Development of E-waste Management Strategies for Selected E-Products in India

THESIS

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CERTIFICATE

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ABSTRACT

The mounting global population has witnessed a rise in demand for Electrical and Electronic Equipment (EEE), causing a consequential increment in the generation of Electronic Waste (e-waste). EEEs play a vital role in modern life in terms of safety, comfort, education and entertainment, there is a tremendous increase in consumption of EEEs worldwide. This is resulting in a spiraling rise in the rate of e-waste generation. A developing country such as India ranks third in the list of e-waste producers globally, just after China and the United States. E-waste is significantly different from other solid waste because it has non-biodegradable material. Interestingly, e-waste can be an alternative source of material to conserve natural resources, and the exploration of the same is termed urban mining. It includes various reusable and precious materials as an economic frontier potential. Also, it contains many hazardous substances which are very harmful to the environment and living beings. Scientific and safe extraction of material from e-waste is necessary, if e-waste is not processed adequately, it can lead to contamination of soil, water and air thereby producing adverse effects on the biosphere. Despite the growing concern about e-waste generation, there is very limited development in appropriate supply chain for e-waste management, especially in developing countries. In India, e-waste collection and recycling are dominated by informal sector. The regulatory framework and vigilance are at the same time inadequate to ensure appropriate handling of e-waste, there is also a lack of awareness among the general public.

This study aims at analyzing the e-waste management strategies and focuses on the e-waste collection system in the Indian context. The research discussed initiates to understand the e-waste management system through a literature survey and interactions carried out in the form of site visits and semi-structured interviews with the various stakeholders such as collectors, dismantlers, recyclers and policymakers. The data were also collected from 491 Indian residents via an online survey for investigating individual's e-waste disposal behaviour and their preferences for e-waste disposal modes. Gaps in research, thus identified, are attempted to be solved by adopting systematic methodologies. To understand the e-waste management strategies i.e. policy & regulations, the necessary condition for a successful reverse supply chain (collection system) and consumer disposal behaviour further an extensive literature review is carried out. Outcomes denoting the existing e-waste policy and its need to upgrade are critically analysed to find factors that can successfully drive the e-waste collection policy. A fuzzy DEMATEL method is employed to evaluate the critical success factors in terms of cause group and effect group. This is further proceeded to assess the sustainable e-waste collection methods for urban and rural regions of India. A fuzzy AHP method is employed for determining the weights of the attributes and sub-attributes while fuzzy VIKOR is employed to identify the ranks of alternatives. Subsequently, an empirical investigation of the resident's disposal behaviour in terms of consumption, replacement, knowledge and awareness about e-waste, barriers and e-waste disposal options is carried out. Also, evaluated the consumer's psychological factors that influence e-waste disposal modes. Finally, a case study is carried out to analyse the reverse logistic system of e-waste collection using the vehicle routing optimization method.

Results obtained will lay the struts for the circular economy concept and develop sustainable e-waste management strategies that align with and accomplish the targeted sustainable development goals. The outcome will aid decision makers, academicians, practitioners and policy-makers in determining possible strategies for improving e-waste management system.

The suggested implications provide scientific knowledge about e-waste supply chain, which is essential for a sustainable society and a harbinger of a sustainable circular economy.

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LIST OF ABBREVIATIONS/SYMBOLS

Adjusted Goodness of Fit Index	AGFI
Analysis of Moment Structure	AMOS
Analytic Hierarchy Process	AHP
Analytic Network Process	ANP
Ant Colony Optimization	ACO
Average Direct Relationship Matrix	ADRM
Average Shared Variance	ASV
Average Variance Extraction	AVE
Brominated Flame Retardants	BFR
Capacitated Vehicle Routing Problem	CVRP
Center of Area	COA
Central Pollution Control Board	CPCB
Chi-Square	χ2
Close Loop Supply Chain	CLSC
Column maximum value of u_{ij}	$\max u_{ij}^{k}$
Column minimum value of l_{ij}	$\min l_{ij}^{k}$
Comparative Fit Index	CFI
Confirmatory Factor Analysis	CFA
Consistency Index	CI
Consistency Ratio	CR
Corporate Social Responsibility	CSR
Crisp value defuzzified from TFN	z_{ij}^{k}
Critical Success Factors	CSFs
Decision Makers	DMs
Decision Making Trial and Evaluation Laboratory	DEMATEL
Defuzzified Direct Relationship Matrices	DDRM
Degree of Freedom	χ2/df

Degree of influence factor i on factor j	$\tilde{a}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$
Deposit Refund System	DRS
Electrical and Electronic Equipment	EEE
electronic retailer	e-retailer
Electronic Waste	e-waste
End of Life	EoL
European Union	EU
E-Waste Disposal Behaviour	EDB
Extended Producer Responsibility	EPR
Fuzzy Direct Relationship Matrix	$\widetilde{A}$
Fuzzy Numbers Into A Crisp Score	CFCS
Fuzzy VIKOR	FVIKOR
Fuzzy-AHP	FAHP
Geographic Information Systems	GIS
Goodness of Fit Index	GFI
Green House Gas	GHG
Hexavalent Chromium	[Cr(VI)]
Interpretive Structural Modelling	ISM
Lead	Pb
Left spread measure of normalised fuzzy number	$x\mathrm{ls}_{ij}^{k}$
Maximum Shared Variance	MSV
Mercury	Hg
Million Metric Tons	MMT
Ministry of Environment Forest & Climate Change	MoEF & CC
Multi Attribute Decision Making	MADM
Multi-Criteria Decision Making	MCDM
Municipal Solid Waste	MSW
National Environmental Agency	NEA
Non-Government Organization	NGO

Normal Fit Index	NFI
Normalised Direct Relationship Matrix	NDRM
Normalised value of (l_{ij}, m_{ij}, u_{ij})	$(xl_{ij}, xm_{ij}, xu_{ij})$
Number of experts	k
Organizational Economic Cooperation Development	OECD
Original Equipment Manufacturers	OEM
Path Coefficient	β
Perceived Behavioral Control	PCB
Polychlorinated Biphenyl	PCB
Polyvinyl Chloride	PVC
Printed Circuit Boards	PCBs
Producer Responsibility Organization	PRO
Radio Frequency Identification Device	RFID
Random Index	RI
Recycling Fund Management Board	RFMB
Reduce, Reuse, Recycle	3Rs
Restriction of Hazardous Substances	RoHS
Right spread measure of normalised fuzzy number	$x\text{us}_{ij}^{k}$
Root Mean Square Error of Approximation	RMSEA
Simple Genetic Algorithm	SGA
Solving the E-waste Problem	StEP
Square Multiple Correlation	R2
Standardized Root Mean Square Residual	SRMR
State Pollution Control Board	SPCB
Statistical Package for the Social Sciences	SPSS
Strength Weakness Opportunities Threat	SWOT
Structure Equation Modelling	SEM
Sustainable Development Goals	SDGs
Swiss Association for Information, Communications and Organization	SWICO

Theory of Planned Behaviour	TPB
Threshold Value	α
Total normalised crisp value	x_{ij}^{k}
Total Relation Matrix	TRM
Triangular Fuzzy Number	TFN
United Nation	UN
United States	US
Vishwakarma Industrial Area	VKI
VlseKriterijumska Optimizacija I Kompromisno Resenje	VIKOR
Waste of Electrical and Electronic Equipment	WEEE

1.1 What is e-waste?

Over the past three decades, the digitization revolution has provided a platform to reach an entirely new market, especially in electronic industries, due to the development of new technologies gazelles and services. There is a substantial social dependency on Electrical and Electronic Equipment (EEE) to live a satisfying life. Therefore, the demand and consumption of EEE are increasing in upper bounds. Whereas consumer requirements are changing in a shorter lag of time either due to a reduction in product life span or EEE technology upgrade, which leads to early disposal before End of Life (EoL). Eventually, obsolete EEE are discarded by owners and is referred to as Electronic Waste (e-waste) or Waste of Electrical and Electronic Equipment (WEEE). Various international treaties describe and categorise e-waste/WEEE on the basis of their category, source of generation, composition and the cause of their EoL.

According to European Union (EU) WEEE Directive 2012/19/EU, "waste within the meaning of Article 3(1) of Directive 2008/98/EC, including all components, sub-assemblies and consumables which are part of the product at the time of discarding". Basel Convention defined "e-waste as substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law". Organizational Economic Cooperation Development (OECD) defines appliances as using a power supply that has reached its EoL and is referred to as WEEE. StEP initiative 2014 (Solving the E-waste Problem) describes e-waste as a term to cover items of all types of EEE and its part that has been discarded by the owner as waste without the intention of re-use. Another definition of e-waste is provided by the Ministry of Environment Forest & Climate Change (MoEF&CC),

India, WEEE means EEE, whole or in part discarded as waste by the consumer or bulk consumer as well as rejects from manufacturing, refurbishment and repair processes.

1.2 E-waste problem and mitigation

E-waste is a stream of solid waste that needs to be handled separately from the Municipal Solid Waste (MSW) generated by the same households, business segments and public/private institutions. It consists of everyday items and parts such as computers, mobile phones, charging cables, televisions, kitchen appliances, imaging devices, toys, leisure, sports equipment and internet devices (Baldé *et al.*, 2017). E-waste is significantly different from other MSW because it has non-biodegradable material. It contains many valuable resource materials such as precious materials (i.e. gold, silver, platinum, palladium, ruthenium, rhodium, iridium, and osmium), rare earth materials (i.e. Cobalt (Co), Germanium (Gr), Indium (In), Palladium (Pd), Bismuth (Bi), and Antimony (Sb)) as well as common building blocks like Copper (Cu), Aluminium (Al) and Iron (Fe), Their by making this waste stream an alternative resource of raw material (Arya and Kumar, 2020). While there are also a host of non-biodegradable materials and hazardous chemicals like various grades of plastics, Polychlorinated Biphenyl (PCB), Brominated Flame Retardants (BFR), Polyvinyl Chloride (PVC), and metals like Lead (Pb), Mercury (Hg), and Hexavalent Chromium [Cr(VI)]. These toxic elements have grave potential to pollute the environment and pose a threat to human health if e-waste is not processed scientifically before disposal. The presence of hazardous substances in e-waste classifies them as a hazardous waste stream, while many valuable reusable materials also can be recovered through proper recycling from e-waste. E-waste has both hazardous and valuable characteristics and therefore must be managed distinctly and scientifically for the sustainable development.

Accumulation of e-waste is an emerging and significant challenge for waste management in both developed and developing countries (Tansel, 2017). Global e-waste production reached 53.6 Million Metric Tons (MMT) in the year 2019 with 7.3 kg per dweller, and it is estimated that the amount of e-waste generated will exceed 74 MMT in 2030 (Forti *et al.*, 2020). The increase in WEEE generation was 17% during the period from 2014 to 2019, while collections increased by only 10% (Forti *et al.*, 2020). In terms of e-waste production, continent-wise, Asia led the ranking with a generation of 24.9 MMT in 2019, followed by the Americas (13.1 MMT), and Europe (12 MMT) while Africa and Oceania generate 2.9 MMT and 0.7 MMT, respectively (Awasthi and Li, 2017). The residents of Europe and Oceania regions generate maximum per capita e-waste, with 16.2 kg and 16.1 kg, followed by Americas (13.6 kg per capita), Asia (5.6 kg per capita) and Africa (2.5 kg per capita), respectively. China ranked first worldwide in terms of e-waste generation with 10.19 MMT followed by the USA (6.91 MMT), India (3.23 MMT), Japan (2.56 MMT) and Brazil (2.143 MMT), respectively. Therefore, this is going to be a staggering problem as the WEEE generation rate continues to rise even higher in the foreseeable future (Ardi and Leisten, 2016). Particularly in many developing economies including India because of the proportionally higher waste generation rate than waste handling capacity.

For management of e-waste, various countries have developed their own rules and regulation for collection, dismantling and recycling. Developed nations have their own and mature e-waste management policies such as EU WEEE Directive 2012/19/EU for European countries, StEP initiatives for United States (US) countries and the 3Rs (Reduce, Reuse, Recycle) initiative introduced by Japan (Wath *et al.*, 2010). Switzerland established and promoted the Swiss Association for Information, Communications and Organization Technology (SWICO), the first comprehensive e-waste management system that covers all aspects of collection to disposal (Chi *et al.*, 2011). In EU countries, the principle behind directives for collection, recovery and reuse has been through EPR, making producers responsible for the take-back of e-waste from commercial and domestic (Gavilán García *et al.*, 2012). Canada, Australia and South Korea are among other countries having well-developed formal e-waste management systems based on these principles and also provisions for steep penalties for improper handling of e-waste (Sthiannopkao and Wong, 2013). Developed countries successfully managed their social awareness programs and education in the past. For instance, more than 50% of Switzerland's citizens expressed a desire to place the highest emphasis on environmental issues as recorded in a survey (Chaudhary and Vrat, 2018).

Many developing nations such as India, Malaysia, Indonesia and China have their own e-waste management rules and regulations getting formulated but these countries are not making large investments towards establishing any resilient framework for e-waste management, which could enable better handling of e-waste virtually guaranteeing the reduction of e-waste generation as well as recovering of valuable resources (Iqbal *et al.*, 2015). The regulatory framework and vigilance are in their formative stage and are inadequate for mitigating WEEE-related issues in the whole country, further public awareness is also deficient. As a result, a large part of e-waste gets dumped or transported from developed countries as a donation, or hands-down etc. (Garlapati, 2016). Some of the direct causes identified by Thavalingam and Karunasena (2016) are that in developing nations there exists insufficient corrective measures, unclear roles of stakeholders, and insufficient investments in the e-waste management sector. These are challenges that are believed to be arising out of a lack of social awareness and inadequate legal & enforcement framework. The same acts as an encouragement to the informal or grey sector handling a vast amount of e-waste, as observed and recorded in Bangladesh, Malaysia, Indonesia, the Philippines and Brazil (Rodrigues *et al.*, 2020). The situation is not much different in the case of India.

Effective e-waste management requires enforcement of legislation at the ground level and describes the responsibility of producers, dealers, collectors, refurbishers, dismantlers, recyclers, auctioneers and bulk consumers involved in the manufacturing, sales, purchasing and processing of EEE (Pandey and Govind, 2014). In 2011, the MoEF&CC India issued guidelines for E-waste (Management and Handling) Rules, 2011 based primarily on the Extended Producer Responsibility (EPR) principle for effective channelization of E-waste to the registered collectors, dismantlers and recyclers (CPCB, 2018). The OECD described EPR as 'an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a products life cycle including its final disposal (OECD, 2016). A further extension of E-waste (management) rules came up in 2016. The amended rule has provisions for Producer Responsibility Organization (PRO), and Deposit Refund System (DRS) (Garlapati, 2016). PRO means a professional organization authorized or financed collectively or individually by the producers, which can take the responsibility for the collection and channelization of e-waste generated from the 'EoL' of their products to ensure environmentally responsible disposal of e-waste (CPCB, 2018). While DRS means that the manufacturer charges additional fees at the time consumers purchase an electronic device, which is reimbursed to the consumer when they return the product to a certified recycler

(CPCB, 2018). Kumar *et al.* (2017) suggested that the role of government is extremely important for the development of required infrastructure and implementation of e-waste management strategy in India. Pathak and Srivastava (2017) proposed an integrated system for e-waste management, which combines informal and formal sectors to achieve the maximum collection and recycling rates and mitigate environmental concerns. The policy needs to be properly designed to appropriately approach the advancement of the formal recycling sector in India (Awasthi *et al.*, 2018).

1.3 Research motivation

India is the third-largest generator of e-waste after China and USA. The WEEE source of generation mainly includes household appliances (42%), information and communication devices (34%), consumer electronics (14%) and others (10%) (Arya and Kumar, 2020). E-waste processing in India is mainly handled by informal sectors where technology intervention is minimal, and they also pose a great threat to the labour face involved as well as the environment in general. A joint study conducted by MAIT-GTZ reported that the informal sector is responsible for the handling of about 90% of the e-waste processed in India (Khattar *et al.*, 2007). E-waste is mostly collected by the informal sector through various routes which include garbage pickers, local recyclers, kawadiwalas (scrap dealers) as well as small and medium enterprises. These sources keep little or no record of the amount and quality of e-waste handled. They are also not conscious of the harmful effects of e-waste disposal (Wath *et al.,* 2010). The informal sector mainly collects e-waste from residents at a very low cost or glean from dump yard (Raghupathy *et al.*, 2010). The main goal of informal sectors is to extract and recover saleable materials and reusable parts, using crude methods (Wath *et al.,* 2011).

The residual materials are discarded on open land, or mixed with other solid waste or are burnt (Baji and ChandraSekhar, 2013; Zhang *et al.*, 2014). Pandey and Govind (2014) focused on the economic value of e-waste and the opportunities it provides for employment in the informal sector in urban India. But, recognized that the crude methods adopted for dismantling and processing are serious for health and environment and society (Reddy, 2015). Several factors are responsible in India for the thriving of the informal sector processing bulk of e-waste such as cheap labour, a strong second-hand market, lack of enforcement, and low investment requirement (Chakraborty *et al.*, 2018).

Formal e-waste recycling requires specially constructed facilities with safety protocols and standard equipment that enable the safe extraction of salvageable materials (Dwivedy and Mittal, 2010). These facilities also need to ensure safe working conditions. Currently, there is a limited number of formal e-waste collection facilities in India (Song *et al.*, 2012). Kaushal and Nema (2013) pointed out that at present, a very low amount of e-waste is processed and separated by the formal sector, under a regulated and safe environment with worker health protection and emission control. Awasthi *et al.* (2016) observed that there is a better opportunity for formal recyclers in terms of resources and income generating opportunities. The major issue faced by the formal sectors is that they face a tough challenge from the informal sector as the latter conducts collection activities bypassing labour regulations. Lack of subsidy or support from the government, lack of strict implementation of regulation, expensive recovery processes, logistics issues (e.g., transport costs), high capital investment, absence of access to state-of-the-art and technology, low-profit margin, absence of competitive price, and rather low-level of environmental awareness are listed any the major challenges faced by formal recyclers in India consumers (Ravindra and Mor, 2019). This is considered a serious threat to the growth of India's recycling capabilities, a country with very inadequate recycling infrastructure (Jayaraman *et al.*, 2019).

1.4 Research objectives

The objectives of this study are as follows:

- Analysis of various critical success factors to design e-waste collection policy in India. Also set appropriate standards and controls to regulate the action of stakeholders associated with e-waste handling in both public and private sector.
- Evaluation of sustainable e-waste collection methods for the urban and rural regions of India.
- Determination of EEE consumption pattern and WEEE disposal behaviour of individuals and households in India.
- Determination of consumer behaviour towards e-waste disposal mode in India.
- Development of an intelligent and responsive vehicle routing model for e-waste collection 'on demand service'.

