-hand items were "new EEE is better," cheaper, and guaranteed and mistrust of the durability of used EEE, which is evident in most developed countries. Smartphones and tablets have reuse potential (Martinho et al., 2017).

3.2.5 Analyzing consumers' recycling behavior

Recycling behavior often overlaps with disposal behavior. Around 16% of the articles explored the behavior, investigating either consumers recycle their product or not (disposed of in a formal collection facility), any monetary incentives demanded by the consumers or not, or in some cases, consumers preferences in selecting recycling facilities among various available options. WTP was another aspect investigated by the articles to identify how much of the recycling fees consumers were willing to pay if any system requires it. This issue was mainly discussed from the developing countries' context because no specific collection and recycling options are available to the customer.

3.2.5.1 Willingness to participate in a recycling system

3.2.5.1.1 Determining factors

According to Zhang, Y. et al. (2019), Thi Thu Nguyen et al. (2018), Milovantseva and Saphores (2013a), Li et al. (2012), and Martinho et al. (2017), main determining factors identified for enhanced participation of the consumers in any recycling system were compensation mode, collection price, and convenience degree, social pressure, laws and regulations, cost of recycling, and inconvenience of recycling. On the other hand, Otto et al. (2018) mentioned that environmental motivation and behavioral costs were the main factors where the latter could be manipulated within the short term. In addition to that, environmental awareness and recycling prices were also critical (Cai et al., 2020). Siringo et al. (2020) mentioned the importance of recycling intention, information, and recycling convenience for participation. From the RL perspective, Blake et al. (2019) found that the structure of the services available, including provision and cost, was significant. Siringo et al. (2020) found similar findings.

3.2.5.1.2 Socio economic factors and influencing components of TPB

Jafari et al. (2017) found that household income, household size, education, e-waste awareness, and marital status were the main factors for consumers' incentive dependency. Kumar (2019) found that for young consumers, 1) attitude; 2) perceived control; 3) subjective norm and 4) individual responsibility were the main influencing factors, while convenience and awareness did not have any influence on the behavior. Saphores et al. (2012) found that moral norms, toxicity knowledge about the toxic content in e-waste, and recycling at work/school positively influence recycling behavior. Colesca et al. (2014) indicated that recycling knowledge, pro-environmental norms, and institutional support had a moderate effect on recycling behavior. Saphores et al. (2006) found that gender, education, convenience, and environmental beliefs had a strong relationship with the willingness to recycle, while income or political affiliation were found insignificant. Table 5 shows the significant and not significant socio-economic and demographic variables responsible for e-waste recycling behavior.

Table 5. Factors affecting e-waste recycling behavior

Socio-economic variable or others	**Significant**	**Insignificant**
Gender	Echegaray and Hansstein (2017), Milovantseva and Saphores (2013a), Martinho et al. (2017), Saphores et al. (2006)	Saphores et al. (2012), Colesca et al. (2014)
Age	Echegaray and Hansstein (2017), Milovantseva and Saphores (2013a)	Saphores et al. (2012)
Income	Echegaray and Hansstein (2017), Araujo et al. (2017), Yin et al. (2014)	Cai et al. (2020), Saphores et al. (2006), Colesca et al. (2014), Saphores et al. (2012)
Marial status		Saphores et al. (2012)
Households size		Saphores et al. (2012)
Location of participants	Echegaray and Hansstein (2017)	
Education level	Araujo et al. (2017), Yin et al. (2014), Saphores et al. (2006), Blake et al. (2019)	Cai et al. (2020) Saphores et al. (2012)
Home ownership		Saphores et al. (2012)
Ethnicity		Saphores et al. (2012)
Political affiliation	Blake et al. (2019)	Saphores et al. (2006)

Recycling behavior is strongly influenced by a “sense of duty” and perceived control, rather than subjective norms and benefits (Kumar, 2017). Nduneseokwu et al. (2017) and Wang et al. (2018) mentioned that attitude, subjective norm, and environmental knowledge significantly influenced consumers’ intentions to recycle. The mediating factor, such as infrastructure, influenced attitude and subjective norm and intention. On the other hand, pro-environmental activities and attitudes toward recycling small household electronics were essential in recycling the specific category of e-waste. Moral norms and environmental beliefs to recycle e-waste and to engage in pro-environmental behaviors were found critical. In e-waste recycling, subjective norms played a more significant role than the other constructs of TPB (Milovantseva and Saphores, 2013a, Wang et al., 2018). Papaoikonomou et al. (2020) found that total attitude (main significant predictor), WTP, information status, and subjective norm were other significant factors of WEEE recycling.

3.2.5.1.3 Characteristics of formal recycling system

According to Wang et al. (2011), Nixon et al. (2009), Dagiliūtė et al. (2019) and Ylä-Mella et al. (2015), in terms of infrastructural success factors, convenience and proximity of recycling facilities and service, and economic benefits and cost should be considered as the main characteristics of a successful recycling system. A centralized collection facility (One-stop drop-off points for all types of e-waste) could be an additional factor (Islam et al., 2020a). Of course, residential conditions and recycling habits were significant issues in such aspects (Wang et al., 2011). However, Lakhan (2016) identified that perceived environmental harm and visible fees (as a sticker on to a product) are strongly associated, which should be considered as counter-productive factors for WTP. Providing the solution to this problem, Dwivedy and Mittal (2013) proposed that visible and transparent fees and exchangeable sponsorship (where the ARF collected for one category of products is used to sponsor recycling of another category of products) in terms of fees should be implemented. Service-level integration could be built by E-waste recycling coupons, given to householders via rates payment receipts (of local councils' rates for general waste collection services) (Blake et al., 2019). The monetary influence was positively and significantly associated with the product take-back efforts, especially for young consumers (Ongondo and Williams, 2011). Song et al. (2012) mentioned that increasing the population's education level and propagandizing e-waste knowledge to promote residents' understanding should be considered a long-term and short-term approach, respectively.

3.2.5.2 Formal e-waste collection channel and EPR

Ramzan et al. (2019) mentioned that voluntary-based formal programs have fewer chances to ensure consumers' participation. Blake et al. (2019) identified that cost to recycle and lack of knowledge are the two barriers to success for the voluntary program. Qu et al. (2019) mentioned that collection price and collector's quality certification were the two critical attributes selecting collection services among the consumers. In terms of service preference, compensation mode, collection price, and convenience degree were the most significant factors for a formal collection channel (Zhang, Y. et al., 2019). Tan et al. (2018) and Arain et al. (2020) found that convenience of collection facilities at various locations, incentives, broader product coverage (especially small-sized e-waste), and a guarantee of information security was the leading product return performance indicators. When delivering products, "make appointment online or by phone first then have it picked up by the recycler" was the preferred method of collection among consumers (Bai et al., 2018). Arain et al. (2020) identified that factors for accessibility to recycling centers were pick-up services, e-waste drives, or providing a recycling drop-off center near campus. Bouvier and Wagner (2011) identified that recycling fees and frequency of the recycling facilities' opening were negatively and positively correlated, respectively, with the number of waste TV sets and monitors collected (e.g., collection rate) in the recycling facilities. Otto et al. (2018) identified collection cost reduction techniques as (1) curbside collection and deposit containers as a direct approach, and (2) the material and social enticements as an indirect approach.

3.2.5.3 WTP for formal EMS

Ramzan et al. (2019) and Li et al. (2012) found that young consumers’ were more in favor of “charging for discarding the product” for a formal EMS, and it varied from 0% to 5% of the recycling fees for the products. On the other hand, Liu et al. (2019) found that consumers’ WTP for e-waste has not increased for WMPs. Chung et al. (2011) identified some preconditions of the WTP. They found that collecting recycling fees involves some critical issues, such as (1) a high degree of transparency (using recycling funds), (2) levied

recycling fee, (3) visibility of the fees, (4) fees paid directly to manufacturers, (5) cost that covers proper recycling, and finally, (6) fees paid at the point of purchase. In terms of method of payment, Dwivedy and Mittal (2013) mentioned that a scheme charging after product take-back occurred is more preferred than advanced recycling fees (ARFs). Lakhan (2016) proposed that fees could be collected as "environmental handling fees are a form of tax."