1.5 Structure of the thesis

Management of e-waste was observed from various perspectives for theory building and to provide a proposed framework and methodology for mitigation in order to improve sustainability and system performance. To suffice these requirement, the thesis is organized in the following chapters:

Chapter 1 presents the introduction of the thesis. Chapter 2 provides a comprehensive literature survey on e-waste management undertaken to explore various perspectives. This includes a literature survey on e-waste policy, collection system, including intelligent collection system, consumer disposal behaviour and research gap identification.

Chapter 3 analyses the various critical factors that influence the e-waste collection policy through a structural approach. Chapter 4 develops a hierarchical model of sustainable e-waste collection methods for rural and urban India. Chapter 5 presents the empirical analysis of individual EEE consumption patterns and WEEE disposal behaviour with help of survey data. Further, Chapter 6, includes the Structure Equation Modelling (SEM) approach developed through the Theory of Planned Behaviour (TPB) concept to investigate the impact of consumer's behaviour towards the e-waste collection system. Chapter 7 discusses a case study on the development of an intelligent collection system through vehicle routing problems with an analysis of the number of vehicles required on a daily basis on customer demand service. Finally, Chapter 8 gives the summary of work done, the contribution from the work, limitations and future scope. A graphical illustration of the adopted thesis outline is mentioned in Figure 1.1.

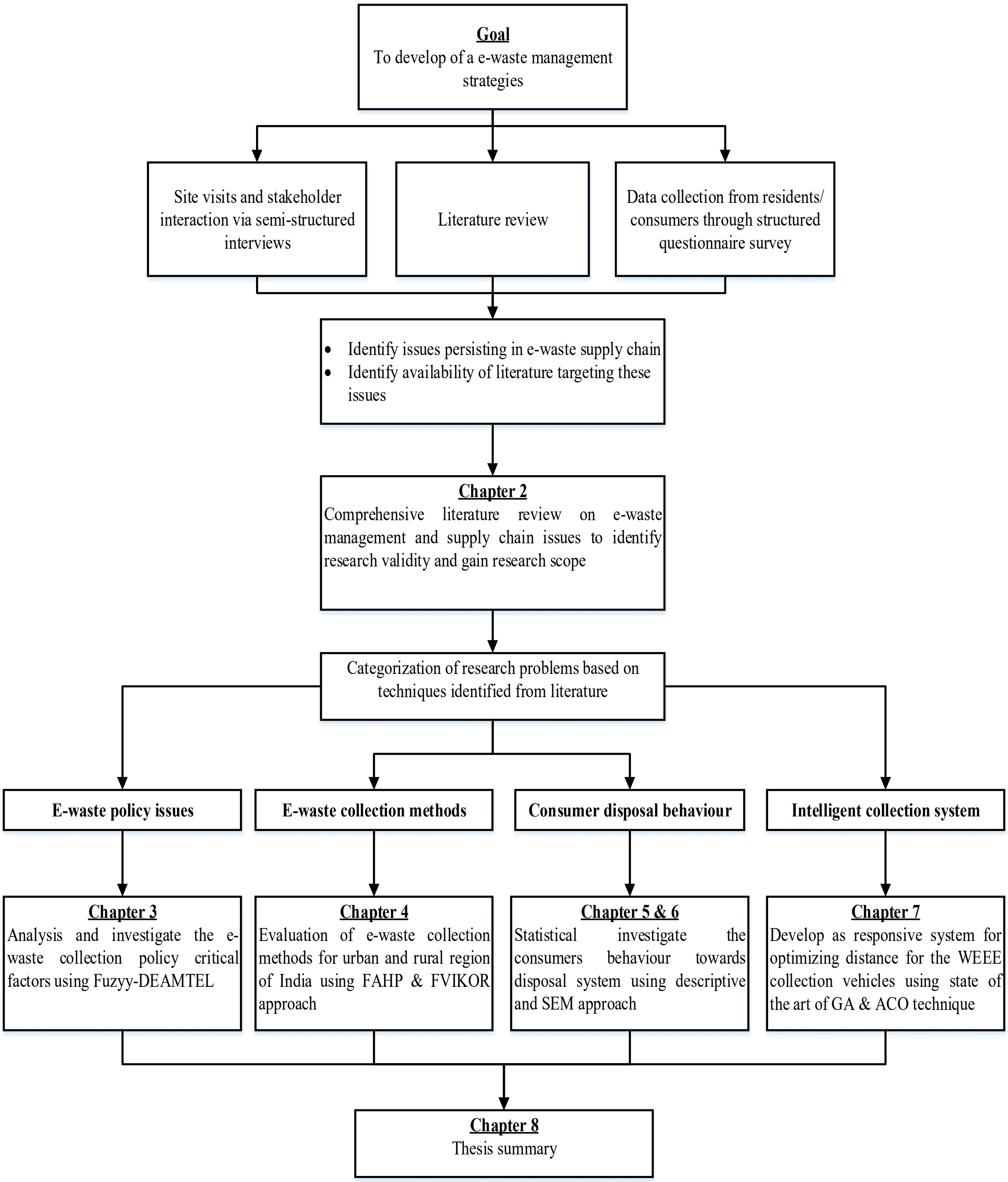


Figure 1.1: Thesis structure

This chapter presents a literature review and establishes the methodologies utilised to evaluate e-waste management in detail with reference to prior articles. The literature review is carried out in various dimensions such as e-waste policy, various collection systems, consumer disposal behaviour, modern and intelligent collection systems. Relevant literature was meticulously explored and extracted from the Scopus database for conducting a bibliometric analysis. It is found that e-waste management, as a topic of research is gaining popularity among academicians and practitioners. This chapter also discusses use of bibliometric tools to evaluate the available literature on e-waste management. A comprehensive outlook of the waste management facets in a developing country has been missing in terms of sustainability and circular economy concepts. This work filled the gap in research, on e-waste management in the Indian context.

2.1 Introduction

With rapid technological advancements in the EEE sector, consumption grew very fast in domestic and commercial applications in the recent past (He *et al.*, 2006). The EEE is progressively being used in various areas such as kitchen appliances, health monitoring devices, transportation, entertainment and information and communication technology. As a result, the contributed to the global e-waste crisis is also increasing (Awasthi and Li, 2017). According to United Nation University (UNU), fifty-four EEE items have been grouped into six categories based on their utility, material composition, average weight and life span. These six categories are temperature exchange equipment, screens and monitors, lamps, large equipment, small equipment and small IT and telecommunication equipment (Forti *et al.*, 2020). EEE contains various recyclable materials and hazardous substances and is disposed of and recycled in different ways (Onwughara *et al.*, 2010). However, e-waste is a non-biodegradable waste and if not managed in an environmentally sound manner, it is highly detrimental to the environment and human health (Singh, *et al.*, 2021a).

The fast-paced EEE market and consumption pattern are well evident worldwide, contributing to year on year rise in e-waste by 10-20% per year (Islam and Huda, 2019). Statistically, the global e-waste generation in 2019 was about 53.6 MMT, or 7.3 kg per habitant (Forti *et al.*, 2020). It is estimated that the amount of e-waste generated in the year 2030 will be more than 74 MMT (Sabbir *et al.*, 2022). The global volume of e-waste is increasing at an alarming rate of about 2 MMT per year. The e-waste data reported by various countries shows that only 17.4% of e-waste is formally collected and recycled while the rest 82.6% of the e-waste generation is not documented or collected by the informal sector for processing (Shittu *et al.*, 2020). It is evident that large amount of e-waste generated in every year is managed outside the official collection system and also in many cases, get shipped to the low or middle-income countries such as Bangladesh, China, Ghana, India, Nigeria and Pakistan as hands down or gift (Duan *et al.*, 2016; Dutta and Goel, 2021; Iqbal *et al.*, 2015; Onwughara *et al.*, 2010). 78 countries are found to have formal e-waste legislation to regulate their e-waste generation, collection and recycling (Forti *et al.*, 2020). Nevertheless, it should be noted that many countries with national e-waste legislation are not able to implement regulations at the grassroots level (Arya and Kumar, 2020). Major factors that influence e-waste regulation and management activity are lack of social awareness (Wath *et al.*, 2010), lack of measurable collection and recycling goals (Gollakota *et al.*, 2020), limited infrastructure for collection and treatment facilities (Ni *et al.*, 2021), growth of the informal sector (Williams *et al.*, 2008), lack of data traceability and communication (Duan *et al.*, 2021), lack of coordination among stakeholders and lack of sustainable management practices on ground (Kazancoglu *et al.*, 2020).

Inappropriate and unscientific recycling has become a great threat to the ecosystem and also human health (Mohammed and Chandran, 2021). E-waste is also a secondary resource of useful materials and extraction of material through urban mining can become a significant environment friendly practice (Singh *et al.*, 2021b). The urban mining of e-waste is a progressive way, it creates a better chance for society to develop sustainable business and job opportunities in recycling activities such as collection, dismantling, segregation and recycling, particularly as it reduces the burden on nonrenewable resources (Tesfaye *et al.*, 2017).

The United Nations (UN) developed the Sustainable Development Goals (SDGs) 2030 for various issues related to the environment, economy and society (United Nations, 2015). A total of seventeen agendas are decided for SDGs 2030 in which six goals are related to a better understanding of e-waste management (Kang *et al.*, 2020). It is also closely linked to Goal 3: good health and well-being, The Goal 6: clean waste and sanitation, The Goal 8: decent work and economic growth, The Goal 11: sustainable cities and communities, The Goal 12: responsible consumption and production and, also The Goal 14: life below water. Various countries are needed to amend e-waste policies and have established action plans according to SDGs 2030. India revised its e-waste policy and has set an ambitious collection target to recover 70% e-waste by 2023 (CPCB, 2019). There is relatively less burden on developed countries to accomplish the agenda of SDGs because have well filled infrastructure for e-waste management, access to advanced recycling technologies and well-established e-waste collection channels.

The origin of e-waste research can be traced back to the 1990s. This was the decade that saw booming of production of electronics items of mass usage. At that time e-waste or WEEE was not a frequently used term, but e-waste was included along with solid waste management and categorized as hazardous waste. In the year, fifty-three countries signed an international environment agreement known as the Basel Convention. This agreement set goods for curbing the transboundary movement of hazardous waste and discussed the restriction necessary for toxic waste movement from country to country (Basel Convention, 2002). Although, the Basel Convention had no direct influence on e-waste management or movement but it had positive influence. After that, there was a series of agreements signed by European Union (EU), while the first directive was Restriction on Hazardous Substances (RoHS) 2002/96/EC, and it entered into force in 2004 (Selin and VanDeveer, 2006). The primary aim was a restriction on movement and dumping of hazardous waste during manufacturing of EEE. Another directive, 2012/19/EU was formulated as recast with more clarity and focus and introduced a new collection target, based on e-waste generated per year. EU subsequently updated and renewed the directives in the year 2014, 2017 and 2019 to revise the collection target with respect to the new EEE put on the market (Habib *et al.*, 2022; Shittu *et al.*, 2020). Researchers have reviewed and critically analysed these reports in order to recognize e-waste management challenges and opportunities, and they provided various opinion on e-waste research.

After three decades of progress, the year-on-year research on e-waste issues has grown rapidly, as much attention has been drawn to this topic in previous years. Some these articles focused on methodological framework, policy design, supply chain issues and environmental mitigation measures (Akon-Yamga *et al.*, 2021; Chandra *et al.*, 2022; Islam and Huda, 2018). The articles also identified a number of topical issues explored in the evolving research literature, each of which provided some insight into the progress in e-waste research.

A comprehensive and quantitative assessment of the development of the trends in e-waste research can help academic professionals to make informed decisions about their future research and guide the industry person to adopt a futuristic decision-making approach in e-waste management (Kitila and Woldemikael, 2019). Moreover, it is an opportunity to efficiently organise, fully summarize, and quantitatively explain the research trend and characteristics determined by a large number of studies in a certain research area. Particularly, e-waste research is a multidisciplinary research area, which covers core technology, supply chain management, environmental science, social behaviour, economic analysis, policies and other areas (Awasthi and Li, 2017; Gilal *et al.*, 2021; Islam and Huda, 2018; Wath *et al.*, 2010). Through this literature search in motive is to present a comprehensive overview of e-waste research in terms of policy-making, waste management system and method, recycling technology, technology in reverse logistics system and available economic and financial schemes.

Compilation of literature is necessary to identify development trends, for which a bibliographic approach is employed. The bibliometric analysis is a statistical tool where the development trends are qualitatively and quantitatively assessed and represented in research fields over a time line (Li and Zhao, 2015). It can be used to not only to systematically identify, organize, and analyse the main elements of a research topic, but also to visually present the growth pattern of a research topics (Fahimnia *et al.*, 2015). The outcome obtained are not only helpful to the researcher but also useful for management information systems and can aid high level decision-making processes. The bibliometric analysis is widely utilized in various applications such as supply chain management, solid waste management, circular economy, waste to energy etc. (Boloy *et al.*, 2021). These articles, along with bibliometric analysis, are comprehensive and statistically beneficial for identifying future impacts with associated development trends.

This chapter contributes to published articles on e-waste management research, including e-waste policy, disposal practices and collection systems as these categories can define the issues of e-waste management. Examined dynamic growth of the related research during 1998-2022 (August 2022) through bibliometric analysis so as to facilitate an overall measure of the current status of e-waste research. In order to, identifies the many characteristics of e-waste research, we tracked top author's contribution, top citation, country's contribution, keywords analysis, and hotspot topic of current research trends. Subsequently, a critical literature review is presented over selected e-waste articles. This review will provide an increased understanding of the current state-of-the-art of trends and opportunities for the future direction of e-waste research also.

This research is driven by the following objective:

- How e-waste research evolved over the past decade?
- What are the major hot spots of e-waste research?
- How many nations or regions contribute to e-waste research?

The main focus of this chapter is to analyze the current trend of e-waste research related mainly to e-waste policy & regulation, disposal behaviour and collection system & methods. Research gaps are also identified as mentioned earlier in e-waste issues and simultaneously recommendations made to mitigate the issues identified in policies, disposal behaviour and collection system. This chapter signifies accomplishing part of the objective by identifying an implementable tool to analyse e-waste issues and understand status in developed and developing countries like India.

2.2 Search field

The research area of e-waste is categorized into three fields namely e-waste policy, e-waste disposal behaviour and e-waste collection system in Scopus data base. To ensure the coverage of related articles three search strings are used. The first search string for e-waste policy is used with a combination of keywords, ("e-waste policy" OR "e-waste regulation" OR " e-waste legislation" OR "e-waste Law"). The second search string for disposal behaviour is ("e-waste" AND ("behaviour" OR "consumer behaviour" OR "younger" OR "resident") AND ("survey" OR "empirical" OR "theory of planned behaviour") and the third search string for collection system is ("e-waste" OR "WEEE") AND ("collection" OR "collection system "OR "collection method". Scopus provides Boolean syntax that allows the authors to combine keywords of the search string with operators like AND, NOT and OR for generating appropriate search results. Archambault *et al.* (2009) compared the bibliometric data of Web of Science (WoS) and Scopus databases and concluded that "WoS and Scopus offer robust tools for evaluating science." Google Scholar is a different database, however, the quality of data is poor due to the fact that it includes non-indexed articles. Moreover, Scopus provides about 20% more coverage than WoS, whereas the results of Google Scholar are inconsistent. SCOPUS managed by Elsevier Publishing boasts itself to be the "largest abstract and citation database of peer-reviewed literature in the fields of science, technology, medicine, social sciences, and arts and humanities" (Nagariya *et al.*, 2020).

A step-wise procedure is adopted for filtering the data. The search string is restricted to search Title, Abstract and Keywords. Again the search was limited to the subject area of Business, accounting and management, Environmental Science, Social Sciences, Economics, Econometrics and Finance and Computer Science. While the documents Type was Journal paper, Conference proceedings, and Book chapters. Further a set of keywords were selected, and the search was limited to the keywords for achieving closeness to related articles. The keywords related to supply chain, logistics and service are selected from the list. The keywords are selected from previous papers of the same area, expert's views and the author's own experiences. The common selected keywords are "Electronic Waste", "Waste Disposal", "Developing countries" and "Waste Management". The selected main keywords for e-waste policy are "Policy", "Legislation", "Public policy", "Informal Recycling", "Extended Producer Responsibility", "Policy Implication", and "Material Flow". While main selected keywords for disposal behaviour are "Consumer attitude", "Adult", "Willing to pay", "Decision making", "Sustainable development", "Survey", "Household", "Theory of Planned behaviour", "Structure Equation Modeling" and "Regression Analysis". The collection system selected keywords are "Resource Recovery", "Policy Approach", "consumer behaviour & attitude", "Reverse Logistics", "Material Flow Analysis", "Barriers", "Vehicle Routing", "Artificial Intelligence", "Supply Chains", "MCDM", "Collection Rate", "Informal Sector", and "Collection Methods". Initially, a total of 678 articles were reported in which e-waste collection system articles were 472, e-waste policy 104 and disposal behaviour related 102 articles are found from the Scopus database. The flow chart of the research methodology adopted in bibliometric study is presented in Figure 2.1.

2.3 Bibliometric analysis

Investigation of the content of the articles by the quantitative and statistical method is employed. The bibliometric tool provides network analysis to categorise and establish emerging areas based on published topic, author, citation and institutional characteristics (Gao *et al.*, 2019). This makes it possible to handle a large number of documents and data easily and also more precisely. This tool profoundly analyses the relationship between publications, citations, co-citations and keywords with strong visualization of the network, which helps researchers to easily and clearly identify gaps in the literature and identify possible future research interests in a specific field (de Albuquerque *et al.*, 2021).

2.3.1 E-waste policy and regulation

Under this category, 104 publications are identified and categorized under four primary document types, and their frequency is presented in Figure 2.2 (a). The largest category is journal papers, contribution to 60% followed by conferences (22%), book chapters (12%) and others (7%). A year-wise analysis of articles focusing on e-waste related to policy and regulations tracks progressive growth in research between 2004 to 2022.

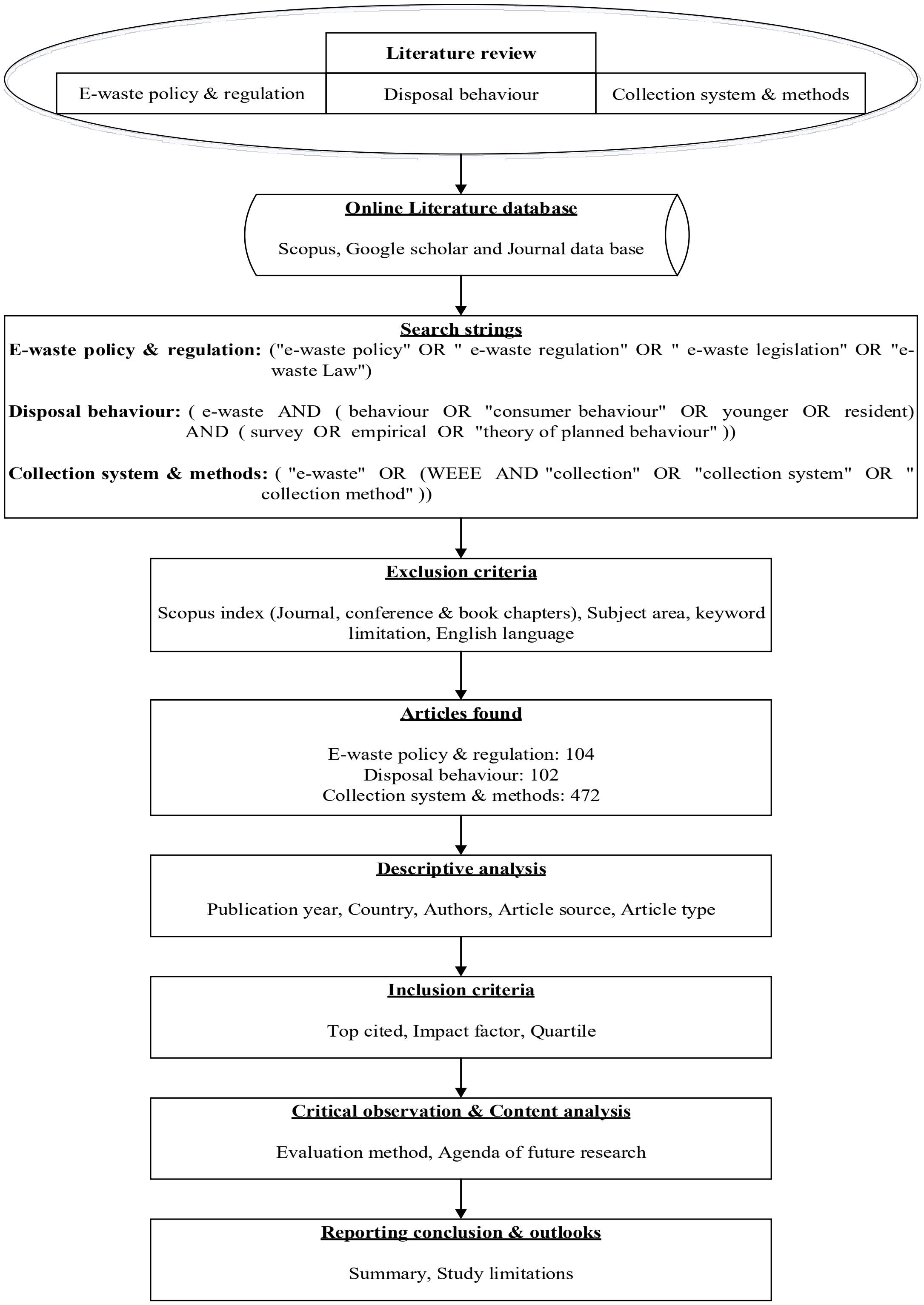


Figure 2.1: Flow chart of research methodology

Year-wise research trends indicate that research publications in e-waste policy appeared majorly from 2018, a steep rise in publications number in recent years showcased a rise in interest among researchers. Noticeably the number of articles per year is not sufficiently large indicates that the area of e-waste policy is largely underexplored. The number of papers published since 2015 is 69 representing 66% of the total publication that appeared since 2004. In Figure 2.2. (b) numbers of articles published till August 2022 are included, so the trend seems to be declining.

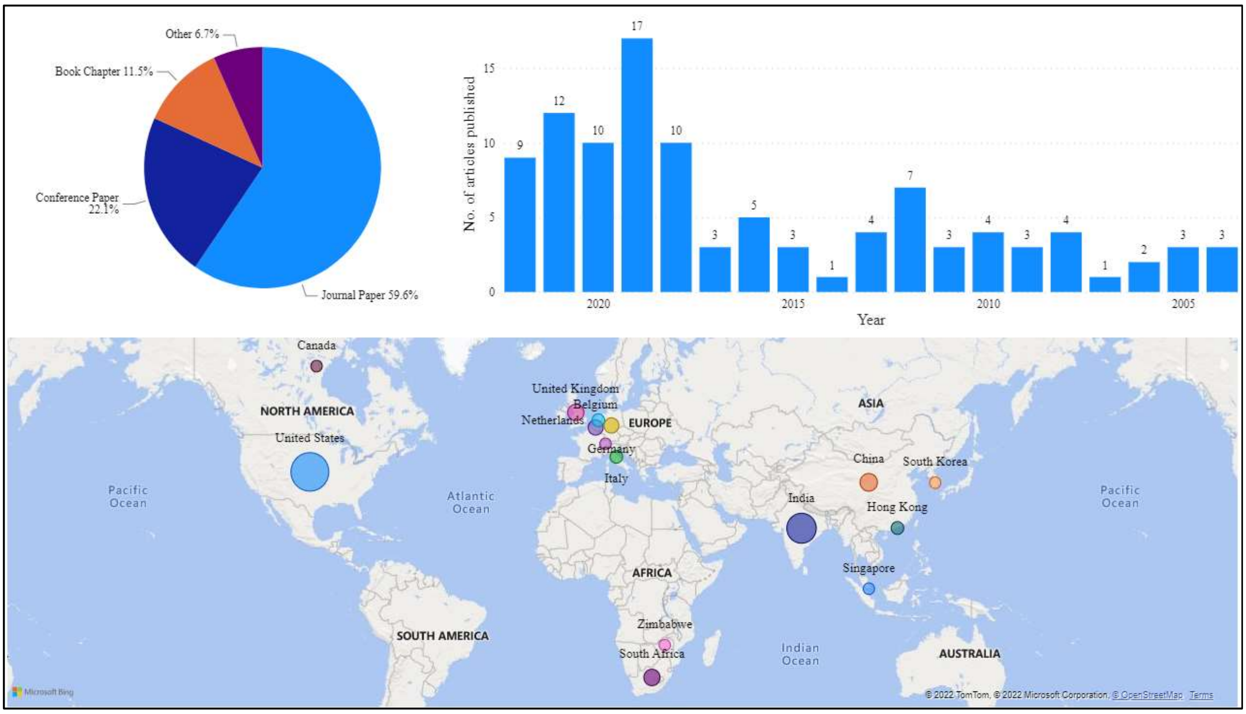


Figure 2.2: (a) Document type, (b) Year wise trend, (c) Country-wise publications density

The country-wise publication trends are shown in Figure 2.2 (c), the United States (US) published the highest number of articles (24%, n=25) followed by India (17%, n=18). The top ten countries contributed 89 articles out of 104 articles making 85.5% contribution in total published articles. The main focus of the authors affiliated with the US was on developing a centralized e-waste policy framework. However, India-based authors broadly focused on various issues of e-waste policy and how the policy framework is to be implemented and developed in the urban and rural regions.

A similarity in the diversification of publications is also visible in publication sources irrespective of the existing diversification in scopes. Scrutiny indicates the diversification in scholarly works across 59 varied sources/journals. Only six publishing sources contributing to more than 3 articles revealed a fondness for certain publishing journals in the field of e-waste policy. Figure 2.3 visualized the top contributing publication sources such as *Resources Conservation and Recycling* (7 publications), *Journal of Cleaner Production* (5 publications), and *Production and Operations Management* (4 publications).

Figure 2.3: Source of publications (e-waste policy)

A total of 159 authors have published at least one article, and only 28 authors publishing more than 2 articles. The maximum contributions are found to be from Borthakur, A, Huisman, J and Kuehr, R (4 documents each). The maximum citation reported by authors is Huisman, J with 176 cites in different articles followed by Kuehr, R (32 citations) and Borthakur, A (29 citations). A visualization of the author's contributions is shown in Figure 2.4.

Figure 2.4: Visualization of author's contribution in e-waste policy related research

Keywords are provided by authors to synthesize predominant ideas of the article and keywords plus are extracted from titles of a cited reference, providing a conceptual base for the article. A scientometric tool like VOSviewer (version 1.6.18) is utilized to search various keywords from the publication title and abstract of a specific topic. This software is an open-source one that offers necessary features to map the network of literature clearly (Vosviewer, 2022). It also provides the facility of grouping the related documents that show expressive relationships into one cluster and describing it as a network. In general, conducting a co-occurrence of both author and index keywords, the research hotspots that are analyzed and identified that are evident via examining the author's keywords. The output from the software shows that the e-waste policy-related keywords are categorized in one cluster. This reveals that hotspot keywords are strongly connected to each other and also strongly related to the other keywords. The Figure 2.5, represents a grid centred on replicating keywords in the literature on general dimensions of policy and regulation. The linkage in the network analysis showed that the main hotspot keywords associated with e-waste policy are EPR, Waste management, laws & regulation, Policy implementation, Regulatory framework, Informal recycling, Circular economy, Material flow analysis, Public health, Hazardous materials, Heavy metals, Environmental impact, E-commerce and Developing countries as shown Figure 2.5. This means policymakers should focus on current hotspot keywords that will assist in revising the e-waste policy and regulation at the broad level.

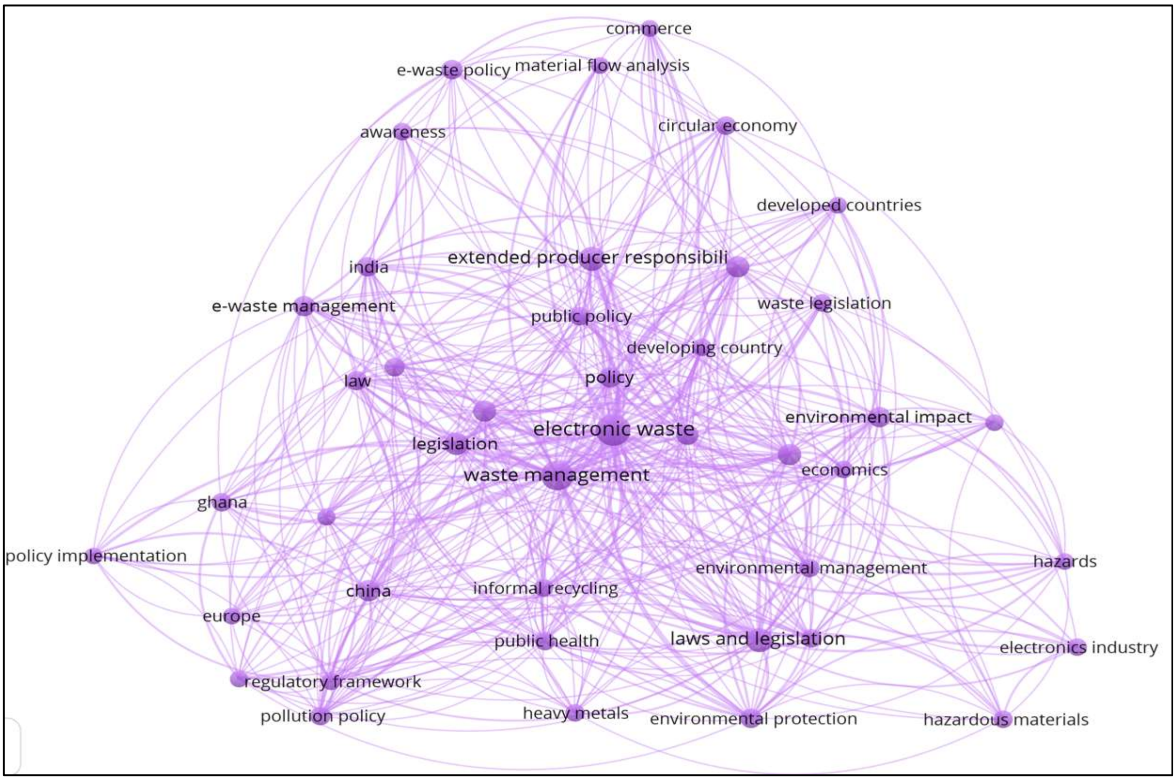


Figure 2.5: Keywords map analysis of e-waste policy

2.3.1.1 Critical analysis of e-waste policy

For the successful implication of the e-waste policy, it is paramount to monitor its outcomes from time to time and identify the need for government involvement in policy amendments. Further, the stakeholders need to play a responsible role in implementing e-waste policies and spreading environmental awareness. Wath *et al.* (2011) argued that the framework for e-waste collection policy should maintain a balance between the economics involved and environmental and public health & safety concerns. Morris and Metternicht (2016) stated that for enhancement in the effectiveness of e-waste collection policy, it is essential to re-assess the roles and responsibilities of stakeholders. Furthermore, identical enablers are required for cases involving the local and the federal government to engage and educate the public on the need for separate e-waste management and the various priorities of the e-waste collection policy. Okorhi *et al.* (2019) presented a survey of various effects of the implementation of e-waste collection policy, including the involvement of local government and solid waste handling agencies. They suggested that e-waste management is distinctly different from municipal solid waste management and emphasised the need of setting up independent standards for e-waste regulation by the government. Several researchers have conducted studies on e-waste management and its sustainability. A study by Carisma (2009) measured the socio-culture and economic aspects as prominent drivers of e-waste management policy in the Philippines. Yu *et al.* (2014) argued that the policy instruments must consider developing the e-waste rules. They critically reviewed the e-waste policy of China and identified potential improvement areas like monitoring and auditing system, identification of the location of the informal sector, sharing of information about treatment technologies with the government, and the need to spread awareness among the public in the hinterland. Li *et al.* (2016) studied the impact of e-waste regulations on improving collection activities and overall sustainable management. Triguero *et al.* (2016) reviewed the waste management policies of 28 European countries and identified three primary drivers that influence the waste management policy. These are: (i) Government responsibility to pay subsidies for waste management; (ii) Consumer responsibility to deposit the appropriate quantity of unsorted waste; and (iii) Producer responsibility to pay the cost of waste management already included in the final prices of EEEs.

Various countries have started to pay attention to the e-waste policy and identify those local variables or drivers that assist in developing a sustainable formal recycling and safe disposal system (Singh *et al.*, 2021a). For example, in Taiwan (Shih, 2017), a Recycling Fund Management Board (RFMB) is established, that analysed the e-waste policy, intending to maximise the recycling rate and improve the fund allocation system. It found that flexibility, fairness and promotion are the key drivers of improvement in the e-waste recycling rate. Leclerc and Badami (2020) reviewed the EPR program of e-waste policy in Canada. It identified a few policy drivers that tend to add up in e-waste regulation, such as enforcement mechanisms & penalties, visibility of environmental handling fees and modulation of 3R (Reuse, Reduce and Recycling). Parajuly *et al.* (2019) argued that the circular economy is an essential enabler for policy intervention in European countries. This driver may fill the gap between conventional drivers such as awareness campaigns, economic incentives, stricter regulations, transboundary movement and consumer behaviour toward an e-waste policy. It suggested that the circular economy concept can influence the socio-economic culture and promote green practices. However, Borthakur and Govind (2017) argued that in developing countries like India, various factors like socio-cultural, economic, political, technological, infrastructural and environmental differences play a pivotal role in public acceptance of e-waste collection policy.

The designing of the e-waste collection policy of India adopted a few points from the legislation of various developed nations in Europe, U.S., and Japan. Some examples of different schemes experimented with in India are 'DRS, 'polluter pay', 'EPR system', 'collection target', stakeholders definitions and responsibility setting etc. However, the policy focuses more on the EPR system, implying the producer's responsibility to recycle e-waste. This is done, possibly to boost India's limited recycling capacity and nudge private investors towards the same (Awasthi and Li, 2017). While in China, the policy focuses more on minimising raw material consumption and in developing sustainable recycling technology and developing infrastructure for recycling activities (Patil and Ramakrishna, 2020).

Singapore is one of the earliest to implement regulations to restrict the transboundary shipment of hazardous waste. The National Environmental Agency (NEA) in Singapore monitors the movement of e-waste and regulate the stakeholders to follow e-waste policy (Patil and Ramakrishna, 2020). Canada also focused on EPR policy for managing their e-waste. The main emphasis was on the design of EPR policy to generate local employment through take-back programmes and to encourage reuse and reduction to address the environmental impacts of EEEs (Leclerc and Badami, 2020). Most developing countries adopt policies that have similarities with developed countries. However, successful policy design and implementation hinge on the culture and unique circumstances of the country (Sthiannopkao and Wong, 2013). In some countries, the policies fell short of receiving public acceptance, and in many, the government's efforts were not matching the requirement (Heeks *et al.*, 2015).

The other essential opportunities are to improve the policy taking a broader outlook like considerations in 'United Nations Agenda 2030' for SDGs. The main priorities of the policy and strategy framing are to focus on the formulation of the following area of policies, enact legislation to reduce waste generation, promote responsible public behaviour on waste management, and promote waste segregation at the source. Other priorities are the 3Rs & recovery of energy from the waste, promotion of waste treatment, and establishing environmentally sound infrastructure for e-waste management (Roldan and Gibby, 2018). Table 2.1 details further research reviewed for gaining deep understanding of e-waste policy system.

From the above literature review, the research gaps have been identified to manage the various aspects of e-waste management and discussed in this section. The extensive literature review shows that drafting of an effective e-waste policy has been a significant concern for policymakers, consumers, and various other stakeholders who are directly involved in e-waste management activities. The various previous studies have focused on the barriers or critical analysis of the implementation of e-waste management issues. Minimal research concentration is observed on the interrelation among various factors on e-waste collection policies in developing countries such as India. Further, no studies have found that identify the influence and efficiency of e-waste collection policy or identify those factors that contribute to the foremost. Many of the referenced articles discusses the influencing variables of e-waste management and recycling. Simultaneously analyses the critical success factors of e-waste policy is essential to identify the prominent effects.