In the studies of Afroz et al. (2013) and Huang et al. (2006), 52.5% of the residents showed a positive attitude towards WTP. Even though manufacturers should be responsible solely for the environment, consumers were willing to pay voluntarily to improve the environment (showing pro-environmental behavior). The amount of recycling cost that was agreed by the consumers (indicated as the highest percentage) was 0–5% of recycling cost (for households) (Yin et al., 2014), 5% - 10% of the product cost (Saritha et al., 2015), 10% of the product price (Shaikh et al., 2020), 1–2% of the product market price (Dwivedy and Mittal, 2013). The quantitative assessment showed that the mean monthly fee of WTP agreed among residents in Kuala Lumpur, Malaysia was US$8.09 per household (Afroz et al., 2015), while Song et al. (2012) found that in China, the mean WTP lower and upper values were US$2.20 and US$ 2.81 US dollar, respectively. Cai et al. (2020) found the amount as US$ 4.10 per month. For product-specific WTP, Arain et al. (2020) identified that US$12.60 to recycle a 32" television, and US$2.90 to recycle a battery, US$11.30 for a laptop, US$7.80 for a cell phone. Arain et al. (2020) also found that batteries, cell phones, and 32" televisions, laptops were among the top products for which consumers were willing to pay a recycling fee. However, Afroz et al. (2012) and Liu et al. (2019) found that some participants thought that paying for e-waste recycling is unrealistic. Song et al. (2012) and Islam et al. (2016) found that the reasons behind not willing to pay for recycling vary substantially depending on the participants' socioeconomic condition. For example, some consumers believed that it is the government's responsibility (services should be free of charge). As the informal sector pays consumers economic benefits, for this reason, most consumers felt reluctant to pay fees. Low household income and satisfaction with the current situation were also found to be the reasons for such a negative attitude. In addition to that, Dwivedy and Mittal (2013) found that higher cost of living, lack of time, and non-mandated regulations were some of the other causes of the attitude.

According to Afroz et al. (2015), education level, age, and household income significantly impacted households' WTP for improving the WEEE management system. Similar results were found by Song et al. (2012). Li et al. (2012) mentioned that educational level and awareness of recycling WEEE positively influenced WTP while income level did not.

3.2.5.4 Reverse logistics

According to Chung et al. (2011) and Ylä-Mella et al. (2015), the existing system should be more convenient, reliable, and accessible to consumers, which are the main characteristics of an RL system, as Favot and Grassetti (2017) found that additional collection points would enhance e-waste collection rate. Regarding the collection channels, more specifically for MPs, drop-off bins at retail stores, wireless service provider stores, mail-back services with incentives, central locations, the library would be potential locations (Milovantseva and Saphores, 2013a, Ongondo and Williams, 2011, Otto et al., 2018). For recycling service selection, Bai et al. (2018) proposed that recycling services would positively impact new MPs' sales. Consumers would choose a seller with the recycling service over other (conventional) sellers, and the price was given importance over convenience. Deng et al. (2017) found that price (the most critical factors), "ease of execution," "ease of contact," "ease of finding the location," "appropriate method of treatment/mobile phone recycling," and "service time" were the key variables in consumers' recycling experience. For highly-priced MPs, rewards are expected, and for cheaper models, convenience (Bai et al., 2018). However, two main barriers act in the process, specifically, for convenience degree of collection mode - excessive time and money (Zhang, Y. et al., 2019). To minimize the RL process complexity and cost, Bai et al. (2018) proposed that third-party recycling campaigns, convenient online second-hand transaction platforms would be beneficial. Jafari et al. (2017) mentioned that government support and private sector investment, awareness-building efforts should be the focus on areas of RL process optimization.

3.2.5.5 Informal sector

The informal sector is one of the key actors in the recycling chain and contributes to the circulation of materials and products. In other words, the informal sector influenced recycling behavior (Wang et al., 2016). Lau et al. (2013) found that selling e-waste to private (informal) e-waste collectors was the most preferred way among consumers due to perceived convenience. Environmental awareness, attitude, perceptions regarding informal recycling, and income were the direct determinants, whereas costs of recycling, social norms, and publicity were indirect factors selecting informal sector e-waste collectors (Wang et al., 2016). Zhang, B. et al. (2019) and Cao et al. (2018) identified that leading collectors' channels were street peddlers, appliance repairing stores, waste collection stations, and dismantling workshops. The informal sector's main characteristics providing collection services were convenient, flexible, accessible, acceptability of a wide range of e-waste categories (Chi et al., 2014).

3.2.5.6 Online-recycling platform

With the digital data-driven society, consumers are more willing to use online-based services for product purchase and product disposal. Zhang, L. et al. (2019) found that young students (as a growing consumer segment) are preferred to use online recycling platforms. Incentives are found interrelated with the willingness to participate in an online recycling platform. For example, Wang et al. (2019) found that willingness to deliver e-waste to online platforms was positively influenced by perceived behavioral control, subjective norms, attitudes, and economic motivation. Wang et al. (2019) also found that due to more significant economic benefits, willingness to participate in the platforms is higher than traditional (informal) section collection and recycling.

3.2.5.7 Critical barriers to recycling

Some of the critical barriers need to be focused on an efficient recycling system. For example, Liu et al. (2019) and Bai et al. (2018) found that information leakage, incentive, and convenience must be considered for any recycling system, while Thi Thu Nguyen et al. (2018) found that the inconvenience of recycling was negatively correlated to residents' recycling behavioral intention. For waste MPs, Tan et al. (2018) and Saritha et al. (2015) identified the main reasons for not recycling were lack of formal collection channels, 'low public awareness of collection responsibility' and 'insufficient promotion of formal collection' and price of returned product. According to Fraige et al. (2012), cost of recycling (the most critical reason), lack of recycling plants, lack of legislation and management systems, lack of awareness, lack of public trust regarding recycled equipment, and the unstable generation of WEEE that needs recycling were the main barriers. Gu et al. (2017) mentioned that consumers' lack of awareness regarding the appropriate destination of e-waste ("do not know where to send waste"), unexpected privacy disclosure, troublesome procedure, and lack of public awareness were the critical barriers to the recycling system.

4. Discussion and consumer-centric CE framework development

To enable a smooth transition towards CE, a multifaceted approach involved integrated measures is critical. This section discusses possible policy initiatives towards sustainable EM and business model innovation from the CE viewpoint, based on the in-depth literature review presented in section 3. Table A1 (in the appendix) provides a consumer-centric CE framework that connects the critical elements of CE building blocks, actors involved, sectoral perspective, and associated pathways of CE (combing elements of Fig. 1 and Fig. 2). This addresses a key gap in academic research to date by integrating all of these aspects in a single framework that focuses on consumer behavior and e-waste. This is potentially advantageous for developing national-level strategies and policies, with Table A1 also enabling the identification of future research opportunities. Section 4.1 and Section 4.2 discuss policy implications and business model development, respectively, in order to answer RQ1 in relation to the need for an operational framework to achieve CE around e-waste.

4.1 Policy implications towards CE

4.1.1 Consumer awareness campaigns and pathways for information dissemination

A diverse range of consumers (households, individuals, university students) was analyzed in the reviewed articles. There is a clear need for increased effort to organize awareness-raising programs and publicize e-waste collection and disposal-related information. Sector-specific programs to raise public awareness should be planned and delivered, targeting households, schools, universities, and the private sector (Islam et al., 2016). Specific education and course materials (in early childhood or elementary education) resulted in the successful collection of small WEEE in Spain (Solé et al., 2012). This approach can lead to the creation of an entirely new consumer base across diverse countries who are environmentally cautious and understand their roles and responsibilities in a sustainable EMS. Awareness-raising campaigns should include e-waste sorting, associated service providers, available disposal methods, material content, recycling campaigns, environmental protection, internet-based online collection system, and product labeling (e-waste logo at the back of an EEE). Additionally, if e-waste is recycled (resource conservation), then information on the amount of material and energy saved should also be the campaigns' components.

The government, more specifically, local government, plays a crucial role in disseminating knowledge and information on e-waste to the public to improve their e-waste management and recycling habits (Davis et al., 2008, Kahhat et al., 2008b). The media used for information dissemination could be via newspaper, audiovisual, personal communication, television and radio, websites or mobile apps, posters, information leaflets, social media, word of mouth (WOM), pilot projects, workshops, and seminars. Among these media, social networking sites are considered to be a cost-effective path for delivering this information (Ramzan et al., 2019). To reinforce moral and social norms, church groups might play a critical role (Saphores et al., 2012). Physical locations for disseminating information could be residential building entrances, shopping centers, and transport (during morning and evening consumers' travel time). The workplace could also be an essential place to raise awareness as working people spend much of their time in these areas.