Table 2.1:Summarized the literature on e-waste policy based on categories

Authors	Research objectives and limitations	Context		Methodology		Tools/ Method	Country/ region
		A	B	C	D		
(Kahhat *et al.*, 2008)	A solution is proposed to ensure a proper end-of-life option while establishing a competitive market for reuse and recycling services. Limitation: The study analyzed only deposit refund scheme system of individual cities in the USA.	✓			✓		U.S.
(Plambeck and Wang, 2009)	The aim of this study is to investigate the impact of e-waste regulation on new product introduction in a stylized model of the electronics industry. The investigation incorporates manufacturers to choose the development time and expenditure for each new version of a durable product, which together determines product quality. Limitation: A challenge for future research is to develop e-waste regulation that adaptively incentivizes electronics manufacturers.		✓	✓		Game theory	U.S.
(Atasu and Van Wassenhove, 2012)	The objective of the study requires an operations-based look at the challenges associated with e-waste law enforcement, particularly because enforcement-related issues are mainly operational in nature. This study enables to understand the stakeholder perspectives, the economic impact of, and different implementations of e-waste policies. Limitations: Policy economics tend to design policy instruments ignoring implementation choices and their effects on stakeholder reactions. Such high-level perspectives however may not work in practice.		✓		✓		Europe
(Pariatamby and Victor, 2013)	The purpose of this study is to analyse policy trends of e-waste management in Asia as well as highlighting potential opportunities in integrating e-waste management as part of a national green growth strategy in Asia.	✓			✓		Asia

	Limitations: Paper not examined as e-waste issues in developing countries are complex and intricately linked to the informal sector as well as socio-economic-political dynamics.						
(Mmereki *et al.*, 2015)	The study proposes various approaches for effective collection and treatment of e-waste and to understand the e-waste management system in Botswana and provide key information and insights that will contribute to the achievement of the goal of developing e-waste policy at broad level. Limitation: Key limitations to this paper was the difficulty to accurately and consistently identify up-to-date data on the quantities of e-waste generated and a dearth of systematic studies that explores the actual e-waste situation in Botswana.	✓			✓		Botswana
(Daum *et al.*, 2017)	The study examines e-waste legislation and institutional hierarchies in Accra, and then summarize the e-waste trade's social implications and discusses potential solutions to the crisis. Limitation: The paper only focus on the e-waste legislation and needs to opportunities how the to minimize the un-organized recycling activities, particularly related to burning and dismantling.	✓			✓		Africa
(Mazahir *et al.*, 2019)	The study proposes a policy that advocates a separate target for product reuse. The analysis reveals that from an environmental standpoint, the recast version is always dominated either by the original policy or the one that advocates a separate target for product reuse. Limitation: The paper does not focuses on the recycling-focused policy for products with a high hazard potential and a use-focused policy for products with a high production footprint, or through a re-evaluation of the product clustering protocols, which would be a fruitful direction for future research.		✓	✓		Optimization	Europe

(Borthakur, 2020)	This study analyzes the EU WEEE Directive and RoHS that have a considerable impact on the e-waste policies of most emerging economies. The fact that a few representatives from the well-known emerging economies are underrepresented in e-waste research necessitates adequate attention from the scientific community and policymakers. Limitations: The constrained of this research is to increasing attention on e-waste of developing countries both from the natural science and social sciences' perspectives. It is also essential to ensure interdisciplinary research approaches on the topic as understanding the roots of the e-waste problem needs a comprehensive effort.	✓			✓	Content analysis	India & South Africa
(Borthakur and Singh, 2022)	This study analyses individual e-waste policies of the middle-class population in the geo-political set-up of the Global South, including complicated and tedious in nature. It explores the various reasons for emerging economies in general and India, in particular, adopts e-waste policies that seem inadequate and ineffective in their local contexts which attempt to identify alternative approaches. Limitation: This research a fundamental study to focus on appraising urban Indian consumers purchase and disposal behaviour of EEE devices. However this study not considered the socio-cultural, economic, environmental and political setup.		✓		✓	Empirical study	India
Note: A- Deterministic, B- Uncertain, C- Experimental study, D- Exploratory study							

2.3.2 E-waste disposal behaviour

Under this category, 102 publications are identified and categorized under three primary document types, and their frequency is presented in Figure 2.6 (a). The largest category is journal papers, contributing 87% followed by conferences (11%) and book chapters (2%). A year-wise analysis of articles focusing on disposal behaviour of e-waste highlights progressive growth in research between 2010 to 2022. Year-wise research trends indicate that research publications on e-waste policy appeared majorly from 2017, a steep rise in publications in recent years showcase a rising interest among researchers which has been quite stable for last 4 years, as shown in Figure 2.6 (b). Remarkably the number of articles per year is not sufficiently large, indicating that the area of e-waste disposal behaviour is less explored. The number of papers published since between 2017-2022 is 71 representing 70% of the total publication that appeared since 2010. In Figure 2.6 (b) the number of articles published till August 2022 are included, so the trend is expecting to be increasing from the previous year.

The country-wise publication trends are shown in Figure 2.6 (c), researchers in China published the highest number of articles (24%, n=25) followed by the US (16%, n=17) and India (7%, n=8) and the top ten countries contributed 86 articles out of 102 articles making 85% contribution in total published articles. Given the relevance of consumer e-waste disposal behaviour, more cross-cultural studies are needed to have a better understanding of the factors that influence e-waste disposal.

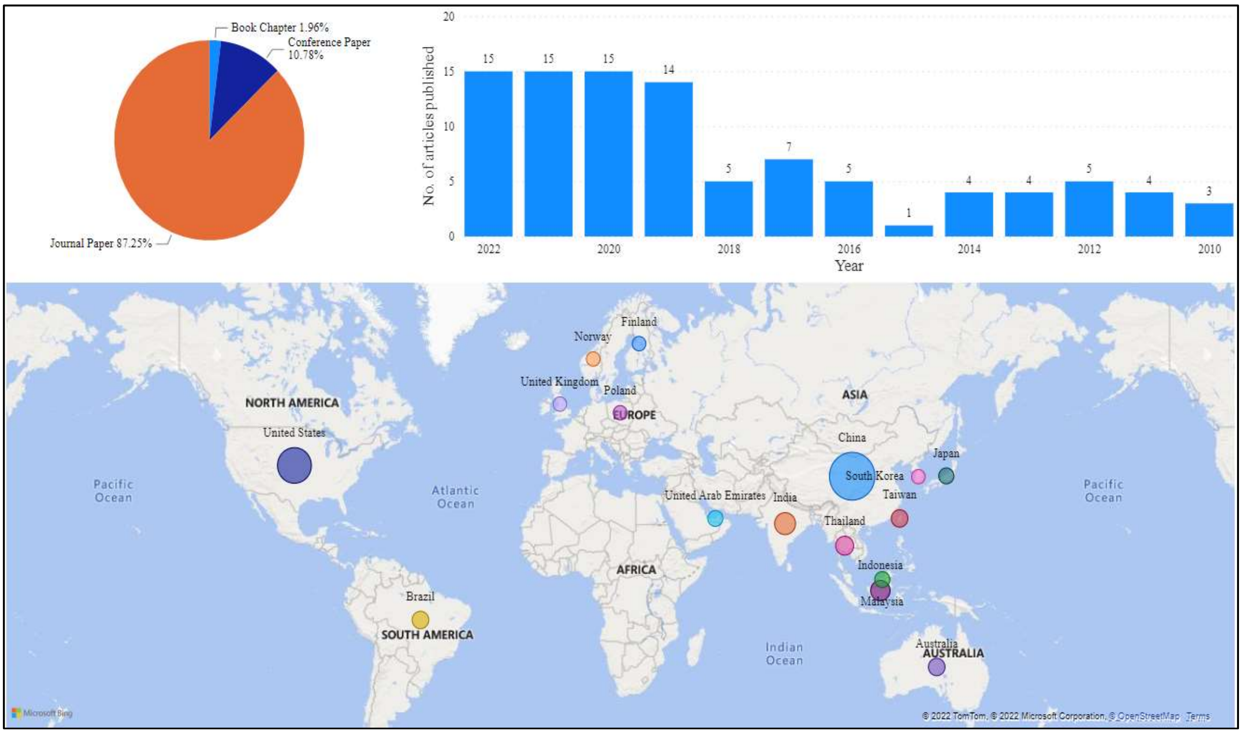


Figure 2.6: (a) Document type, (b) Year wise trend, (c) Country-wise publications density

According to the analysis, 50 journals published 104 articles between 2010 and 2022. The top 9 journals contributed 61 articles (60%) with more than 4 articles revealing a fondness for certain publishing journals in the field of e-waste disposal behaviour. Figure 2.7 visualized the top contributing publication sources such as *Resources Conservation and Recycling* (14 publications), *Journal of Cleaner Production* (11 publications) and *Sustainability* (9 publications). Likewise, the *Journal of Environmental Management* (6 publications) and *Waste Management* (5 publications). Similarly, the journals of *Environmental Science and Pollution Research*, *Global Journal of Environmental Science and Management*, *Environment Protection Engineering*, and *Journal of Consumer Behaviour* each had four publications.

Figure 2.7: Source of publications of e-waste disposal behaviour

Figure 2.8: Visualization of author’s contribution of e-waste disposal behaviour

The authors who have made major contributions to e-waste disposal behaviour, with a total of 160 authors with at least one article, and 29 authors publishing more than 2 articles. The maximum contributions are found to be from Ogunseitan, O.A, Shapiro, A.A. and Wang, Z (5 documents each). Similarly, Li, J, Nixon, H and Zhang each contributed 4 articles. The maximum citation is reported by authors is Wang, Z with 698 cites in different articles followed by Ogunseitan, O.A (497 citations). A visualization of the author's contributions is shown in Figure 2.8.

The notion of capturing customer e-waste disposal behaviour has recently attracted attention of researchers. Extrinsic variables such as recycling accessibility (Nixon *et al.*, 2009), monetary rewards, willingness to pay and incentives for recycling (Wang *et al.*, 2011), past e-waste disposal experience (Saphores *et al.*, 2012), and subjective norms have been used to capture consumer disposal behaviour in a previous study (Dixit and Badgaiyan, 2016). The outcomes from the software reveals that the hotspot keywords basically investigate the e-waste disposal behaviour of consumers, presented in Figure 2.9. The prominent keywords such as the theory of planned behaviour is applied in e-waste disposal research, and this theory is popular in the research society. However, it is necessary to examine and observe the individual consumer's perception about the disposal behaviour. In terms of statistical analysis methods, the hotspot keyword structural equation modelling is the most commonly used data analysis method in consumer e-waste disposal research. The other method is regression, and descriptive analysis is also used to investigate the consumer disposal behaviour of various EEE.

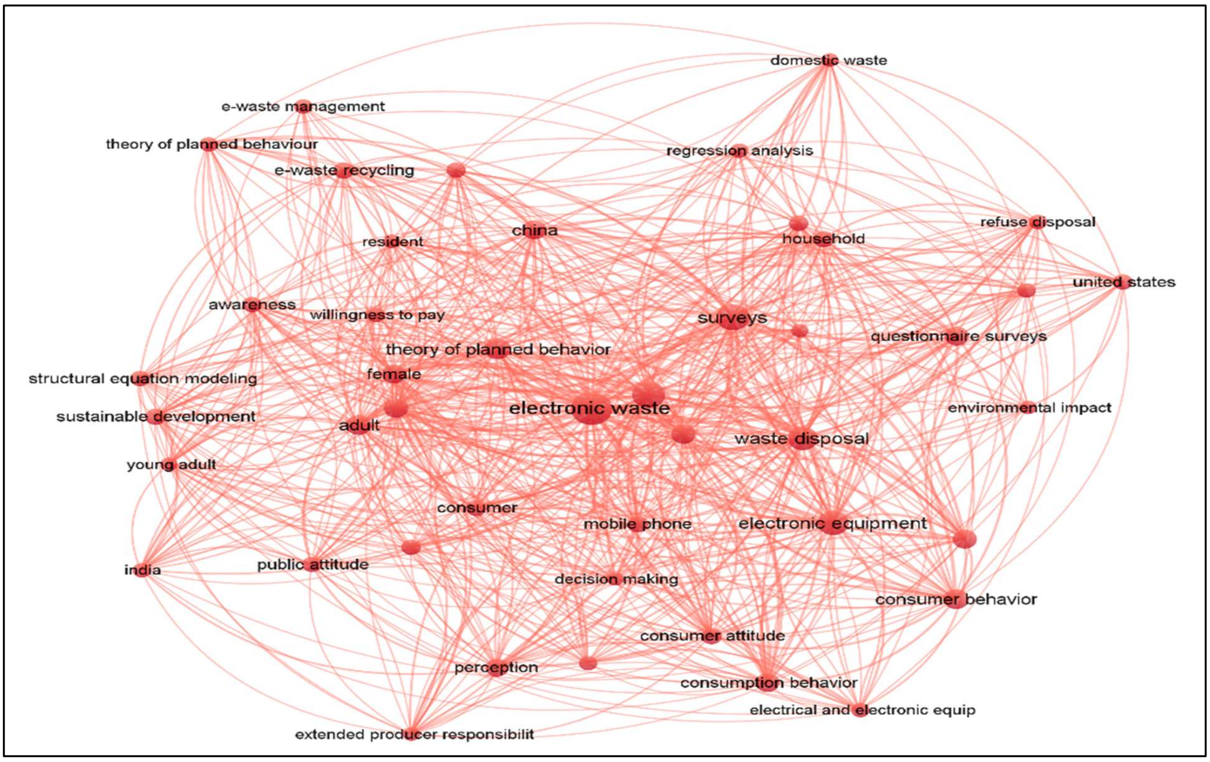


Figure 2.9: keywords map of e-waste disposal behaviour

2.3.2.1 Critical analysis of e-waste disposal behaviour

The consumer ethos is one of the most critical factors in the scientific management of e-waste. This factor initiates the correct disposal system of e-waste, and it is necessary to know consumer intentions and likings about e-waste disposal (Gollakota *et al.*, 2020). The need of the hour is to understand the consumer's current habits and identify the relevant vulnerabilities of the e-waste disposal practices to create targeted awareness campaigns and policies and schemes to encourage scientific disposal. A study by Wang *et al.* (2018) noted that the lack of publicity and knowledge of e-waste recycling practices among consumers in China is the major stumbling block to the right kind of consumer behaviour. They suggested improving the publicity content and increasing the public engagement events to enhance understanding of the e-waste recycling system. Ramzan *et al.* (2019) attempted to assess the young consumer's behaviour toward sustainable e-waste management practices in the Northwest China region. They found that the youth have a better awareness of the environment. At the same time, they lack knowledge about e-waste rules and regulations, collection systems, recycling programs, and the distinction between the formal and informal recycling sectors. Arain *et al.* (2020) studied the e-waste recycling behaviour of students and faculties at Midwestern University in the United States. The survey revealed a lack of knowledge about disposal sites among respondents. Increasing recycling facilities in nearby areas and the development of low or free-of-cost recycling were recommended to promote e-waste recycling behaviour. Ananno *et al.* (2021) measured consumer's behaviour toward e-waste management in Bangladesh. The survey shows that 37.9% of consumers are agreeable to paying for e-waste recycling. Additionally, they observed that environmental education among consumers contributes to a willingness to pay for e-waste recycling.

The awareness among consumers about the importance of sustainable e-waste management is necessary to improve the collection rate and reduce the impact on the environment (Simiari *et al.*, 2020). For instance, the consumer behaviour of north European countries shows a strong belief in environmental protection and, thereby, are more likely to engage in formal e-waste recycling activities (Shevchenko *et al.*, 2019). Discerning consumers also make themselves aware about how to dispose of their e-waste formally. In developing countries such as India, consumers may lack similar disposal behaviour and motivation. E-waste is often seen in India as a commodity with some inherent values, causing hesitation among consumers to dispose of instantly (Borthakur and Singh, 2021). Therefore, consumers cling to their obsolete electronics, such as those stored at home or given to dependents or sold to the secondary market. Thus, it mostly finds second or even third-hand users down in the income chain in the country. Such consumer disposal behaviour delays the entry of e-waste into the recycling and recovery stream and increases the e-waste inventory in a cumulative year (Shaikh *et al.*, 2020). Important literatures are categorized based on its context, methodology and tools utilized tabulated in Table 2.2.

The perspective of e-waste disposal behaviour is observed from the literature review in this chapter. It reveals that the behavioural culture of e-waste disposal is country-specific. The literature found that China and the US have majorly investigated the different aspects of e-waste disposal behaviour among consumers such as consumption patterns, EEE volume, length of ownership, and disposal constraints, with a focus on individuals and households at the broad level. However, India-specific studies are lacking on demography focused disposal behaviour. Few authors have analyzed consumer behaviour at the city level. There is no consistency in the literature for analysing the direct and indirect effects on consumer disposal behaviour considering these aspects. The literature also lacks evaluation of the impact of consumer's psychological behaviour on the intention of e-waste disposal. Previous studies have focused mainly on evaluating consumer intention to recycle e-waste. At the same time, the researchers have not adequately addressed the factors influencing consumer decisions.

Table 2.2: Summarized the literature on e-waste disposal behaviour based on categories

Authors	**Research objectives**	**Context**		**Methodology**		**Tools/ Method**	**Country/ region**
		A	**B**	**C**	**D**		
(Saphores *et al.*, 2006)	This study investigates individual willingness to recycle e-waste through a mail survey in California. Probit models found that key factors were gender, education, convenience, and environment, explaining the willingness to drop off e-waste at recycling centres. Limitation: this study not measured the socioeconomic, demographic, and behavioral variables is the need for extensive information, which may be challenging to collect. A mail survey is likely not the best vehicle for that purpose as illustrated by our response rate	✓		✓		Descriptive & Probit	U.S.
(Wang *et al.*, 2011)	A survey was performed to explore the residents' characteristics of recycling behaviour and preference for e-waste recycling patterns in Beijing. The logistic regression model was developed to estimate and explain residents' willingness to e-waste recycling. The model showed that four determinants such as the convenience of recycling facilities and services, residential conditions, recycling habits and economic benefits, have an impact on residents' willingness and behaviour in e-waste recycling. Limitation: This paper majorly focuses on consumer recycling behaviour. While, it not considered the stakeholder responses towards promoting residents' willingness in e-waste recycling.	✓		✓		Logistic regression	China
(Lau *et al.*, 2013)	A survey was conducted on local households and private e-waste traders and reviewed the existing reverse supply chain of household e-waste. The majority of obsolete e-waste was sold by households to private e-waste collectors, and the informal e-waste collection network is efficient and popular with local households.	✓		✓		Descriptive study	Hong Kong

	Limitation: The constraint of this study is non-profit making organisations also collect e-waste from institutions and private business corporations, but as separate estimates of the proportion of household e-waste going to each disposal data is not available.						
(Gao *et al.*, 2015)	The research model was empirically tested with a sample of 203 users of online household e-waste collection services in China. The most significant determinant for the behavioural intention to use online household e-waste services was effort expectancy. However, facilitating conditions did not have a significant impact on users' behaviour in using online household e-waste collection services. Limitation: Limited constructs are considered in this study. Additional constructs influence on the adoption of online household e-waste collection services.	✓		✓		SEM	China
(Echegaray and Hansstein, 2017)	The study examines the determinants of consumer intentions and behaviour towards e-waste recycling in Brazil. Modelling measures were obtained from a general population survey sample after the TPB and found that the majority of respondents held a positive intention toward recycling electronic appliances. Limitation: The drawback of the underlying view of facts as the result of rational, cognitive, highly individualistic decisions, ignoring the social and structural conditions that influence daily practices such as refuse disposal.		✓	✓		SEM	Brazil
(Nowakowski, 2019)	The objective is to identify the reasons that individuals stockpile EoL equipment. A behavioural model of WEEE disposal by household individuals is proposed and tested with a survey. Results from questionnaires show the differences in behaviour for individual categories. Limitation: Researchers could add the social and psychological issues that have an impact on disposal attitude of e-waste. The survey of this study only include the small waste equipment. It	✓			✓	Descriptive	Poland

	is necessary to conduct further research for other groups of waste equipment.						
(Arain *et al.*, 2020)	The study evaluates the consumer behaviour, including barriers, surrounding e-waste recycling at a large Midwestern university in the United States. The results indicate that free access to disposal, lack of consumer knowledge about products and disposal sites, and access to a recycling facility within a reasonable distance are all important factors in consumer decisions. Limitation: Questionnaire for data collection is very limited as respondents were not asked to report highest level of education achieved. Unable to collect survey responses from community members not associated with the university may have been self-selection bias.	✓			✓	Descriptive	U.S.
(Nguyen *et al.*, 2021)	The study examines the influencing factors of end-user willingly to pay the payment preferences toward e-waste recycling. The logistic regression model was employed to analyze a qualified data set collected through a personal interview survey in Danang city, Vietnam. Limitation: This paper has not considered the e-waste recycling factor for measure the consumer behaviour.	✓			✓	logistic regression	Vietnam
(Kummer *et al.*, 2022)	A survey was conducted to assess the consumers' behaviour concerning the individual disposal of WEEE. The consumer survey showed that predominantly regular routes for the disposal of WEEE are used, and relevant quantities are not only physically "lost," but also significant deficits in the monitoring itself. Limitation: The survey data is used to projected the e-waste generation not compared with the national data.	✓			✓	Descriptive	Germany
Note: A- Deterministic, B- Uncertain, C- Experimental study, D- Exploratory study							

2.3.3 E-waste collection system

Total 472 publications are identified and categorized under three primary document types, and their frequency is presented in Figure 2.10 (a). The largest category is journal papers contributing 76% followed by conferences (23%) and book chapters (1%).

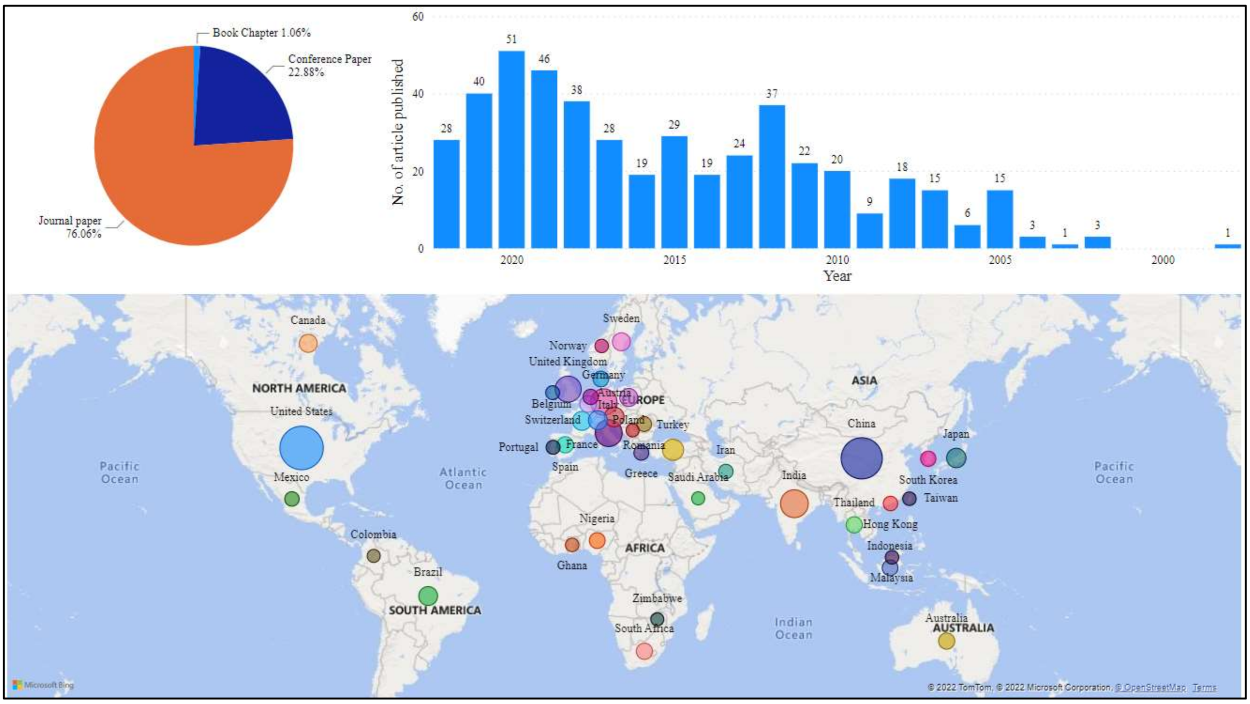


Figure 2.10: (a) Document type, (b) Year wise trend, (c) Country-wise publications density

Figure 2.10 (b) shows the publication trends over the years 1998-2022. In general, the growth in the number of publications is less and uneven in the initial year 1998-2006. Thereafter, the researchers are observed to continue focusing on the e-waste collection issues from 2007, which may be due to the enactment of the EU e-waste directive and several country's initializations of resource utilization. The number of articles greatly increased after 2010, for instance, between 2011 and 2012, the increase was from 22 to 37 in Scopus database, likely because of the recasting of the e-waste directives, re-categorization of e-waste and increased targeted collection rate of e-waste. While research interest incrementally increased between 2016 to 2020 and 163 articles were published during this period. This may be commented that the research growth on the e-waste collection system has been in place to develop a sustainable business model for overcoming the issues and provide solutions for e-waste collection in developed and developing nations.

Analyzing the geo-local contribution reveals that the US (71 documents), China (66 documents) and India (36 documents) are among the top countries from where researchers contribute to the e-waste collection system, as presented in a country publication density map in Figure 2.10 (c). Among the top ten journals, the studies on e-waste collection systems were mostly published in *Waste Management* (63 publications), *Resources Conservation and Recycling* (48 publications), Waste Management and Research (28 publications), *IEEE International Symposium on Electronics and The Environment* (18 publications), *Journal of Industrial Ecology* (15 publications) and *Environmental Science and Pollution Research* (11 publications). Likewise, the *Journal of Environmental Management* had 9 publications. Similarly, the journals *ACM International Conference Proceeding Series*, *Journal of Material Cycles and Waste Management*, and *Science of the Total Environment* each had four publications, as visualized in Figure 2.11. these analysis reveals that these journals a better source for publishing contemporary research in the field of e-waste collection systems, which deals with resource conservation, sustainability and environmental issues.

Figure 2.11: Source of publications of e-waste collection

Figure 2.12: Visualization of author's contribution (≥ 3 articles)

The top authors contributing in research of e-waste collection system are Nowakowski, P. (8 publications) and Li, J. (7 publications). Likely wise, Atasu, A, Behdad, S, Rotter, V.S and

Van Wassenhove, L.N published 6 articles each, the author's contribution is visualized in Figure 2.12.

The research on the e-waste collection system is an interesting topic in the research society due to developing a sustainable business model and identifying the various e-waste collection methods that can lead to improving the collection rate and sustainability. The important keywords are captured in the Vosviewer software that was used in the previous study. Figure 2.13 shows the hotspot keywords to overcome during solving e-waste collection theoretical and practical issues. The important keywords used for e-waste collection are Supply chain management, Reverse logistic, Reuse, Material recovery, Urban mining, Informal collection, Material flow, Close Loop Supply Chain (CLSC), Collection location, Barriers, Resources recovery, Environmental impact, Collection route, Infrastructure, Sustainability and Stakeholders. Other important keywords such as Multi-criteria decision making, Mixed integer linear programming, Life cycle assessment, Forecasting, Fuzzy logic, System dynamics and Vehicle routing methods are used to solve the various collection related issues, and these methods are popular among the researchers. Whereas the circular economy should be used to develop sustainable business models for urban mining, reuse and recovery and is not prominently visible.

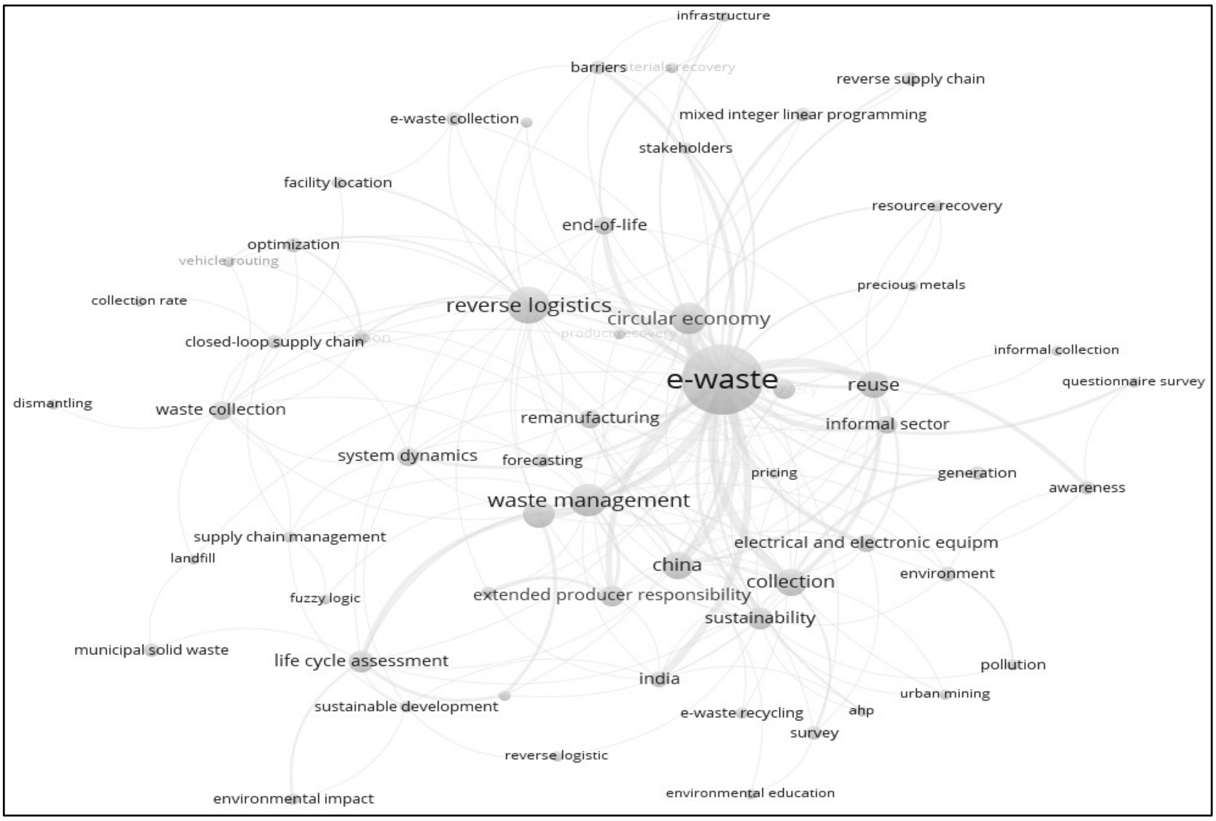


Figure 2.13: Keywords map of e-waste collection

2.3.3.1 Critical analysis of e-waste collection system

E-waste collection is a typical activity to mitigate environmental impact and also to recover valuable raw materials. The success of e-waste collection depends on the consumer's disposal behaviour. A recent study expressed the need to properly design and effectively execute an e-waste management schemes to counter the growing e-waste threat (Borthakur and Govind, 2019). Similarly, the successful e-waste management depends on efficient e-waste collection method that can minimise the negative impacts on the natural environment and human health (Nowakowski and Mrówczyńska, 2018). Major variables that effecting the e-waste collection schemes in India are low level of public participation, lack of environmental awareness, prominent presence of informal sector, insufficient accessibility of collection schemes and lack of government initiatives. To increase collection rate and at same time to reduce the impact of these variables, the developed countries such as Switzerland and Japan have successfully implemented the EPR concept. EPR is a scheme with far reaching implications and sustainability integrated into it to protect the environment and human health by preventing or reducing the adverse impacts of the generation and mismanagement of e-waste. Based on this concept, electronic producers are responsible to take care of their product's entire product lifecycle, especially focus on the EoL management (Widmer *et al.*, 2005) and at same time, they can encourage the consumers to secure disposal of e-waste through certain monetary benefits (Ilankoon *et al.*, 2018). However, the challenges issues while implementation of EPR based legislation in developing countries such as India are the lack of authorized recycling facilities, lack of channelized collection infrastructure, illegal transboundary movement and lack of financial support from government (Baldé *et al.*, 2017). Although the effective e-waste collection method is deemed to be developed by policy makers (government authorities) in collaboration with producers, recyclers, collectors, academic experts and general participants (citizens) to deal with uncertainty and complexity in e-waste collection and disposal. The effectiveness of such schemes will need to be verified time to time against various changing variables.

In developing countries, there is prominent presence of both formal and informal sectors in e-waste collection and processing. The informal actors such as paddlers, small traders, dismantlers, aggregators and recyclers operate in a low economy but with a well-established reverse supply chain network (Turaga *et al.*, 2019). In such informal sectors, labour regulation, safety norms and environmental responsibility are frequently flouted. Primarily e-waste recycling informal sector is a market-driven industry, and the majority of e-waste processed (collection and recycling) in India by the informal sector (Dwivedy *et al.*, 2015). It is recognised that formal e-waste recycling practices are more complex than informal recycling in India. Formal actors are legally authorised under the e-waste management rules to collect and process e-waste with acceptable levels of industrial safety, social responsibility and environmental protection (Kahhat *et al.*, 2008). Formal actors are mainly active in developed urban areas to meet the bulk consumer demand for secondary materials. However, formal collection centres often face challenges in supplying sufficient material to recycle e-waste in India (Kumar, 2019). One major bottleneck of formal e-waste collection is the behaviour of consumers whereby there is apathy to actively participate in formal disposal and recycling activity. This hampers establishment of a robust supply chain. Various authors have also identified the influencing factors that affect the consumer's behaviour regarding e-waste disposal. These are categorised into social culture, economic, demographic characteristics, idiosyncrasies. Thus there are various barriers and some enablers that exists in e-waste reverse logistic scenarios (Kochan *et al.*, 2016). Domina and Koch (2002) stated that consumer behaviour toward e-waste recycling activities is directly co-related to the ease or convenience and accessibility of e-waste disposal facilities. The significant contribution of e-waste recycling behaviour is recycling attitude, previous recycling experience, and pro-environmental behaviour. Demographic characteristics such as age, income level and education have high influence on consumer disposal behaviour. For instant, age is a factor in disposal behaviour, with older persons more willingly participating in recycling schemes than younger persons (Jafari *et al.*, 2017; Wang *et al.*, 2011). Similarly, consumers with higher incomes participate in recycling schemes more often than consumers with lower incomes (Nnorom and Osibanjo, 2008). Financial benefits and disposal reward schemes are also a significant contribution to raising the consumer's awareness and interest level in e-waste disposal (Qu *et al.*, 2019). In addition, the government plays critical role in e-waste recycling to formulate laws, regulations, policies, and provide incentives and required push to producers and consumers to participate in e-waste recycling programs. Some reviewed literature is summarized in Table 2.3.

Further, the literature documents less contribution to identify and evaluate the various e-waste collection methods in the urban and rural regions of a specific country. It is also found that the reported literature mostly covers e-waste collection in urban areas, and there is hardly any study reported for rural areas. While identify the various attribute related to e-waste collection, the literature also lacks the important aspect of potential risk in business sustenance as an attribute. It is understanding that the potential threat to business can come from the change in regulations, change in technology and change in subsidy guidelines but their relative importance has not been ascertained.

Table 2.3: Summarized the literature on e-waste collection system based on categories

Authors	**Research objectives**	**Context**		**Methodology**		**Tools/ Method**	**Country/ region**
		A	**B**	**C**	**D**		
(Sinha-Khetriwal *et al.*, 2005)	This study analyses a comparative evaluation of the disposal of EoL appliances in Switzerland and India, including appliance collection and the financing of recycling systems, as well as the social and environmental aspects of the current practices.	✓			✓	Comparative study	Switzerland & India
(Yang *et al.*, 2008)	The study investigates the existing e-waste flow at the national level. The reuse of used appliances has become a high priority for e-waste collectors and dealers because reuse generates higher economic profits than simple material recovery. The results of a cost analysis of e-waste flow show that management and collection cost significantly influence current e-waste management.	✓			✓		China
(de Oliveira *et al.*, 2012)	The study evaluates various e-waste collection systems in different countries and compares them to the current Brazilian reality. The main difficulty associated with the implementation of e-waste recycling processes in Brazil is the collection system, as its efficiency depends not only on the education and cooperation of the people but also on cooperation among industrial waste generators, distributors and the government.		✓		✓	Comparative study	Brazil
(Kilic *et al.*, 2015)	The study considered ten scenarios of e-waste collection systems regarding different collection rates, and analyses through a mixed integer linear programming model. The result shows that the optimum locations of storage sites and recycling facilities obtained for each scenario satisfy the minimum recycling rates stated by the EU directive for each product category.		✓	✓		Mixed integer linear programming	Turkey

(Ghisolfi *et al.*, 2017)	The proposed model evaluates the sustainability of supply chains in terms of the use of raw materials due to disposal fees, collection, recycling and return of some materials from desktops and laptops using the system dynamics method. The results show that even in the absence of bargaining power, the formalization of waste pickers occurs due to legal incentives		✓	✓		System dynamics	Brazil
(Nowakowski and Pamula, 2020)	The proposed study analyses the system operated on a server or mobile app. A novel method of classification and identification using neural networks is proposed for image analysis: a deep learning convolutional neural network (CNN) was applied to classify the type of e-waste, and a faster region-based convolutional neural network (R-CNN) was used to detect the category and size of the waste equipment in the images.		✓	✓		Deep learning convolutional neural network	Poland
(Sagnak *et al.*, 2021)	The study proposes a novel approach to manage strategies that contribute towards making such online platforms economically, socially, and environmentally sustainable by mitigating their interacting barriers. The approach consists of a barrier assessment process and a strategy evaluation and planning process. The most impactful barriers are the lack of dissemination of information, lack of government support, insufficient infrastructure, and awareness and attitude of consumers. Lack of government support is the most influential causal barrier. Lack of information dissemination is a significant causal barrier with the highest overall impact on sustainability.		✓	✓		MCDM	India
(Batoo *et al.*, 2022)	The study addresses the issue of the improper collection of e-waste leading to a negative impact on human health causing air pollution, as well as long-term effects on the environment. The behaviour-based swarm model using a fuzzy controller (BSFC) is proposed for efficient e-waste collection. The approach is provided for the online system that enables people to request the collection of e-waste components and solve the vehicle's routing problem. The optimization result demonstrates the decrease in the collection cost and the on-time e-waste collection from the household.		✓	✓		Artificial intelligent	Saudi Arabia
Note: A- Deterministic, B- Uncertain, C- Experimental study, D- Exploratory study							

2.4 Sectional summary

This chapter presents a literature survey of e-waste management issues related to policy, disposal behaviour and collection system. A bibliometric analysis is conducted to determine the specific literature on e-waste management issues. This chapter also presents a critical review of the identified literature on e-waste policy, disposal behaviour and collection system. Thereafter, research gaps are identified. The salient points are summarized as follows:

- Chronological compilation of literature is necessary to identify development trends, for which a bibliographic approach is found appropriate.
- The bibliographic analysis is a tool as development trends are qualitatively and quantitatively assessed in research fields over time.
- E-waste management issues are found strongly related to policy, disposal behaviour and collection system.
- The e-waste policy and regulation need to align with UN SDGs 2030 for a better focus and sustainability.
- The issues relating to e-waste policy are reviewed from time to time and prominent factors identified to drive e-waste policy.
- Efficient e-waste collection system is necessary to provide a better sustainable business model.
- Evaluation of the various e-waste collection methods for the urban and rural regions are necessary.