The contents of awareness-raising material and frequency of circulating the information were found to be crucial in the reviewed studies. For information materials, attractive design and colors could be used and feedback sheets on current service satisfaction could be added. Product labeling with easily visible e-waste signs should be designed. Household waste collection bins should have stickers that inform consumers not to dispose of their e-waste items into the bin should be prepared (Lakhan, 2016). Source separation at the generation point (e.g., households) should be encouraged for adequate recovery. Publicizing information on the CE should also be promoted in a broader context.

4.1.2 Consumer-focused economic incentives

Economic incentives aimed at consumers are crucial to ensuring that disposed e-waste reaches formal collection and recycling facilities. Economic incentives can eliminate unused EEE items' storage behavior and improper disposal of e-waste (Nowakowski, 2019). Liu et al. (2019) and Tan et al. (2018) concluded that for value-added products, such as smartphones, incentives are critical. Mobile phone penetration rate should be considered as a regional development indicator. MPs often become obsolete due to "service contract ending," (Martinho et al., 2017, Ongondo and Williams, 2011), with MP network service providers commonly providing additional internet data packages as a motivator for consumers to upgrade to a new MP.

Direct incentives such as trade-in for cash (Tan et al., 2018), OFN (Chi et al., 2014) or discount/cashback offers (Martinho et al., 2017) have been found to be practical ways of providing financial incentives to encourage a CE for e-waste. In determining the optimal level of incentives, the discarded (or reusable) items' local market price needs to be estimated, with Kumar (2017) highlighting the importance of understanding "consumer selling behavior" in order to determine an appropriate incentive to return products such as MPs. This is particularly important in developing countries with intensive competition between the informal sector and formal e-waste collectors. However, according to Benabou and Tirole (2003), incentives are weak behavior reinforcers over the short term and negatively impact long term behavior. Incentives are also dependent on socio-demographic variables (Botelho et al., 2016), such as household size, income level,

education, marital status (Jafari et al., 2017). Students could be given monetary rewards (approximately USD 5 per student for small household appliances) considering value retrieved from secondary materials (Pierron et al., 2017).

Deposit-return schemes should be given special attention as an essential economic instrument (Saphores et al., 2012) for developed nations and developing countries. Despite being a developing country, the scheme was preferred by 36% of the Vietnamese respondents (the most-preferred scheme) in a Vietnamese study (Nguyen et al., 2021). The flow of e-waste can be streamlined under this system by establishing testing facilities and maintenance centers for R&R, by which reclaimed products can be transferred to a social organization for further use. Currently, a lack of legal incentives promoting repairs and second-hand sales is considered a barrier to reuse practice (Bovea et al., 2017). Kahhat et al. (2008a) proposed a deposit-refund system based on radio-frequency identification device (RFID).

4.1.3 Infrastructure development

Wang et al. (2011) found that the availability of collection and recycling services to consumers significantly affect their awareness levels. Without proper collection and recycling facilities, it is hard to implement a (formalized) EMS (Liu et al., 2019). Construction and improvement of e-waste recycling infrastructure are the first steps that governments should take to foster increased collection and recycling rates. Regional infrastructure development with the help of public support has been found to be particularly vital (Nowakowski, 2019), with a need for governments to subsidize investments in necessary facilities. Special collection events for small and IT equipment could be arranged. Permanent collection points and event collection in highly populated areas could be established (Fraige et al., 2012). An active monitoring system identifying e-waste flows in various final disposal points needs to be investigated by the waste management authorities and other stakeholders through collaboration and coordination mechanisms. Overall, there is a clear need to bridge the information supplied to consumers regarding formal collection and recycling facilities and local recycling infrastructure development for enhancing consumers' level of awareness.

4.1.4 Legislation and regulatory interventions

Policy formulation should be focused more on consumers' attitudes towards e-waste, with the behavioral insights provided by the reviewed studies used to inform government regulations and programs. To increase awareness around national e-waste recovery programs, it is important to consider age, household size, income, gender, and education level. EPR implementation with government and non-government organizations (NGOs) should be given more attention. In most instances, existing e-waste-related regulation was found to be weak and did not reflect consumers' economic perspectives. The imposition of penalties for improper disposal were also suggested by study authors and making consumers responsible at the collection stage was found crucial. In most of the cases, consumers from developing countries demanded price incentives (at the time of disposal due to the presence of informal collectors), and subsidy amounts that can motivate consumers to choose formal collection facilities need careful attention. In connection to this, regulatory reform and legally-binding provisions that make consumers more responsible for overall EM should be considered. Incentives to informal sector e-waste collectors also need to be provided for efficient and environmentally responsible recycling (Lau et al., 2013).

Advanced recycling fees (ARFs) mandated in e-waste-specific regulations are an option for mediating consumers' disposal habits. Although ARFs were identified by a majority of articles as a burden for consumers, if legal obligations bound consumers to pay the fee (in the form of ARF or recycling fees at the time of disposal). Implementing ARFs through product pricing was also found to eliminate economic bottlenecks in an EMS in Switzerland (Islam et al., 2018, Khetriwal et al., 2009).

Extended producer responsibility (EPR) implementation in developing nations is particularly challenging as it imposes a cost on consumers (Dwivedy and Mittal, 2013). The prospect of EPR as a mandatory program needs further attention from policymakers, which will eventually restrict illegal imports and informal sector downstream recycling process. As EPR holds manufacturers and producers accountable for sustainable product lifecycle management, two of the indicators (of product design) - product durability (quality) and

product lifespan- should be directly interlinked with the EPR policy agenda. Official take-back schemes through a compulsory retailer-based collection system should be considered further, as voluntary schemes often fail to ensure widespread public participation (Blake et al., 2019, Echegaray and Hansstein, 2017, Liu et al., 2019).

Increasing awareness among consumers is one of the fundamental tasks of any C&RS. However, a lack of information regarding collection centers' existence and locations was found to be a barrier to a CE for e-waste, highlighting the need for a greater focus on increasing consumer awareness in national policy planning. Milovantseva (2016) argues that public support for green product design regulations can increase their likelihood of adoption by governments. Emphasis should also be placed on providing small and medium enterprises (SMEs) with incentives and subsidies that encourage green entrepreneurship for product design and development of local recycling facilities.

Technology transfer for implementing EPR-related initiatives should be included in regional development planning. Training and capacity building of formal recycling sector stakeholders need to improve. Dwivedy and Mittal (2013) mention that market mechanisms fail within current EMSs due to externalities (informal sector in developing countries). Innovative financing mechanisms need to be established for setting up infrastructure in developing countries and internationalization of recycling law is needed in the light of EU WEEE Directive and EPR. The CE package initiated by the EU could be an example for policymakers in developing countries.

4.2 Business model innovation

4.2.1 Product design

According to Chuang and Liao (2018), "there is a pressing need to understand cultural differences in behaviors, particularly in the context of designing less resource-intensive products and services." Understanding consumers' engagement with EEE is vital to product design, especially as the reviewed studies show that psychological undesirability has far more effect than technological obsolescence on consumer behavior. Furthermore, it is seen that most of the consumers (regardless of the country) tended to save old EEE for spare parts, creating opportunities for modular product design and simple repairability using a user-friendly instruction (e.g. diagrams/process figures). In most cases, product user manuals provide information on product use with limited troubleshooting information or repair instructions. Supply of spare parts and repair service availability are interrelated, and products and parts manufacturers should focus on this issue during product design. Aspects such as material use (recycled or virgin materials), product lifespan related data (date of manufacturing, expected expiry date, years of service guarantee), visible e-waste logo, and RFID based product tracking system (to include recycling fees, monitor at the recycling centers/improper disposal) should be integrated with product design for sustainable EM planning. According to Dindarian et al. (2012), there are hardly any incentive available for designing products that facilitate reuse.

4.2.2 Secondhand product and supply chain

The growing secondhand product market is evident worldwide, primarily involving online product selling platforms such as eBay and Gumtree (in Australia). Oversight of this market by central authorities is needed to support local business and achieve consumers’ trust in used products. Service guarantee and quality assurance could be the key to a thriving used product market that integrate e-waste recycling services. The benefits of secondhand product purchase and use, and secondhand product stores and outlets should be considered by service providers. Incentive-supported modular repair service for WMPs could vastly reduce rapid product replacement.

4.2.3 Reverse logistics service provider

Economic incentives given to consumers in the form of collection price could form an integral part of the reverse logistic (RL) service model. The responsibilities of service providers are multifaced, including determining the appropriate mode of compensation, and ensuring that services are convenient to users. The

cost of recycling is an important aspect that should be visible (collected at the product purchase point). RL service providers must ensure the transparency of the process, and necessary policy and regulation should be formulated to support regular operation and maintain continuous consumer satisfaction. Telephone reservation and direct communication with the RL service provider would further enhance the product return process, with consumers preferring government-supported RL service providers for reasons of accountability (Park et al., 2019).

RL service providers may use the existing network of waste collection authorities (municipal council collection), and in this process, they can educate consumers and increase awareness. In this way, consumers' pro-environmental behavior could be further enhanced. Local government can play a critical role in enhancing public relations activities around e-waste collection, (Islam and Huda, 2020a), especially for WMPs. Information dissemination should be considered an essential operational activity for both local government and service provider. Campaigns focused on product lifespan with incentives could be organized to capture high-value materials from stored or unused items (e.g. MPs).

In collecting SE e-waste, opportunities exist for new small businesses to be developed around modular e-waste collection that, integrate OFN, exchange offers, and cash/coupon arrangements (in the case of reversible items). Subjective norms have been found to be critical to e-waste recycling, and RL service providers (both government-operated and privately-owned under government regulation) could significantly mediate behavioral intentions. This has the potential to reduce mobile phone storage, which has become a social norm. RL service providers could be standardized through certification (by government departments) to maintain the quality of e-waste collectors, including capacity to deliver repair services specific products.

Reliability and accessibility of service (e.g. number of collection points) was found to be critical in the articles reviewed. Generally, population centers should be targeted (Qu et al., 2019), potentially including retail stores (in the form of a drop-off bins), mobile network service providers' outlets (for WMP collection), libraries, supermarkets (dedicated areas for electronics stores). The service provision of reverse logistics arrangements should assess reasonable distance, ensuring collection points at the centers. Free mail-back service with incentives could also help to collect e-waste, especially for small e-waste items, as consumers are more concerned about service time and rewards from the collection channel. A flexible door-to-door collection could be established based on mobile apps and telephone reservations. Young consumers should be particularly encouraged to use online platforms for e-waste recycling. Partnering with informal sector collectors could help expand the collection network. Government support and policy initiatives are mainly required for this instance, especially providing incentives (Dwivedy and Mittal, 2013). On the other hand, establishing relationship with charity and secondhand product stores and businesses would bypass product flows that are generally destined for recycling only. In this aspect, consumers' perceived behavioral control-related issues should be closely observed, particularly any changes in recycling behavior in the presence of a government-supported RL service provider.

4.2.4 Online markets and data management for EG

More products are now being sold online than ever before, and in the recent COVID-19 pandemic, sales of electronic products have been skyrocketing (World Economic Forum, 2020). Simultaneously, the online market - both new product sales and second-hand market, should be considered an essential element of product life management. For this case, the use of internet-of-things (IoT), "big data analytics" for combining socio-economic data with the distribution of waste across a geographical location, and blockchain technology could provide new insights on consumption habits as well as improved data quality on EoL product traceability (Zhang, A. et al., 2019, Zhang et al., 2010). The importance of data-oriented product labeling was found by several researchers, for example, research by Bovea, M.D. et al. (2018) and Huang et al. (2006). Major indicators of e-waste generation levels include device replacement rates, household device penetration rates, and products' service life (Arain et al., 2020, Fraige et al., 2012). Data can be collected on product lifespan by identifying the date of manufacturing and when consumers posted an advertisement for a product. This way, firsthand product use characteristics (lifespan-related data) could be gathered and utilized by applying various statistical models, such as the Weibull-distribution-based sales-stock-lifespan model.

4.2.5 Mobile applications and social media

The use of technology, especially mobile apps, to support behavioral change is increasingly considered a useful tool to reduce e-waste (Kang et al., 2020). Although platforms such as Love Recycling, Taolv, Haoshou, and Baidu have already become popular platforms (Wang et al., 2019), broader service coverage is required for this effort. Further attention is also required around standardized price-setting and service innovation (for persons over 60 years of age). Government intervention is required for online/internet-based collection platforms for e-waste collection and recycling, as concerns over privacy are critical. These services should be expanded not only for waste MP but also for other e-waste items. Promoting the platform to rural and remote areas is another key task, which could be developed using optimized artificial intelligence (AI) algorithms (Nowakowski et al., 2018) and integrating IoT and subscription accounts on social media platforms (Jiang et al., 2021). Providing substantial incentives and training to local formal collectors should be considered in a smart EMS.

4.2.6 Charity organization and retailer coordination

Many used products flow to charity organizations after initial product use. The most viable donation organizations are a charity and local schools (Gupta et al., 2014), where product reuse is often significantly higher than for other niche consumer segments. For example, Kahhat and Williams (2012) found that 60% of computers donated to charitable organizations were reused. This shows that there is a secondary product market (other than the conventional online EEE selling-buying platforms), which requires specific attention. There is an opportunity for charity organizations to provide repair services at a larger scale, creating jobs in local communities (Islam and Huda, 2020c). Technical, financial, and physical support from government, business and philanthropic organizations is needed to support the operations of charitable organizations. Donation sites and information campaigns on product reuse could be organized at schools and offices of social service providers.

An integrated approach could be adopted that incorporates EEE retailers, whereby consumer might buy secondhand refurbished products from retailers (repaired by charity organizations), alongside new equipment (Islam and Huda, 2020b). In that case, certification and quality assurance would be required to achieve consumer trust and acceptability. Retailers should be provided the necessary infrastructure support to collect disposed items by consumers, and retailers might provide cash/incentives to consumers. Establishing optimized collection points for repair services and setting standardized repair price also require further attention. Secondhand product circulation will be successful if retailers, manufacturers, service providers, governments, and charity organizations work together.

5. Analysis of research gap and future research directions

After reviewing 109 articles in this work, several research gaps were identified and analyzed in detail. These are discussed below to address the requirement of RQ2 around the potential for further research studies:

- Apart from China and India, the number of studies that have been performed on consumer beahvior around e-waste in developing countries is limited and requires further attention (as per Fig. 3). Germany is also a gap, with only one paper identified despite it being one of the largest e-waste generating nations globally (Islam et al., 2020b). It is understood that German EM is well developed; however, investigation on consumers' repair and reuse, and storage behavior would substantially provide insight for other developed nations, which is currently missing in the academic research.

- Through the policy and business interventions discussed in section 4, there is an opportunity to study changes in consumers' behavior over time (before and after interventions are implemented).

- Consumers from so-called innovative sities (highly IT enabled cities or cities with high tech companies present) should be investigated further. This was revealed as a key research opportunity in this review, with a potential list of cities prvided by Leskin (2018). This also supports the call from Borthakur and

Govind (2019) for "more locale-specific" studies to understand the dynamic behavior of e-waste disposal and awareness across nations.

- Consumer behavior across product categories needs further attention. For example, disposal behavior for SE and LE category is entirely different. As such, how consumers act for spercific products (e.g., DVD player vs. refrigerator) or for specific groups of products (e.g., SE vs. LE) require investigation. Through this, potential improvement opportunities could be identified for specific types of products.

- There is a clear opportunity for researchers to further investigate consumer consensus around ARF systems. In some studies, the WTP amount was investigated but the desired amount of incentives (cash or any other method) that consumers required was not investigated. Furthermore, WTP-related studies should focus more on implementing analytical methodologies such as analytical hierarchy process (AHP), analytical network process (ANP), and conjoint analysis. In responding to WTP-related questions in a survey, pictoral representations of e-waste collection and recycling services could be provided to deliver information to consumers about their roles and responsibilities (financial and physical).

- The economic benefits of internet or online-based system from consumers' perspective require future research. In this regard, identifying flows of e-waste would be a key first step, and implementing material flow analysis (MFA) models would be beneficial. MFA is capable of quantifying which platforms are profitable (traditional vs. online collection) considering all the actors (e.g., government, consumers, network platforms, processing facilities) in the RL supply chain (Islam and Huda, 2018a).

- Most of the studies reviewed were focused on the individual and household-level. Specific attention should be given to other consumers such as government offices, higher education institutions, and large multi-national companies. Technological companies should be future study areas, as mentioned by Fraige et al. (2012).

- This study identified that a smaller number of studies were conducted considering the young population, more specifically, students studying at the universities. Future studies should focus on this group of people as it is also found from the articles that this group's possession rate in some of the EEE is higher than the general population, indicating that different social norms may apply to this group.