- An intelligent system for e-waste collection should be a future goal to meet the reverse supply chain challenges and to improve collection efficiency in general.
- The most suitable disposal system of e-waste can be found though the study of consumer intentions and likings about e-waste disposal behaviour.
- It is necessary to understand the consumer's current habits and identify the relevant vulnerabilities of the e-waste disposal practices to create targeted awareness campaigns and formulate policies and schemes to encourage scientific disposal.
- The methodologies to identify the psychological factors and investigate the impact on e-waste disposal behaviour is required.

CHAPTER 3 DESIGN AND DEVELOPMENT OF AN E-WASTE COLLECTION POLICY OF INDIA

This chapter presents a structural approach to evaluate the identify Critical Success Factors (CFSs) that influence the e-waste collection policy using the fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL). This chapter also develops the cause and effect interrelationship among the CSFs, and their impacts are evaluated to segregate the CSFs into cause group (prominent influencing and independent) and effect group (influenced and dependent).

3.1 Introduction

Handling policies of e-waste or WEEE are an essential aspect of the environmental ethics of a country. EEEs are generally categorised based on their usage and useful life for drafting the e-waste policy. While EEEs play a vital role in modern life in terms of safety, comfort, education and entertainment, WEEE poses a severe environmental risk if not treated and disposed of appropriately. Due to rapid technological advancement, higher affordability, increasing purchase power, decreasing cost, shorter useful life cycle, increased customisation, and promotional events like exchange schemes, there is a tremendous increase in consumption of EEEs worldwide. For example, the present penetration rate of mobile subscribers worldwide is 67 % and expected to reach 71% in 2025 (GSMA, 2019). The expected life cycle of EEEs like mobile phones at present is shorter than two years, while computers have a useful life of about three years (Öztürk, 2015). This ever-shortening life span of EEEs contributes to a great extent to WEEE growth. According to various sources (Ayodeji, 2011; Baldé *et al.*, 2017), the worldwide increase in e-waste generation at present is assessed to be at a rate of 10% - 20%

annually. There is great concern about the lack of government support and ineffective regulatory framework on e-waste handling in many countries, resulting in a continuous increase in informal recycling activities that pose a severe risk to the environment as they can bypass environmental regulations (Al-Anzi *et al.*, 2017). Unscientific e-waste handling is causing severe damage to the environment by contaminating soil, water and atmosphere, ultimately affecting human lives (Cao *et al.*, 2016). Hence, appropriate policy implication in e-waste handling is of critical importance for a country and its well-being, and it necessitates social awareness drive to tackle the problem.

In contrast, in developing countries such as India, the regulatory framework and vigilance are inadequate for mitigating WEEE related issues at the same time, general public awareness is also deficient. As a result, a large part of e-waste gets dumped or transported from developed countries as a donation, or hands-down etc. (Garlapati, 2016). Some of the direct causes identified by (Thavalingam and Karunasena, 2016) in developing nations are insufficient corrective measures, unclear roles of stakeholders, and insufficient resource investment in the e-waste management sector. These are challenges that are believed to be arising out of lack of social awareness and inadequate legal & enforcement framework. The same gives rise to the informal or grey sector handling a vast amount of e-waste, as observed and recorded for Bangladesh, Malaysia, Indonesia, the Philippines and Brazil (Rodrigues *et al.*, 2020). The situation is not much different in the case of India.

Apart from technological shortcomings, one of the problems for India is its substantial population. India is currently ranked third globally in terms of e-waste generation, which assessed as 3.23 million tons (Forti *et al.*, 2020). The estimated volume of e-waste generation in India grossly exceeds that of e-waste processing capacity (0.78 million tons), as (CPCB, 2019) observed. As per the assessment carried out in 2017 (Awasthi *et al.*, 2018), the various sources that prominently contribute to the growth of e-waste are household appliances (42%), information and telecom equipment (34%), consumer electronics (14%), and other electronic equipment (10%). Many regulatory agencies also pointed out laxity in implementing e-waste policies and lack of enforcement as a prominent drawback in India (Tocho and Waema, 2013). Furthermore, identical enablers are required for cases involving the local and the federal government to engage and educate the public on the need for separate e-waste management and the various priorities of the e-waste collection policy.

The motivation of this research to accomplish the following objectives:

- To identify and shortlisted CSFs for designing an e-waste collection policy based on a literature survey and content validity with the expert's committee.
- To evaluate and categorised CSFs as cause group and effect groups, those need to be managed.
- To perform sensitivity analysis for examining the robustness of the result minimise biases during the decision-making process.
- To set appropriate standards and controls to regulate the action of stakeholders associated with e-waste handling in the public and private sector.

The chapter presents a work attempts to identify the CSFs influencing the designing of e-waste collection policy in the Indian context. A Multi-Criteria Decision Making (MCDM) technique through an appropriate framework is adopted. Fuzzy DEMATEL chosen for evaluating the

CSFs. DEMATEL analysing the influencing behaviour of CSFs on other CSFs. The method is utilised primarily to develop two sets of CSFs that is cause group and effect group considering multiple expert judgments and the fuzziness associated with their decisions.

The study provides a novel research contribution in the e-waste management field, focusing on designing e-waste collection policy in the Indian context. The methodology exploits interrelationship among the various influencing factors and enables policymakers to incorporate those factors to strengthen the e-waste policy in terms of acceptable collection strategy. Prioritising CSF requires attention to the factors which are critical causal CSFs to others. The study provides research implications for researchers and practitioners to understand the evaluation process of CSFs better and identify significant CSFs while drafting an e-waste collection policy. A sensitivity analysis is also conducted to check the robustness of the result.

3.2 Evolution of e-waste policy

With a motive to mitigate short and long-term impacts on environmental and human health arising out of e-waste, the Indian government has enacted several e-waste policies from time to time. The evolution of the e-waste policy in India may be classified into five phases (CPCB, 2018), as illustrated in Figure 3.1.

The period during 1986 to 2003 can be termed as initiation phase as several pioneering initiatives were taken during this phase to identify, categorise and assign the responsibility of handling various waste streams. Acts such as Environment Protection Act 1986 was brought in, to identify various types of pollutants to the environment. After about three years, Hazardous (Management and Handling) Rules 1989 was introduce to define hazardous wastes and their sources. Subsequently, a series of Hazardous (Management and Handling) Amendments in 2000 and 2003 were brought forward which identifies and categorises various harmful wastes into twelve categories. The term e-waste was introduced and recognised as a waste stream with contamination potential under schedule three of the hazardous waste rules in 2003. There was no separate regulation explicitly formulated to address the e-waste related problem. However, this can still be considered a profound first step to subsequently develop specific legislation for various waste streams and environmental issues arising out of it.

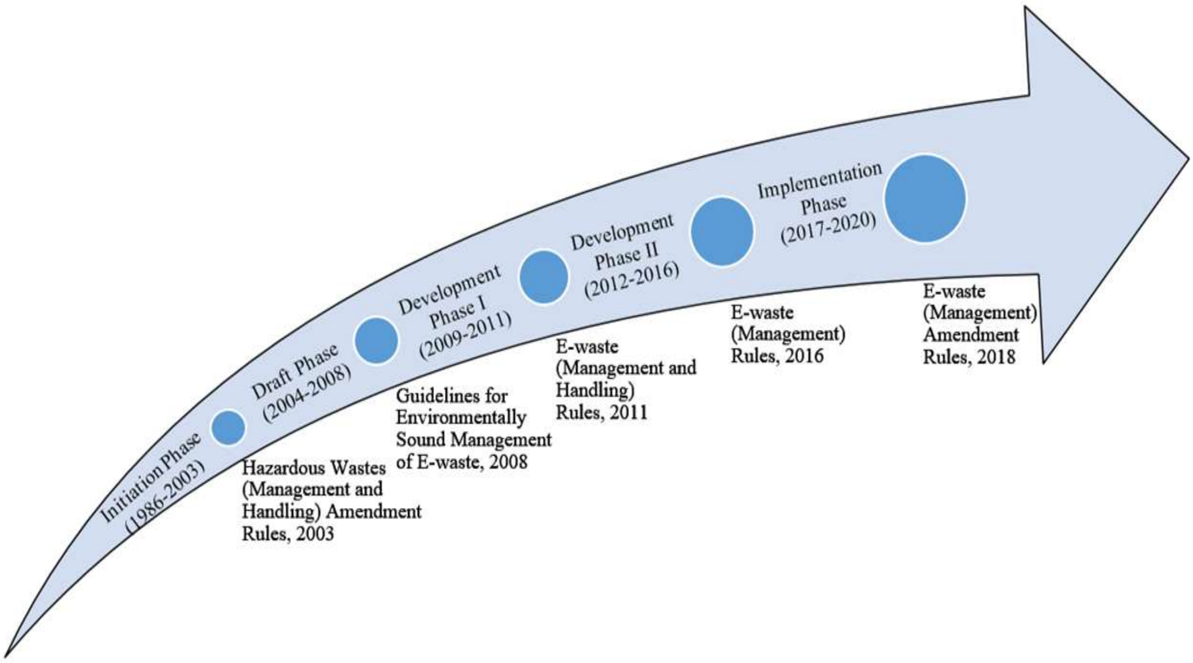


Figure 3.1: Evolution of e-waste policy of India

During 2004 to 2008, several studies were commissioned, and detailed guidelines were drawn, this time interval can be defined as the Draft phase. An explicit formulation of guidelines for environmentally sound management of e-waste was initiated by the MoEF&CC and Central Pollution Control Board (CPCB), Government of India in the year 2008. Under this initiation, identification and assessment of various sources of e-waste were made. Classification of e-waste according to its components, composition, and harmful effects were attempted. These documents also addressed the recycling potential of e-waste for economic benefit. However, the guidelines of e-waste did not adequately explain the roles and responsibilities of various monitoring agencies such as State Pollution Control Boards (SPCBs), local bodies, as well as other stakeholders.

The period from 2009 to 2011 can be termed as a Development Phase-I as the first consolidated policy framework on e-waste management was debated during 2010-11 and was passed in 2011 which was termed as E-waste (Management and Handling) Rules, 2011. The policy laid down the roles and responsibilities of stakeholders and monitoring agencies. It also introduced the concept of EPR in India although was in place in developed nation. This policy defined various stakeholders of a business model around e-waste management, grouped under manufacturer, producers, collectors, dismantlers, and recyclers. However, the Development Phase-I fell short of defining transboundary movement of e-waste under various schemes as a hazardous and a mitigation plan for the same. Other criticisms are that it did not adequately address economic implications, merits, demerits, barriers and drivers of e-waste management in India (Wath *et al.*, 2010).

The next distinct phase identified is from 2012 to 2016 as Development Phase-II. The levels of responsibilities of the various government bodies were explained in the E-waste (Management) Rules, 2016, and it is presented in Table 3.1. The prominent feature of this policy was a target-based approach for e-waste collection under EPR. The adoption of the same policy was based on existing international best practices which demonstrated a higher success rate for implementation of EPR. The policymakers took references from many countries like the Netherlands (recycling rate 45%-75%), Japan (recycling rate 50%-60%), South Korea (recycling rate 55%-70%) and UK (recycling rate 50%-80%) (CPCB 2019). In these countries, the e-waste management policy was in a much more mature phase with set targets of recycling rate. Whereas in India, successful and sustainable collection infrastructure was not yet established. Further, the implementation plan of this rule for the producer under EPR provision was to subsequently set a guideline of collection target. During the first two years, the recommended target was 30%, and the subsequent bi-yearly target was increased by 40%, and so on up to 70% (CPCB 2019). Under the rule, the producers were required to share the details of EEEs and collection target of the forthcoming years based on sales forecast to the CPCB in a prescribed format.

Table 3.1: Responsibility of government authorities in e-waste legislation, India

Level of authority	**Entities**	**Responsibilities**
Central government	MoEF&CC, CPCB, general administration	Draft policy & regulations, Training program, Random inspections, Submission of the annual report
State government	SPCB, committees of union territories, general administration	Inventorization of e-waste, Grant & authorisation, Maintaining online information, Monitoring, Random inspection
Urban local bodies	Municipal committee/council or corporation	Ensure e-waste to be separate with municipal solid waste, collection of orphan e-products and sent to authorised recyclers
Port/Customs Authority	Dock committee for transboundary movement	Verify the importer authorisation, Monitoring illegal activities, Reporting to CPCB

The development during the year from 2017 to 2020 can be term as implementation year. The policymakers duly considered the feedback obtained from various stakeholders to formulate a comprehensive E-waste (Management) Amendment Rules, 2018. The provision in this rule was that producers should be liable to share collection targets with government authorities. Another condition was that in the event of any violation of environmental law, strict action might be taken in the form of cancellation of registration.

As of 27th July 2019, CPCB had registered 312 authorised recycling/dismantling units across India (CPCB 2019). The units are located in 18 states, as shown in Figure 3.2, and the overall registered recycling capacity was 0.78 million tons. The highest number of recycling units are located in Maharashtra (75 units), followed by 71 units in Karnataka and 41 units in Uttar Pradesh. Out of the total formal recyclers, only 51 units had installed capacity exceeding 5000 tons per annum. The total installed capacity of registered recyclers was 0.78 million tons, four times lesser than the projected e-waste generation of 3.23 million tons. Several studies have revealed that the implemented e-waste policy in India and other developing countries face unique challenges (Patil and Ramakrishna 2020; Singh et al. 2020). These include a thriving informal sector in the absence of strict enforcement of regulation, lack of public awareness, and lack of financial resources to implement the necessary intervention steps to manage e-waste.

3.3 Materials and methods

This section highlights the identification of e-waste collection policy CSFs, research gaps, and the importance of fuzzy-DEMATEL method in relation to the proposed methodology.

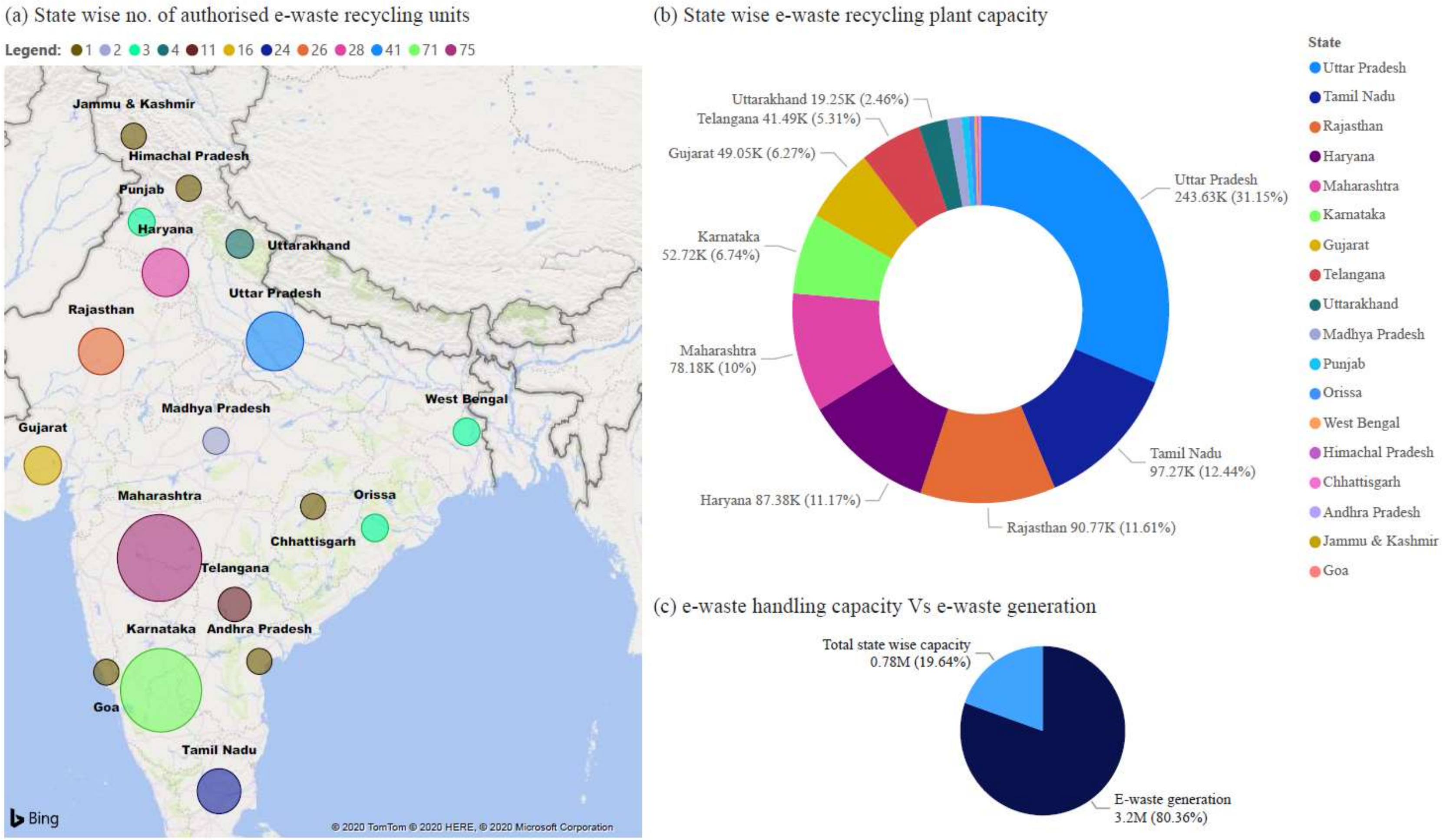


Figure 3.2: State-wise location of recycling units with installed capacity (as of 27/06/2019)

3.3.1 CSFs identification for e-waste collection policy

The identification of CSFs was based primarily on an extensive literature review. A list of CSFs prepared through various available electronic databases such as Google Scholar and Scopus. Appropriate search strings used to identify related keywords for CSFs, the phrases used included e-waste, electronic waste, collection policy, regulation & legislation in relation to the collection system. After selecting and reviewing the literature, a comprehensive list of CSFs has been identified, keeping in mind the design of the e-waste collection policy. However, some CSFs have also been taken from India's e-waste policy such as infrastructure development, certification and licensing, EPR, collection systems, information visibility and recycling technology. Based on this list, discussions and content verification was conducted with the expert committee to finalise the CSFs. After several rounds of discussion, feedback is taken from the expert committee. Based on that, changes were made in the wordings and text of the original description of CSFs. The process improved the clarity of thought process, and the expert's committee involvement brought validity. A total of twenty-three CSFs got shortlisted. These were later grouped under six different broad aspects taking the help of experts. These six aspects are (1) Research & development, (2) Education & social behaviour, (3) Economic instrument, (4) Traceability, (5) Responsibility, and (6) Legislation & Regulation and the same is tabulated with explanation in Table 3.2.