- Close attention is required around product return management through follow-up research into, for example, the funding mechanisms needed for informal collectors, price setting for various types of e-waste (dedicated to consumers), and the role of various stakeholders in the development of facilities.
- Wang et al. (2011) found that substantial differences exist in term of e-waste storage behavior among homeowners and renters in China. Future research should target these two groups of residents and investigate their e-waste disposal and recycling behavior, including in other countries. Furthermore, the authors found that income and level of education were not significant predictors for the group, so better statistical aspects considering other socio-economic variables such as the number of families in the households, the number of children need to be considered. Echegaray and Hansstein (2017) mentioned that high-income group adequately dispose of e-waste in appropriate channels in Brazil. However, it is necessary to understand why low-income residents are not involved in recycling and their potential demand for such services, including in other developing countries.

- As cheaper products tend to have shorter lifespans, product design characteristics need to be investigated further. By analyzing samples across a range of products, a bill of materials (BoM) could be developed, and essential design modifications (cost and quality efficient products) could be identified by engaging YUSs. Babbitt et al. (2020) recently applied BoM for collecting disassembly properties of EEE.

- Consumers' eco-friendly behavior remains until the product purchase, but is diminished in the use-phase, and at the EoL phase. Future research should identify the reasons for such practices focusing on product design, environmental labeling, and other factors. Echegaray and Hansstein (2017) mentioned that e-waste is not seen as a recyclable item as compared to other recyclable items such as paper, plastics, and others. "Why consumers do not consider e-waste as recyclable items?" is an open research question.

- According to Borthakur and Govind (2019), e-waste-related studies are now being conducted mostly from natural/applied science disciplines. An interdisciplinary approach is required in understanding consumers' behavior towards e-waste from social science and policy research areas. A holistic techno-economic perspective (considering engineering perspective and social changes) needs to develop within the field of research (Awasthi and Li, 2018).

- The introduction of internet-based collection systems has created an integrated cyber-physical space in which EM occurs, with Cao et al. (2018) proposing that block-chain technology could be applied in transportation and payment in the online e-waste collection system. This platform can collect data on annual EEE production, sales, recycling amount of e-waste, and these data can be used as valuable inputs for future policy formulation. IT is one of the emerging research areas that requires considerable attention.

- Regarding online collection systems and formal recycling platforms, further research is needed into participant perceptions, especially for low-income and low-education participants. For older people, the scope, and service innovations required for internet-based recycling platforms requires further attention. Apart from MPs, there is a knowledge gap around how consumers dispose of their other e-waste items in the collection channels. Estimating acceptable collection prices (as per consumer demand) also requires further investigation.

- Cross-cultural studies are required to understand consumers' demand for specific e-waste collection options (door-to-door, council pickup, permanent collection points, online-based system), and the associated need for incentives. For example, do citizens from China intend to behave the same when they emigrate to developed countries such as the USA, Australia, or Canada? How do cultural differences affect e-waste related consumer behavior (e.g. local people vs. immigrants)?

- Few studies were found that had been performed on R&R behavior. Further investigations are required into consumer perceptions of this issue and local government policy on the topic (e.g. how local waste collection authorities engage consumers with repair shops and charity organizations). Major inhibitors need to be investigated further from developed countries' contexts.

- Financing mechanisms for deposit-return systems is a research gap, that requires further investigation. The mechanism's impact on the online-based collection platforms and retailer-based collection needs special attention to identify optimal exchange offers for consumers. MPs and other small IT and equipment require further consideration in this regard.

- According to Wang et al. (2011), the most critical factors attributed to using appropriate recovery channels are recycling habits, economic benefits, the convenience of recycling facilities and services, and residential conditions. These aspects need to be considered further for urban areas in developed countries. It is assumed that most consumers feel reluctant to dispose of e-waste through formal collection and recycling channels due to the considerable amount of time involved.

- TPB was found to be one of the most widely utilized methods on the research topic. Future research should pay attention to the large population size, and source, more representative samples from rural and urban populations. Face-to-face interviews should be used more often to understand other consumer behavior dimensions, as this was performed in only a limited number of studies. In addition, it was observed that most of the studies applied TPB in the case of recycling behavior (as seen in Table A2 in the appendix), leaving further opportunities to assess consumers' consumption, reuse, and repair and storage behavior. In the case of CB, TPB application could observe connection with recycling intention, especially for products which are environmentally-friendly or designed under theoretical concepts such as green phones or green vacuum cleaners. Product-focused case studies involving TPB are also limited, as it was observed that recycling and disposal behavior is largely associated with the product type and category. Solar PV panels will be an emerging e-waste stream (Islam et al., 2020c, Mahmoudi et al., 2019), and, in that case, TPB application would provide a broader understanding of consumers' consumption and recycling behavior. Moreover, other constructs (of TPB) might be considered in consumption-related issues, such as product design, repairability, availability of recycling-oriented service (in a take-back system) connected with a product purchase, incentives, and disposal convenience. Nduneseokwu et al. (2017) mentioned that case-specific variable integration, such as situational factors, psychological factors, and eco-friendly values, could be integrated into an extended TPB model. These factors could be added by investigating possible interrelations between multiple behaviors at once, such as storage and repair and reuse. The general TPB constructs were not assessed for secondhand product purchase, and in the future, researchers should identify the factors associated with the consumers' reuse behavior. For example, do peer-pressure and social norms affect the R&R behavior? These issues were not extensively analyzed and need further attention. The impact/influence of TPB application among the participants could be observed over time (same number of samples after implementing intervention and observe the change of intentions).

- Consumer preferences for retailer-based collection points for e-waste disposal require further attention. EU WEEE Directive places a specific focus on retailer-based collection (Directive, EC, 2012). Improving WMP collection channels and residents' environmental awareness is one of the future research areas (Zhang, Y. et al., 2019).

- Computer and IT-related equipment were found as dominant product categories. Future research should obtain specific data (via a survey) on lifespan profile that eventually will help estimate EG for each category within a given region. Urban mining is an essential aspect that connects with this idea, and policymakers can identify opportunities for improvement in future policy planning from the studies.

6. Conclusion

In this comprehensive literature review article, consumers' behaviors and awareness regarding e-waste were thoroughly reviewed by analyzing 109 articles published in international peer-reviewed journals. The studies were categorized according to various behavioral aspects, such as consumption, repair and reuse, storage, disposal, and recycling. Finally, the article proposed a consumer-centric circular economy framework that indicates necessary policy initiatives and opportunities for business model innovation towards attaining a circular economy (CE) for the first time in academic research.

The research contributions of this review article are: (1) it provided a guide or reference for future researchers to accumulate all the information and knowledge surrounding consumer behavior-related topics focusing on e-waste; (2) it attempted to establish a connection (framework development) between CE (building blocks and pathways) and consumer behavior around e-waste for the first time. In many cases, published papers did not consider the CE concept into their central research theme, focusing instead on various behavioral aspects. The

framework incorporated behavior-specific aspects into CE pathways, creating interdisciplinary research opportunities in the field; (3) besides, presenting, a quantitative assessment of the research progress in the field, the article provided a transparent and replicable methodology, which could also be utilized collecting materials from other available databases; (4) in this paper issues related to policy and business model innovation are discussed, respectively, which provide suggestions for both researchers and policymakers in system-level development and future research areas; and (5) on the research topic, potential future research directions have been identified, which could be useful for future researchers.

One of the critical research findings is that consumers are demanding a substantial change in existing e-waste management systems. Issues requiring the attention of researchers and policymakers around both product and service innovation include formal e-waste collection options, data and information security, collection prices, modes of compensation, service options (online, door-to-door, curbside collection, proximity to permanent recycling centers), confidence and participation in online recycling platforms, and low-cost repair.

Consumers' awareness regarding e-waste should be raised through education and campaigns. More diversified strategies involving social media and information provided at physical locations are required to have an impact on consumers' storage and repair and reuse behavior. A specific focus is required on frequency and content development for awareness-raising campaigns. Regulatory frameworks require further attention in relation to informal sector recycling, extended producer responsibility, payment size and method in take-back systems, public engagement provision, and mandatory product stewardship schemes. In developing a national EM policy, regional aspects and city-wide socioeconomic diversity should be considered, rather than implementing a one-size-fits-all solution. To achieve better material circularity, government support through tax relief and subsidies should be provided to local recycling companies and cooperation should be established between electronic product manufacturers and local waste management authorities.