Table 3.2: Identified CSFs of e-waste collection policy

Implication dimensions	**CSFs**	**#**	**Explanation**
Research & development	Green practices	K1	To develop a framework of green recycling activities for handling e-waste.
	Technology involvement	K2	To identify environmentally sound technologies and possess adequate technical capabilities, requisite facilities and carbon footprint monitoring.
	Infrastructure development	K3	To provide guidelines for infrastructure to handle the rapidly growing streams of e-waste.
Education & social behaviour	Environmental program	K4	To incorporate and progressively acquire knowledge on specific e-waste effect on environment to adopt an environmentally friendly approach.
	Government initiatives	K5	To develop e-waste awareness program under 'Swachh Bharat Mission' about safe disposal of e-waste.
	Training & empowerment	K6	Develop a suitable platform for an employee training program like skill development for formal and informal actors.
	Publicity	K7	To increase the environmental awareness among consumers and establish a channel for expressing willingness to participate in the e-waste recycling activities.
	Public ethics	K8	Shaping ethical relations of consumers about responsibility to dispose of e-waste by proper channel.
Economic Instrument	Stakeholders awareness about circular economy	K9	To promote circular economy concepts for recovery, reuse and recycling of e-waste.
	Entrepreneur support	K10	To provide details of various start-ups under subsidies schemes that encourage business model development for e-waste handling or recycling.
	Funding schemes	K11	To explain flexible financial support guidelines for the stakeholders regarding hazardous waste disposal, real data of e-waste collection and recycling.
	Tax incentive	K12	To explain tax provision for the consumer who brings their e-waste to be recycled and to agencies/firms that collect e-waste for recycling.

Responsibility	Extended producer responsibility (EPR)	K13	To encourage manufacturers/producers to manage the environmental impacts of their products through the entire life cycle of a product.
	Corporate social responsibility (CSR)	K14	To provide guidelines to the business community to engage in CSR activity related to their e-waste.
	Individual stakeholders responsibility	K15	To clarify the responsibilities of all stakeholders under the regulation.
Traceability	Information visibility & transparency	K16	Involve all stakeholders, including the upstream and downstream members of e-waste supply chain to keep necessary data and information about recycling activities.
	Transboundary movement	K17	To comply with the international treaties for export or import and follow Basel Convention rules.
	Estimation of e-waste generation	K18	To develop a framework for a national database of e-waste generation estimation every year.
	Collection mechanism	K19	To provide details of various e-waste collection methods in policy guidelines.
Legislation & Regulation	Monitoring & enforcement	K20	To secure the outcomes of e-waste management at present as well as in the future.
	Legal framework	K21	To establish a legal framework for e-waste management and include the provision of reusable materials and hazardous substances in mainstream business.
	Regulatory framework	K22	To establish local authorities' duty to develop a waste management framework, i.e., promote an integrated municipal solid waste management for identified e-waste.
	Certification and Licensing	K23	To develop a flexible framework for providing licensing as collectors, recyclers, logistic providers and also develop certification procedures for the producers who generate e-waste.

3.3.2 Proposed research framework

The framework consists of two phases. The first phase identifies and lists CSFs related to e-waste collection policy based on an extensive literature survey and expert's discussion. The second phase involves applying the fuzzy DEMATEL technique to develop the interrelationship among the CSFs for analysis of causal relation between one CSF over another. Finally, the findings are discussed with the expert's committee to assist them in reframing e-waste collection policy and develop tactical schemes by policymakers for successful and broad acceptance level of e-waste collection policy. The various steps adopted in the proposed research framework for evaluating the CSFs are illustrated in Figure 3.3.

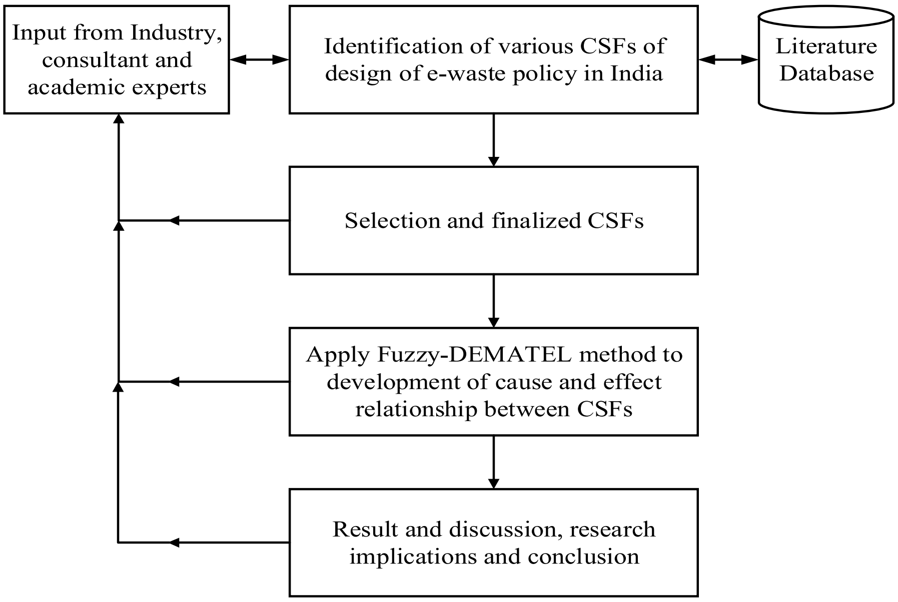


Figure 3.3: The various steps involved in the proposed research framework

3.3.3 Research method

The objective of the current study is to evaluate and identify the causal relationship between the CSFs. Various MCDM methods are available such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Interpretive Structural Modelling (ISM), and DEMATEL. Among these methods, AHP could not determine the relationship between factors (Parmar and Desai, 2020). ANP only quantify and develop inner or direct dependency between factors (Tseng, 2009). While the ISM technique establishes the hierarchical interrelationships between the factors, it does not significantly influence the factors. It does not divide the factors into cause and effect groups (Mangla *et al.*, 2016). DEMATEL is one of MCDM methods. It develops the direct and indirect influence relationship within factors and converts the influence factors into the cause group and effect group (Gupta and Barua, 2018).

DEMATEL is a mathematical computational method invented by Research Centre of Science and Human Affairs Program of the Battelle Memorial Institute Geneva (Gabus and Fontela, 1973). DEMATEL can be an effective way to solve the various complex management problems by developing complex causal relationships with matrices or diagraphs. The matrices or diagraphs portray a contextual relationship among the factors or elements of the system. The results of DEMATEL represent the relationship between factors by categorising them into cause and effect group (Tsai *et al.*, 2020). Considering the common biases and vagueness in human judgment in an actual situation, a fuzzy set theory has been used to extend the traditional DEMATEL into fuzzy-DEMATEL (Karuppiah *et al.*, 2020).

In waste management applications, the fuzzy-DEMATEL method has been utilised by various researchers in analysing the problem. Tseng and Lin (2009) identified critical issues and developed a cause and effect model for municipal solid waste management in Metro Manila. dos Muchangos *et al.* (2015) recognised the influential barriers to municipal solid waste management policy planning in Maputo city, Mozambique. Wang *et al.* (2017) analysed the barriers of formal enterprises of household e-waste collection in China. Sahu *et al.* (2018) modelled the enablers of green e-waste management practices for mobile phone companies in India. Sharma *et al.* (2020) identified as a circular economy concept the most influencing key enablers of e-waste management in India. Singhal *et al.* (2020) examined various critical factors for remanufacturing companies in India. Hence, fuzzy-DEMATEL is adopted here to develop contextual relations between various influencing CSFs for the acceptability of e-waste policy in the Indian context.

The fuzzy-DEMATEL method consists of the following steps:

Step 1: To establish an expert committee

Literature review and brainstorming/critical discussion are necessary to ascertain the research problem. For critical discussion, three committees were formed, and each committee consisted of six experts. The experts range from academia, the recycling industry and waste management consultants; most have more than ten years of experience in their respective fields. All experts are assumed capable of problem-solving and having significant knowledge of e-waste management comprising policymaking, designing of e-waste handling practice, and e-waste management in the Indian context. The responses are collected through telephonic interviews and email conversation.

Step 2: To construct the initial fuzzy direct relationship matrix ($\widetilde{A}$) for each expert (k)

In this step, for qualitative judgment, expert committee is asked to rate CSFs on a Triangular fuzzy number (TFN) scale as presented in Table 3.3. Here, $\tilde{a}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$ indicates the degree of influence factor i on factor j while k indicates number of experts, and n indicates number of factors. Then for each expert a $n \times n$ non-negative fuzzy direct relationship matrix is established as shown in equation (3.1).

$$\widetilde{A} = \begin{bmatrix} 0 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 0 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 0 \end{bmatrix}_{n \times n} \quad (3.1)$$

Table 3.3: TFNs linguistic scale

Definition of linguistic variables	**Intensity of fuzzy scale**	**TFN** ***(l, m, u)***
No influence (NI)	$\tilde{0}$	(0.00,0.00,0.25)
Very low influence (VL)	$\tilde{1}$	(0.00,0.25,0.50)
Low influence (L)	$\tilde{2}$	(0.25,0.50,0.75)
High influence (H)	$\tilde{3}$	(0.50,0.75,1.00)
Very high influence (VH)	$\tilde{4}$	(0.75,1.00,1.00)

Step 3: To develop a defuzzified direct relationship matrix

Initial fuzzy direct relationship matrix of each expert is defuzzified into crisp form. The development of Defuzzified Direct Relationship Matrices (DDRM) is through the conversion of the fuzzy numbers into a crisp score that is CFCS, as proposed by (Opricovic and Tzeng, (2003). The stepwise procedure of CFCS is mentioned from equation (3.2) to (3.8).

(1) Normalisation:

$$xl_{ij}^{k} = \frac{\left(l_{ij}^{k} - \min l_{ij}^{k}\right)}{\Delta_{\min}^{\max}} \quad (3.2)$$

$$xm_{ij}^{k} = \frac{\left(m_{ij}^{k} - \min l_{ij}^{k}\right)}{\Delta_{\min}^{\max}} \quad (3.3)$$

$$xu_{ij}^{k} = \frac{\left(u_{ij}^{k} - \min\ {}_{ij}^{k}\right)}{\Delta_{\min}^{\max}} \quad (3.4)$$

Where $\Delta_{min}^{max} = \max u_{ij}^{k} - \min l_{ij}^{k}$

(2) Compute left (ls) and right (us) spread of normalised fuzzy numbers:

$$x\mathrm{ls}_{ij}^{k} = \frac{xm_{ij}^{k}}{(1 + xm_{ij}^{k} - xl_{ij}^{k})} \quad (3.5)$$

$$x\mathrm{us}_{ij}^{k} = \frac{xu_{ij}^{k}}{(1 + xu_{ij}^{k} - xm_{ij}^{k})} \quad (3.6)$$

(3) Compute total normalised crisp value:

$$x_{ij}^{k} = \frac{\left[x\mathrm{ls}_{ij}^{k}\left(1 - x\mathrm{ls}_{ij}^{k}\right) + xu_{ij}^{k} * xu_{ij}^{k}\right]}{[1 - x\mathrm{ls}_{ij}^{k} + x\mathrm{us}_{ij}^{k}]} \quad (3.7)$$

(4) Compute crisp value:

$$z_{ij}^{k} = \min l_{ij}^{k} + x_{ij}^{k} * \Delta_{\min}^{\max} \quad (3.8)$$

Step 4: Development of an average direct relationship matrix (A_{ij}), Normalised Direct Relationship Matrix (*D*) and Total Relation Matrix (TRM) 'T'

The aggregate DDRM is obtained from each expert by developed Average Direct Relationship Matrix (ADRM) using equation (3.9).

$$A_{ij} = \frac{1}{k}\left(z_{ij}^{1} + z_{ij}^{2} + \cdots + z_{ij}^{k}\right) \quad (3.9)$$

The normalisation of ADRM is done using equation (3.10)

$$D = \frac{A}{S} \qquad \text{Where } S = \max\left(max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}, max_{1 \le i \le n} \sum_{i=1}^{n} a_{ij}\right) \quad (3.10)$$

The total relationship matrix T is computed by equation (3.11)

$$T = D(I - D)^{-1} \text{ Where } I \text{ is an identity matrix} \quad (3.11)$$

Step 5: To calculate row sum (R_i) and column sum (C_j) of TRM (T). Equation 3.12 and 3.13 are used to find R_i and C_j.

$$R_i = \left[\sum_{j=1}^{j=n} T_{ij}\right]_{n*1} \quad (3.12)$$

$$C_j = \left[\sum_{i=1}^{i=n} T_{ij}\right]_{1*n} \quad (3.13)$$

Step 6: To establish the cause and effect relationship

The value of R_i and C_j determine the cause or effect nature of a factor based on the computation of (R_i+ C_j) and (R_i- C_j). Where, (R_i+ C_j) represent the degree of prominence of the factor "i" in the entire system and (R_i - C_j) represent net cause and effects that factor "i" contributes to the system. Furthermore, the interrelation among the CSFs is developed based on the threshold value α, which is calculated by using equation (3.14).

$$\alpha = \frac{\sum_{i=1}^{n'} \sum_{j=1}^{n'} T_{ij}}{n'} \quad (3.14)$$

The threshold value α is computed from the matrix T. When values in the matrix T exceed α, it indicates a strong interrelation between factors. The weak relationship between the factors are generally eliminated.

3.4 Case analysis

The authors developed a framework for examining CSFs related to acceptance of e-waste policy in Indian scenario, incorporating the perspectives of various stakeholders that are necessary for a successful implication of a sustainable e-waste management system. The data required for the fuzzy-DEMATEL analysis is collected in the state of Rajasthan in India. Some recently reported studies in other application areas have applied DEAMTEL as a tool for analysis in fuzzy situations, taking the inputs from three to five expert committees (Parmar and Desai, 2020; Singhal *et al.*, 2020).

3.4.1 Estimation of CSFs using fuzzy-DEMATEL

Based on the expert's committee's opinion, the initial pairwise matrices are built. The inputs are provided by expert's committees on a 0 to 4 scale (Table 3.3) depending upon the influence of one factor over another factor and the same is then converted using a fuzzy linguistic scale. Further, fuzzy responses matrices of individual committees are converted in crisp value by using equation (3.5-3.8). Thereafter, the metrics of the three committees were averaged using equation (3.9) and normalized to the ADRM using equation (3.10) presented in Table 3.4. The TRM is constructed using equation (3.11), as shown in Table 3.5. Table 3.6 represent the rankings of the CSFs, where R and C are computed using equation (3.12).

3.5 Results and discussions

To evaluate the interconnect among the listed CSFs, the R and C values are computed from the TRM (Table 3.5), and a causal diagraph is drawn as presented in Figure. 3.4. The X-axis denotes (R + C), which depicts the prominence of factors (i.e. the cause group), and Y-axis indicates (R – C), which is the effect group, the same is also known as a receiver group. The positive value of CSFs on the Y-axis in the figure will represent the cause group, while negative value as effect group. The advantage of the causal diagraph is that it becomes easier to capture the complexity in decision making. The relative value of various CSFs is used to determine the influencing and influenced factors. The diagraph should help make it easier for policymakers to consider CSFs for designing the e-waste collection policy.

Table 3.4: Normalised ADRM of all three experts committees

CSFs	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18	K19	K20	K21	K22	K23
K1	0.003	0.076	0.000	0.052	0.000	0.000	0.000	0.052	0.000	0.052	0.003	0.000	0.000	0.076	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
K2	0.052	0.003	0.027	0.000	0.000	0.076	0.003	0.000	0.000	0.052	0.000	0.076	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000
K3	0.052	0.052	0.003	0.052	0.003	0.000	0.000	0.000	0.003	0.076	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.076	0.000	0.000	0.000
K4	0.052	0.100	0.052	0.000	0.003	0.003	0.000	0.027	0.000	0.000	0.052	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.076	0.003	0.000	0.000	0.000
K5	0.076	0.076	0.052	0.000	0.000	0.052	0.100	0.000	0.003	0.000	0.000	0.000	0.000	0.052	0.000	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000
K6	0.052	0.000	0.076	0.027	0.003	0.003	0.052	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.076	0.000	0.076	0.000	0.000	0.000	0.000
K7	0.003	0.052	0.000	0.076	0.052	0.000	0.000	0.052	0.000	0.000	0.000	0.052	0.000	0.076	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K8	0.003	0.000	0.100	0.076	0.052	0.000	0.000	0.003	0.052	0.000	0.052	0.000	0.000	0.000	0.076	0.000	0.000	0.076	0.000	0.000	0.000	0.000	0.000
K9	0.052	0.003	0.052	0.052	0.000	0.000	0.076	0.100	0.000	0.052	0.000	0.000	0.076	0.100	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
K10	0.003	0.076	0.003	0.000	0.027	0.000	0.000	0.052	0.000	0.000	0.052	0.000	0.003	0.000	0.000	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000
K11	0.003	0.003	0.076	0.027	0.000	0.027	0.000	0.000	0.027	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K12	0.052	0.052	0.000	0.003	0.100	0.000	0.003	0.000	0.003	0.000	0.076	0.000	0.100	0.000	0.000	0.100	0.027	0.000	0.000	0.000	0.000	0.000	0.000
K13	0.076	0.052	0.000	0.000	0.076	0.052	0.000	0.000	0.000	0.076	0.000	0.076	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K14	0.003	0.000	0.052	0.000	0.000	0.000	0.003	0.000	0.076	0.003	0.000	0.000	0.000	0.000	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K15	0.052	0.052	0.000	0.100	0.000	0.052	0.100	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K16	0.003	0.076	0.000	0.052	0.003	0.000	0.003	0.000	0.100	0.000	0.000	0.000	0.000	0.100	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K17	0.052	0.100	0.076	0.000	0.000	0.052	0.000	0.000	0.000	0.076	0.027	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K18	0.100	0.000	0.052	0.000	0.076	0.076	0.052	0.000	0.000	0.003	0.000	0.000	0.100	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K19	0.076	0.100	0.027	0.052	0.000	0.000	0.000	0.100	0.000	0.000	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K20	0.003	0.000	0.027	0.000	0.076	0.003	0.000	0.000	0.076	0.000	0.000	0.003	0.000	0.000	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K21	0.052	0.027	0.000	0.003	0.000	0.027	0.000	0.052	0.000	0.076	0.000	0.000	0.000	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K22	0.003	0.052	0.052	0.076	0.027	0.000	0.027	0.000	0.000	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K23	0.003	0.052	0.076	0.052	0.003	0.027	0.003	0.027	0.003	0.003	0.003	0.003	0.027	0.052	0.076	0.027	0.076	0.052	0.027	0.076	0.076	0.076	0.003