Manufacturers have a role to play in the product end-of-life stage and the product design stage to enhance consumer perceptions of convenient product disassembly (for recycling) and enhanced repairability. Online product selling and exchange sites play a critical role in influencing consumption behavior. In that regard, the government can develop a national inventory database on (category-wise) product sales and (statistical) parameter identification for waste generation estimation. Consumers' selling behavior and its impact on manufacturers' reverse logistics operations should be considered a research opportunity. Service innovation in e-waste collection for the aged population and the case of small e-waste items should have a particular focus.

Despite the complex interdisciplinary nature of the research, this paper provides an introductory guide to researchers investigating several issues in one single place. Most importantly, it is often hard to provide a generalized recommendation linking circular economy principles (building blocks) and associated pathways as socio-economic conditions, policy, and regulation are both country and culture specific. In this case, a more interdisciplinary research approach could be taken by future researchers in the field.

A global focus on consumer awareness and behavior towards e-waste has been considered in this review article, collecting, and analyzing articles published in the international peer-reviewed journals. As the focus topic encompasses an interdisciplinary field of research, if any paper missed the WoS database keywords, it might not appear in the collection and would not have been included in the analysis. Future research should utilize other keywords and integrating other search engines such as scholar.google.com. Extending the literature review to journals in other languages may address some of these gaps, but language barriers could also create difficulties around researchers learning from other nations' experiences.

It is hoped that this paper will have value for policymakers in developing strategies and for researchers in conducting future research into the multidimensional research theme of advancing knowledge around e-waste and circular economy. For future research, an interdisciplinary approach is required that seeks to understand the complex dynamics of consumer behavior including how it varies across different products and waste streams.

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Appendix

Table A1. Consumer-centric CE framework focusing consumer behaviors towards e-waste

Main issue or task to accomplish	Associated behavioral impact	Building block of circular economy	Sectorial perspective	Circular economy pathways	Actors involved	Proposed measures achieving circular economy
Understanding and perceptions of e-waste						
Awareness and capacity building	B3	PSU, P	E, S	M, R, Rf, Rc	C, G, SP	- Provide general awareness on the environment and health impact of improper e-waste handling via environmental education, publicity campaigns, social media, and public consultation at the local level
Information material	U	P	M, S, B, L	M	SP, G	- Designing campaigns and educational materials focusing on age
Familiarity of collection and recycling programs						
Amendment in legislation	U, B3, B5	P, PSU,	L	-	G	- Implement legislative provision letting the public know about the existence of e-waste-related policies and regulation as well as the e-waste handling process
Information dissemination on policy, regulation, and economic opportunities	U, B5, B3	P, R, B, T	L, B, E	Rc	G, SP	- Provide information on the reward and punishment system, environmental degradation caused by informal sector recycling, economic and environmental benefits of online-based (e-commerce) collection system
E-waste recovery program/scheme-related awareness	U, B3, B5	R, P,	B, S	Rc, R, Rf	G, SP	- Communication campaigns at the local level on available recovery program (special attention to WMPs and SE which are portable or easily thorn away with household waste), (nearest) collection points and availability of dedicated for e-waste collection services (e.g., door-to-door, curbside pickup), schedule of collection points (opening and closing hours), type of e-waste collected at the points, an environmental contribution of appropriate recycling (secondary material resource utilization) by

						public announcement and media coverage, internet, social media
Economic incentives from recovery/take-back program	B3, B5	B, R, P	E, M, B	Rf, Rc	G, SP	- Improved publicity of economic incentives on the returned product at university and colleges
	B3, B5, U	R, P, PSU, T	E, E, S, B, L	Rc	G, SP, C	- Community-based intervention for the high e-waste recovery rate and inclusion of the concept of urban mines at the policy level
Consumption behavior						
Event-oriented collection system	B3	B, PSU, R	B, M	Rc	G, SP	- Arrange targeted awareness-raising campaigns, and provide product take-back service in special events and occasion in a year - Information campaigns dedicated to young consumers, especially users of laptops and MPs at universities
Integrated consumption and reuse	B4	B, PSU, P	B, M, Tech	M	PoM, PaM	- Enhanced repair service for LE extending product lifespan
Product-specific consumption	B1	B, PSU, R, P	Tech, E, M, S, B, L	M, R, Rf, Rc	C, SP, G	- Develop national and regional level EM planning by analyzing consumption pattern and focusing on categories products: screen category (plasma TV sets, laptops), LE (e.g., refrigerator, WM, AC), SE (e.g., digital camcorders, digital camera, irons, hand blenders, hairdryers, vacuum cleaners, and heaters), small IT (tablets, DCs, MPs, routers, and modems)
Multi-channel device acquisition source	B1, B3, B5	B, PSD, R, P	M, B, L	M, R, Rf, Rc	G, PoM	- Recognizing importers (of cheap non-brand EEE) under a product take-back system
Role of online EEE retail websites	B1, B3, B5	B, P, PSD, R, PSU	M, E, B, L	Rc, R	G, PoM, SP	- Assigning well-defined role and responsibility of (foreign and local) online and physical retail outlets in EM planning

Government's product take-back services	B1, B3, B5	PSU, PSD, R, P	S, L	M, R, Rc, Rf	G, SP	- Improved planning on product take-back and awareness-raising while promoting government-supported IT training program to avoid high product obsolescence rate, and later orphan products in the waste stream
Green products' eco-labeling and environmental features in products	B1, B3, B4, B5	PSU, PSD, P	Tech, M	M, R, Rf, Rc	C, PoM, PAM	- Provide information on expected service lifespan, use of material (% of recycled material), environmental benefits (water and energy-saving if the product used an extended period), CO2 emission, date of manufacturing, and others in pictorial form (and mostly in the user manual) rather long texts - Promote pro-environmental and sustainability-related educational campaigns during new product launch organized by famous brands - Extend green product design (simple disponibility and material recovery) concept to LE - Develop young consumers' demand-oriented product design for product lifespan extension (e.g., battery life, convenient replacement of screen, and others)
Mitigating measures against high device replacement	B1, B3, B4, B5	PSU, PSD, P	Tech, M	M, R, Rf, Rc	C, PoM, PAM	- Establishing authoritative quality assurance services for repair - Make available brand-specific spare part such as a battery for MPs and laptops by original equipment manufacturers (OEM)
Campaigns on product lifecycle thinking	U	PSU, PSD	S	M, R, Rf, Rc	SP, G,	- Organize information campaigns at universities and education institutions on product life cycle thinking
Product lifespan and EG	-	PSU, PSD	Tech, E, B, L	M, R, Rf, Rc	G	- Develop a national-level product-specific lifespan database (using local data) as an input utilized for regional and national EM planning
Product labeling	B1	PSD, P	Tech, M, B	R, Rf, Rc	PoM, PaM	- Integrate "energy and resource use" and expected device lifespan in eco-product labeling

Mobile phone - lifespan	B3, B4	B, PSU, PSD, P	B	R	SP, G	- Develop mobile phone-related lifespan database combining direct waste analysis and contract history maintained by network operators
Monitoring of mobile phone network operator	B1, B3	PSD, P, R, B	B, L, E	R, Rf, Rc	SP, PoM, PaM	- The role of network operators (mainly for MPs) and their activity associated with the waste disposal scenario should be monitored by a centralized waste management authority as the product contain high-value material.
Storage behavior						
Lack of awareness for hibernated resources	U, B2, B4	PSD, P	S, B	M, R, Rf	G, PoM, PaM	- Organize information and publicity campaigns on unutilized resources (environmental value), consumers' product stewardship responsibilities, recycling program, locations of collection points, recycling facilities - Arrange mass training and (online) information shearing platform for repair
Data backup service	B3, B5	PSD, P, B, R	Tech, S, B	Rc	SP	- Data removal process at the point of purchase with necessary data backup service
Lack of spare parts usage platform	B2, B4	PSD, PSU, B	Tech, E, M, S, B	R, Rf	SP, G, PoM, PaM	- Online and offline (at repair café) spare parts sharing opportunity supported by part/device manufacturers
Disposal behavior						
Increasing awareness on disposal	U, B3	PSD, P	S, L	Rc	C, G, SP	- Door-stepping information campaigns (on the environmental, economic, and social problem) caused by improper disposal (with household waste) of e-waste, cost of disposal, current e-waste-related regulations, and availability of legal channels for disposal (location of collection points) with a specific focus on young (student) consumers
Components of new product launch	B1, B3	PSD, B, P	S, B, M, L	Rc	C, PoM, G	- The new product launch's marketing campaign should raise consumers' awareness of proper e-waste disposal.

Mobile apps development	B3	B, PSU, PSD, P	Tech, S, B	M, R	PaM, C, SP	-	Developing online information platform (mobile app) finding the current state of malfunctioning of a product and possible measures to be taken
Product-specific collection campaigns	U, B3	PSD, R, B	S, B	Rc, R	G, SP, PoM	-	Organize product-specific collection campaigns (e.g., WMPs)
Role of manufacturers in disposal	B3	PSD, PSU, R, P	B, M, E	R, Rc	PoM, SP	-	Organize manufacturers' collection system for LE (white goods) and relatively greater size of IT equipment
Point of e-waste collection	U, B1, B3	PSD, P, R	E, B, S	R, Rc, Rf	G, SP	-	Establish disposal points at the point of purchase (e.g., retail stores)
Product design (PD) – Parts replacement	B1, B2, B3, B4	PSD, T, R	Tech, E, B	R, Rc, Rf	PoM, PaM	-	Modular product design for reduced malfunction and rapid parts replacement
PD – Product label	B1, B2, B3, B4, B5	PSD, T, R	Tech, B	M, R, R, Rf	PoM	-	Develop product labeling on expected service lifespan of a product
Lack of appropriate amount of incentives	B3, B4, B5	PSD, P, R	M, B, E	M, R, Rf, Rc	PoM, SP, G	-	Setting appropriate collection price against informal sector collectors along with other incentives such as OFN, discounted price for new product purchase, deposit-refund under formal e-waste take-back service
Monitoring products' quality	B3, B4, B2	PSD, R, P, T	S, B, E	R, Rc	SP	-	Assessment of cost of disposal against product reuse potential
Mixed collection method development	B3, B4	PSD, B, R, P	E, S, B	M, R, Rf, Rc	SP, G	-	Develop a creative (online/mobile app-based) e-commerce platform by integrating online and offline resources integrating RL service providers
Focus on universities providing incentives	B1, B2, B3, B4, B5	PSD, B, R, P	S, B, E	M, R, Rc	G, SP, PoM	-	Universities as an e-waste collection hub (as well as district urban mines) providing incentives to students for a higher collection rate
Inclusion of informal sector	B3, B5	PSU, P, R, B	E, B, S, L, E	R, Rc	G, SP	-	Introducing the informal sector as a collection service provider along with a formal RL system
Product-specific collection channel	B3, B2, B5, B4	B, PSD, PSU, R, P	B	R, Rc	SP	-	Arranging a free-of-charge door-to-door collection system (for both SE and LE)

Integrated collection system	B3, B5	PSD, R, P, T	E, Tech	Rc	G, SP	-	Integrating e-waste collection with general household waste handling system (using sperate collection vehicles)
Capacity enhancement of second hand (repair) stores	B3, B4	B, PSD, P	Tech, S, B	M, R, Rf	SP, PoM, PaM	-	Enhancing technical capabilities of secondhand stores and repair shops for the enhanced refurbished product delivery (especially for smartphones, laptops, tablets, and notebooks)
Promotion of online recycling platform	B5	B, PSD, R, P	Tech, S, B, E	Rc	G, SP	-	Encourage e-waste sorting and promote online recycling platforms among young consumers
Enhancing capabilities (EC) of the charity organizations	B3, B4, B5	B, PSU, PSD, R, P	Tech, E, M, S, B	M, R, Rf	G, SP, PoM, PaM	-	Technical and social capability enhancement of charity organizations with the support of government and product manufacturers
EC of repair and secondhand stores	B4	PSD, B, R, P	E, B	M, R	PoM, PaM	-	Develop efficient product return management of retail stores (for brand new products), second-hand stores, and repair shops
EC of local manufacturers	B3, B5	PSD, R, P	B, S, E	R, Rc	PoM	-	Improved arrangements of local manufacturers' e-waste collection (especially waste MPs)
EC of local government	B3, B5	P	L, B, S	M, R, Rc	G, PoM	-	Enhanced role of local municipalities and manufacturers educating consumers and collecting e-waste
Repair and reuse behavior							
Information dissemination	B4	PSD, P,	S, B	R, Rf	SP	-	Dissemination of information on repair shops' locations, price of repair work, the time required for repair work
Enhanced consciousness about secondhand product use	B4	B, PSU,	E, S, B	R	C, SP	-	Quality assurance authority should be built as an intervention, especially in cost and confidence, highlighting acceptability of a service
EPR integration and incentives for repair	B4	P	L	R, Rf	G, PoM, PaM	-	EPR integration in product repair-related tasks and guaranteed repair service for costly EEE as an incentive
Consumers' engagement in product design	B1	PSD, T, P, B	B, Tech, E, S	M, Rf	PoM, PaM	-	Enhance initiatives on green product design engaging consumers, specifically energy-saving products, and LE

Input material and disassembly characteristics	B1	PSD, P	Tech, E, E, B, L, M	Rf, Rc	PoM, PaM, G	-	Increased disassembly properties for optimized separation and parts replacement (mainly for cheap EEE items) and improved used of recycled material and remanufactured components
Informed decision making on product purchase	B1, B3, B4	PSD, P	S, Tech, B	R, Rf	PoM, PaM	-	Information dissemination of product durability, environmental contribution, repair-ability via design and labeling
Product labeling associated to product use and EG estimation	B1	PSD, P	Tech, L, B	M, R, Rf, Rc	PoM, PaM, G	-	Date of manufacturing, expected lifespan (based on service guarantee), the material used, and material quantity in product labeling and/ or user manual
Standardization - cost	B4, B2, B3	PSD, P, B	B, S, E	R, Rf	SP, PoM, PaM	-	Repair-cost optimization depending on product types and conditions
Standardization – service delivery	B1, B2, B4, B4	PSD, P, PSU	E, M, S, B	R, Rf	C, SP, PaM, PoM	-	Product-centric malfunctioning list development and improved availability of cheap spare parts for rapid repair
Product-specific repair initiatives	B1, B4, B2	PSD, P	Tech, E, M, S, B	R, Rf	PoM, PaM	-	Initiate increased product-specific repair initiatives (especially for MPs, TV sets, laptops, and refrigerators)
Role of manufacturers	B4	PSU, PSD, P	Tech, B, L	R, Rf	PoM, G	-	Engagement of manufacturers in repairing the product with minimal cost
Community engagement	B1, B2, B4	PSD, P	S, Tech	M, R	C, G	-	Creating a community knowledge platform for product repair
Repair and charity organization	B1, B2, B4,	PSD, PSU, P	S, L, B	M, R, Rf	G	-	Engagement of charity organization with government support
Secondary market development (SMD) - certification	B4	PSD, P, B	M, L, B	R, Rf	G, SP, PoM	-	Creating centralized authority for certification of quality reusable EEE
SMD – product price	B1, B4	B, P, PSD	M, S, B	R, Rf	PoM, PaM	-	Optimized price setting for repaired products without compromising durability and performance
SMD – service assurance	B1, B4	PSD, B, P	Tech, E, M, B	R, Rf	PaM	-	Service guarantee (as product lifespan warranty) of repaired products at stores (second-hand/ repair/refurbished product stores)

SMD – Periodic performance evaluation	B1, B4	PSD, B, P	S, Tech, E, M	R, Rf	G, SP	-	Monitoring performance of repair stores and charity organizations against technical and service delivery standard
Recycling behavior							
Recycling-related information campaigns	B5, B1, B3	PSD, P	L, E, S,	Rc, M, R	G, SP, PoM, C	-	Consumer awareness campaigns for environmental benefits on recycling, laws and regulations, recycling centers' location, available disposal options under formal collection channels, operating hour of the recycling centers, resource use, formal collection channels, environmental impact caused by informal sector recycling
Recycling service optimization	B3, B5	PSD, B, R, P, T	Tech, E, M, S, B	Rc	SP, G	-	Determination of optimized collection center location, product-specific cost of recycling (collection price optimization depending upon original product price), collection modes (cyber and physical), e-waste collector's quality certification, service reservation (online and via phone)
Establishing collection points	B3, B5	PSD, B, R, P	B, E, S,	Rc	G, SP, C	-	Development of pickup service (door-to-door), placing collection centers at population centers (e.g., library, train stations)
Integration of cyber-physical system	B5	B, PSU, PSD, R, P	E, B, S	Rc	G, C, SP, PoM	-	Motivate young consumers using online recycling platforms (if available), including incentives integrating online money transaction platforms
Incentives in recycling system	B5	B, R, PSD, T, P	E, M, S, B, L	Rc	PoM, SP, G	-	Ensure incentive-oriented participation of consumers under mandatory scheme covering a wide range of product at e-waste collection points and usability of incentives (in the form of coupons) for the products
Mandatory Information security	B5, B3, B4	B, PSD, R, P, T	Tech, B, L	R, Rf, Rc	G, SP, PoM	-	Guaranteed information security (if required) for disposing of items
Visible recycling fees	B3, B5	B, PSU, R, P	E, L, S, B	Rc	G, SP	-	Transparency of e-waste handling authority in terms of optimized cost (depending upon product price)

						contributed by consumers introducing visible recycling fees (for gaining greater public trust)
Structure of recycling fees	B3, B5	P	E, L, S	Rc	G, SP	- Assessment of recycling fees collection method (advanced recycling fees at point of purchase/fees collection at the point of disposal or in the form of tax (with other household municipality tax)
Capacity improvement of retailers	U, B1, B3, B5	P, PSD, B	E, B, L	Rc	G, SP, PoM	- Capability enhancement of retail stores collecting e-waste for recycling
Flow of (disposed) product	B3, B4, B5	B, PSD, R, P	M, E, B, L	R, Rf, Rc	G	- Monitoring final product flow from repair shops and secondhand product selling platforms
Recycling infrastructure development	B2, B3, B5	P, T, R	Tech, E, B	Rc	G	- Increase formal recycling facilities and associated low-cost technology for economies of scale

Note:	
Associated behavior and aspects	U: knowledge and awareness, B1: Consumption, B2: Storage, B3: Disposal, B4: Repair and Reuse, B5: Recycling
Building blocks of circular economy	B: Business model, PSU: Product/service use, PSD: Product/service design, R: Reverse supply chain, P: Policy, T: End-of-life Treatment
Sectorial perspective	E: Environment, Tech: Technical, E: Economic, M: Market, S: Social, B: Business, L: Legislative
Circular economy pathways	M: Maintain/prolong, R: Reuse/redistribute, Rf: Refurbish/Remanufacture, Rc: Recycle
Actors	C: consumers/users, SP: Service provider, PoM: Product manufacturers, PaM: Parts manufacturers, G: Government/policymakers

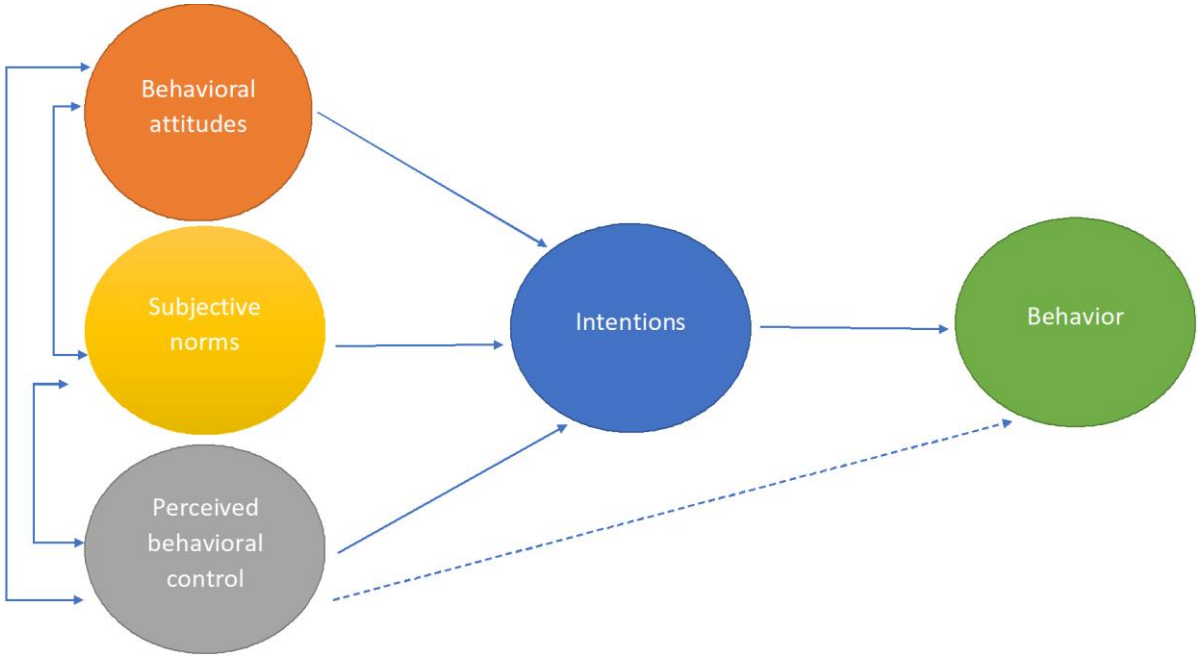

Fig. A1. Main constructs of TPB, adapted from (Ajzen, 1991)

Table A2. TPB-related studies on consumers' behavior towards e-waste

Reference	Country	Product	Behavior considered	Aspects considered	Main factor identified for behavioral intention			Additional construct considered in the study
					Under the construct of	Under the construct of	Under the construct of perceived	

					behavioral attitude	**subjective norm**	**behavioral control**	
Liu et al. (2019)	China	MPs	Recycling	Difficulties in recycling WMPs	Perception of negative effects, environmental sensitivity, and environmental responsibility	Personal influence and group influence	self-ability and recycling convenience	-
Echegaray and Hansstein (2017)	Brazil	E-waste in general	Recycling	Intention and behavior gap among consumers in major metropolitan cities	Favorable views of recycling	Perceived social acceptance of recycling	infrastructure and convenience	"Socio-demographic and socio-economic variables", "degree of awareness", and "personal (environmental) assessment" towards the problem
Kumar (2019)	India	E-waste in general	Recycling	Cross-cultural study on young consumers' recycling behavior	-	-	-	Individual Responsibility, consequences Awareness, Sense of duty, and convenience
Nduneseokwu et al. (2017)	Nigeria	E-waste in general	Disposal	Assessing key determinants on recycling intentions in a formal collection system	-	-	-	Infrastructure, environmental knowledge, and economic incentive

Thi Thu Nguyen et al. (2018)	Vietnam	E-waste in general	Recycling	Examining key factors influencing the behavioral intentions or pro-environmental behavior	Environmental awareness and attitude of recycling	Social pressure and laws and regulations	Cost of recycling and inconvenience of recycling	Past recycling experience, residents' socio-economic characteristics
Wang et al. (2019)	China	E-waste in general	Recycling	Assessing wiliness to participate in an online recycling platform and identification of influencing factors	-	-	-	Economic motivation and convenience
Wang et al. (2018)	China	E-waste in general	Recycling	Impact of information publicity	Personal norm and recycling attitude	-	-	Awareness of consequences, ascription of responsibility, and personal norms variables as component for NAM model
Shaharudin et al. (2020)	Malaysia	E-waste in general (mostly small and IT equipment)	Disposal	Assessing disposal intention of small portable e-waste items	Perceived convenience and perceived benefits	Perceived norms	Perceived policy effectiveness	-
Yuan et al. (2020)	China	MPs	Trading (selling) behavior	Investigating decision-making mechanism of recycling rate of reusable mobile phone	Active wiliness to vote, environmental protection, public literacy,	Environmental policy constraints, neighbor's behavior, family member influence,	Specification of recycling channel, trading determination, active trading behavior	Under "Recycling facilities and services": recycling facility convenience, trading convenience,

					consumer trading returns	promote environmental education		recovery time cost and information leak sensitivity
Papaoikonomou et al. (2020)	Greece	E-waste in general	Recycling	Investigation on the factors affecting recycling intention	-	-	-	Outcomes and consequences and concern for the place of residence, total attitude, WTP and information status regarding WEEE recycling
Kumar (2017)	India	MPs	Selling	Understanding motivations and intentions of consumers' selling WMPs and its impact on RSC management	-	-	-	Sense of duty and perceived benefits
Wang et al. (2016)	China	E-waste in general	Recycling	Analyzing influencing factors towards consumers' recycling behavioral intentions and impact of informal sector recycling on the intentions	Environmental awareness and attitude of recycling	Norms and publicity	Convenience of recycling, cost of recycling, perceptions of informal recycling	Socio-demographic variables (gender, age, income, and education)

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Declaration of competing interest

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

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