Table 3.5: Total relation matrix

CSFs	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18	K19	K20	K21	K22	K23
K1	0.024	0.100	0.022	0.071	0.008	0.015	0.012	0.063	0.011	0.062	0.015	0.010	0.008	0.081	0.087	0.009	0.006	0.006	0.006	0.002	0.010	0.004	0.000
K2	0.075	0.031	0.041	0.014	0.013	0.084	0.011	0.015	0.006	0.070	0.012	0.081	0.010	0.014	0.011	0.010	0.014	0.002	0.007	0.003	0.103	0.000	0.000
K3	0.065	0.075	0.016	0.060	0.015	0.009	0.004	0.012	0.011	0.086	0.009	0.011	0.007	0.008	0.011	0.002	0.008	0.002	0.005	0.077	0.007	0.000	0.000
K4	0.082	0.130	0.071	0.020	0.017	0.022	0.005	0.043	0.007	0.024	0.058	0.024	0.081	0.009	0.011	0.004	0.004	0.005	0.079	0.009	0.013	0.000	0.000
K5	0.108	0.105	0.075	0.026	0.019	0.071	0.115	0.017	0.014	0.020	0.005	0.017	0.015	0.073	0.024	0.012	0.007	0.103	0.007	0.006	0.010	0.000	0.000
K6	0.078	0.040	0.095	0.050	0.012	0.013	0.057	0.021	0.032	0.022	0.009	0.019	0.009	0.015	0.009	0.007	0.079	0.003	0.080	0.007	0.004	0.000	0.000
K7	0.029	0.083	0.025	0.092	0.065	0.013	0.012	0.060	0.020	0.011	0.013	0.061	0.016	0.093	0.013	0.084	0.004	0.011	0.008	0.002	0.008	0.000	0.000
K8	0.043	0.037	0.127	0.103	0.065	0.021	0.025	0.020	0.058	0.019	0.060	0.009	0.022	0.015	0.090	0.010	0.003	0.084	0.009	0.010	0.004	0.000	0.000
K9	0.078	0.042	0.081	0.080	0.023	0.012	0.083	0.118	0.017	0.073	0.016	0.016	0.087	0.116	0.023	0.010	0.007	0.015	0.007	0.006	0.004	0.000	0.000
K10	0.022	0.094	0.027	0.011	0.034	0.016	0.006	0.056	0.006	0.016	0.059	0.016	0.007	0.005	0.007	0.003	0.078	0.008	0.002	0.002	0.009	0.000	0.000
K11	0.018	0.018	0.085	0.037	0.006	0.030	0.005	0.006	0.030	0.011	0.005	0.031	0.008	0.005	0.003	0.004	0.004	0.001	0.005	0.007	0.002	0.000	0.000
K12	0.084	0.092	0.024	0.022	0.114	0.024	0.020	0.010	0.020	0.023	0.081	0.021	0.107	0.027	0.010	0.104	0.032	0.012	0.003	0.002	0.009	0.000	0.000
K13	0.102	0.085	0.018	0.013	0.090	0.066	0.015	0.013	0.006	0.090	0.013	0.086	0.015	0.016	0.011	0.011	0.014	0.010	0.006	0.001	0.008	0.000	0.000
K14	0.017	0.013	0.060	0.016	0.003	0.005	0.016	0.012	0.078	0.014	0.003	0.003	0.008	0.011	0.055	0.006	0.002	0.002	0.002	0.005	0.001	0.000	0.000
K15	0.075	0.090	0.023	0.125	0.012	0.062	0.107	0.045	0.015	0.013	0.011	0.015	0.013	0.025	0.011	0.086	0.006	0.005	0.014	0.002	0.009	0.000	0.000
K16	0.023	0.091	0.021	0.064	0.008	0.010	0.015	0.017	0.111	0.016	0.006	0.010	0.015	0.115	0.010	0.006	0.002	0.002	0.006	0.002	0.009	0.000	0.000
K17	0.078	0.130	0.093	0.016	0.015	0.066	0.007	0.012	0.007	0.097	0.041	0.090	0.011	0.010	0.008	0.010	0.015	0.002	0.006	0.007	0.013	0.000	0.000
K18	0.139	0.047	0.073	0.034	0.093	0.097	0.079	0.019	0.008	0.028	0.006	0.018	0.106	0.024	0.114	0.016	0.010	0.011	0.010	0.006	0.005	0.000	0.000
K19	0.101	0.130	0.052	0.073	0.018	0.015	0.006	0.111	0.009	0.019	0.018	0.089	0.016	0.012	0.018	0.011	0.005	0.010	0.007	0.004	0.013	0.000	0.000
K20	0.024	0.019	0.041	0.017	0.080	0.013	0.021	0.013	0.079	0.010	0.003	0.007	0.009	0.016	0.056	0.007	0.002	0.009	0.002	0.003	0.002	0.000	0.000
K21	0.062	0.045	0.017	0.016	0.007	0.034	0.005	0.062	0.009	0.084	0.009	0.005	0.003	0.058	0.013	0.002	0.009	0.005	0.004	0.001	0.004	0.000	0.000
K22	0.022	0.074	0.069	0.087	0.033	0.011	0.033	0.008	0.005	0.012	0.082	0.011	0.009	0.007	0.004	0.004	0.002	0.004	0.007	0.006	0.007	0.000	0.000
K23	0.055	0.108	0.118	0.090	0.029	0.057	0.027	0.050	0.025	0.039	0.023	0.027	0.045	0.070	0.098	0.040	0.084	0.058	0.039	0.085	0.087	0.076	0.003

Threshold value α = 0.029

Table 3.6: Final ranking of the CSFs

CSFs	Degree of influential impact (R)	Degree of influenced impact (C)	Prominence factor (R+C)	Prominence Ranking	Causal relation (R-C)
K1	0.632040	1.401847	2.033887	2	-0.76981
K2	0.629402	1.676864	2.306267	1	-1.04746
K3	0.501773	1.275289	1.777062	4	-0.77352
K4	0.718558	1.134744	1.853303	3	-0.41619
K5	0.850070	0.779014	1.629084	6	0.07105
K6	0.660759	0.766005	1.426764	10	-0.10525
K7	0.722682	0.687598	1.410280	11	0.035084
K8	0.833885	0.804836	1.638721	5	0.029049
K9	0.912183	0.585466	1.497649	8	0.326718
K10	0.484289	0.859820	1.344109	12	-0.37553
K11	0.320857	0.557696	0.878553	20	-0.23684
K12	0.842101	0.676106	1.518207	7	0.165995
K13	0.690136	0.624467	1.314603	14	0.065669
K14	0.329576	0.824864	1.154441	16	-0.495290
K15	0.764872	0.698479	1.463350	9	0.066393
K16	0.558073	0.455615	1.013688	19	0.102458
K17	0.733440	0.396058	1.129498	17	0.337382
K18	0.943690	0.370911	1.314600	15	0.572779
K19	0.737660	0.322488	1.060148	18	0.415172
K20	0.434336	0.255213	0.689549	22	0.179123
K21	0.455762	0.342629	0.798391	21	0.113133
K22	0.495013	0.084116	0.579129	23	0.410897
K23	1.332417	0.003448	1.335866	13	1.328969

3.5.1 Ranking of CSFs based on R+C values

The order of CSFs is evaluated through the degree of prominence measured by (R+C) values. A PARETO chart is developed based on the degree of prominence to identify the group of significant CSFs. The PARETO chart (Figure 3.5) identifies seven CSFs (i.e. K2, K1, K4, K3, K8, K5 and K12) as the most critical and prominent factors. The CSF K2 designated Technology involvement is found to be the most crucial factor. In decreasing order of importance thereafter CSFs are Green practices (K1), Environmental program (K4), Infrastructure development (K3), Public ethics (K8) and Government initiatives (K5). Therefore, it is recommended that policymakers pay more attention to these CSFs for designing the e-waste collection policy.

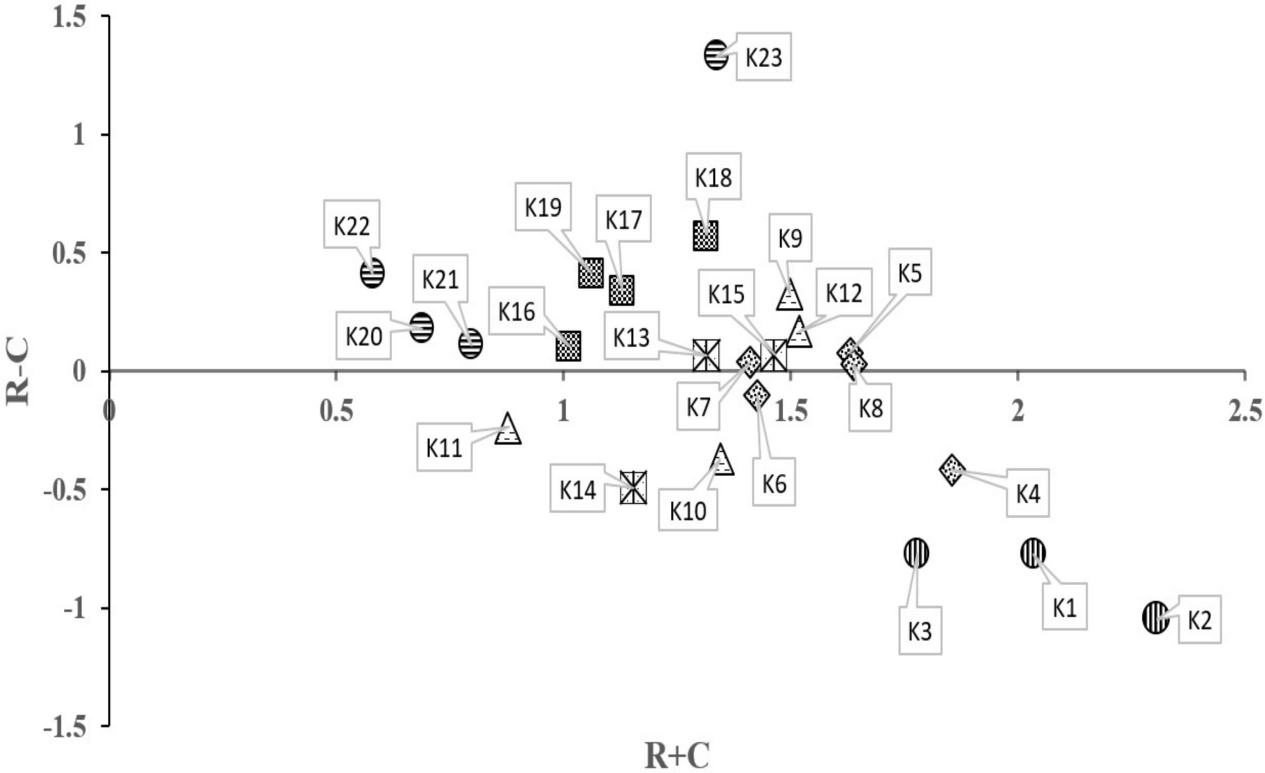


Figure 3.4: Causal diagraph among CSFs

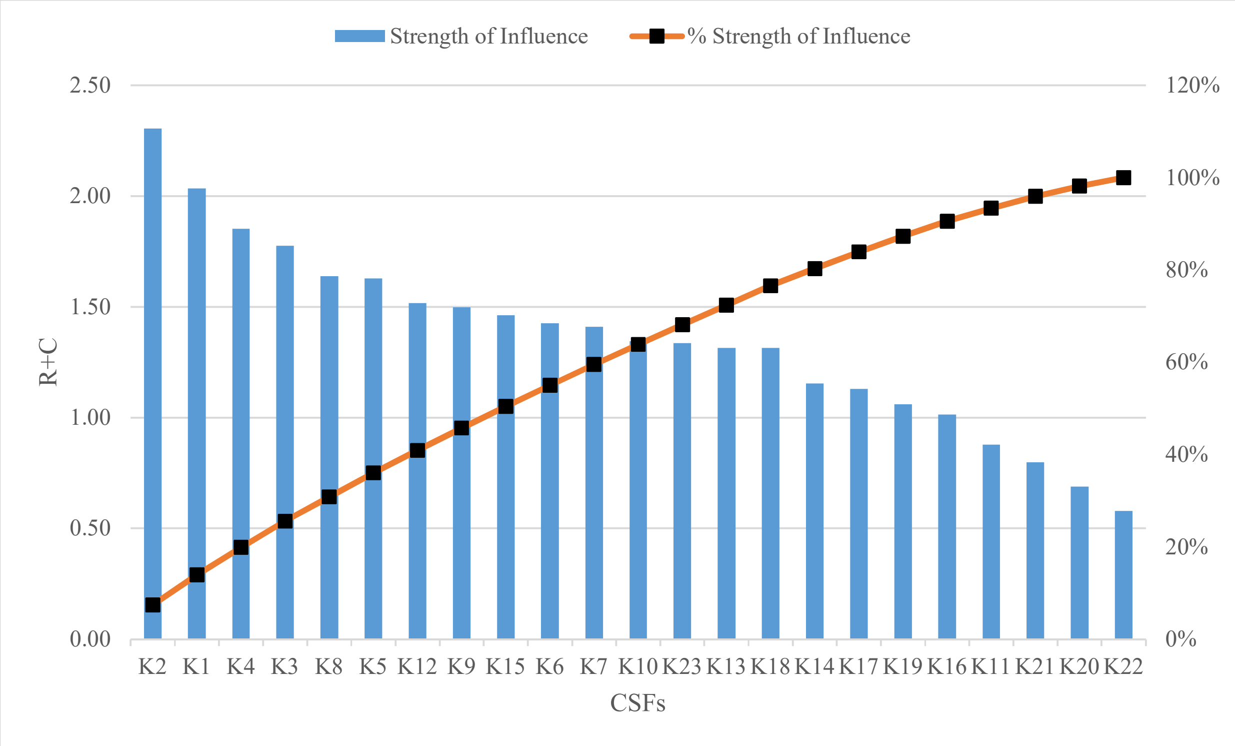


Figure 3.5: Prioritized the CSFs based on R+C values

3.5.2 The categorization of CSFs into cause group and effect group based on R-C values

Based on their R-C score (Table 3.6), CSFs are classified into cause and effect groups. Out of the twenty-three CSFs, fifteen factors have a positive (R-C) value and are put in the cause group. While the rest eight with negative (R-C) values, are identified as the effect group.

The listed CSFs in the cause group indicate prominent independent factors that significantly influence other factors. The highest positive value of R-C is obtained for Certification and licensing (K23) followed by Public ethics (K18), and Collection mechanism (K19). The R-C values of cause group CSFs are presented in Figure 3.6 in order of prominence. The primary factors or indicators of the cause group are summarised in Table 3.7. It is recommended that the prominent cause group CSFs be critically analysed by policymakers before any implementation decision.

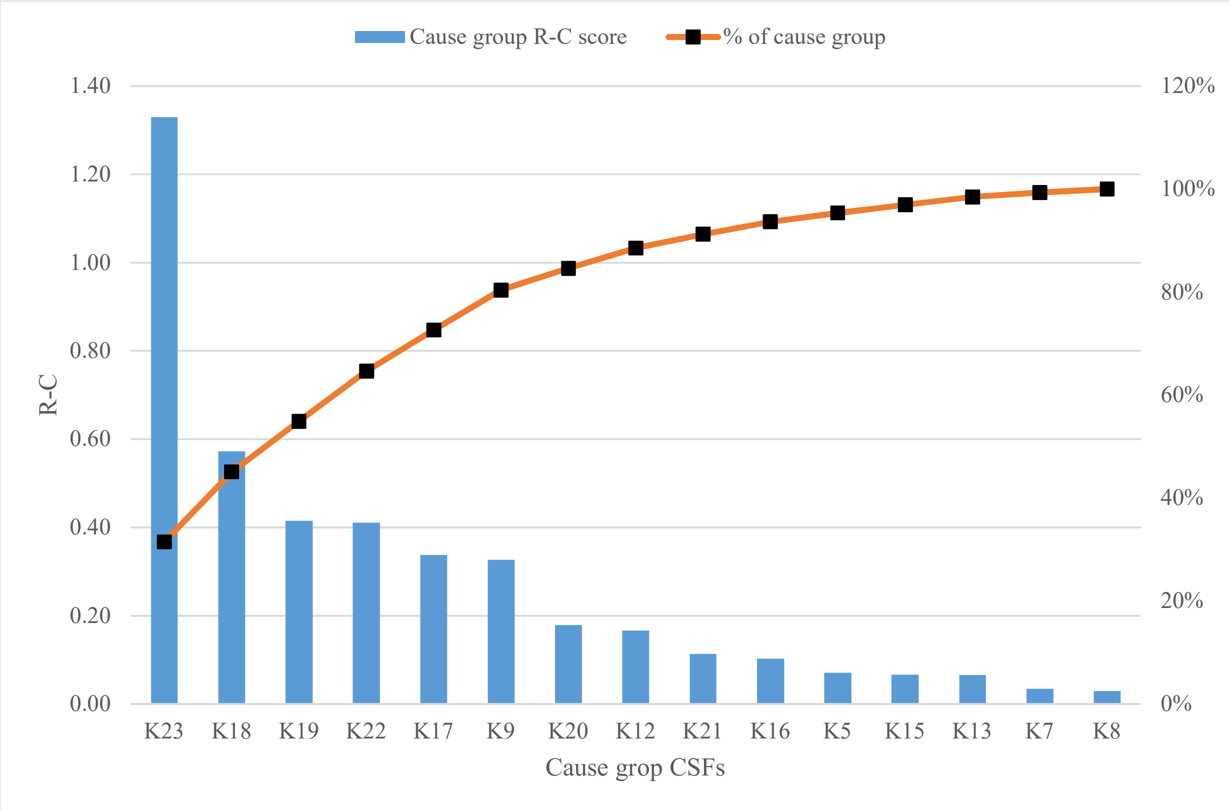


Figure 3.6: Cause group CSFs based on R-C score

The effect group CSFs are listed in Figure 3.7, the prominent CSFs of the effect group are Technology involvement (K2), Infrastructure development (K3), Green practices (K1) and CSR (K14). The significance of effect CSFs are explained in Table 3.8. The key indicator for the effect group CSFs needs to be identified to measure the performance of the CSFs.

Table 3.7: Cause group CSFs description

S.No.	Indicators check for cause group	Description
1	The highest degree of influential impact power of R	K23 - Certification and licensing has the highest degree of influential impact power of R equal to 1.332, which means K23 factor has the highest impact on the other CSFs.
2	Highest R – C score in the group	K23 - Certification and licensing has the highest value of R–C equal to 1.335, which indicates K23 is also least influenced by all other factors.
3	Lowest R – C score in the group	K8 - Public ethics CSFs has the least value of R-C equal to 0.83, which indicates K8 highly is influenced by most other factors.
4	Highest R+C score	K5 - Government initiatives have the highest R+C score equals to 1.64, and this CSFs has the potential to improve the system, and it requires attention by the policymakers.

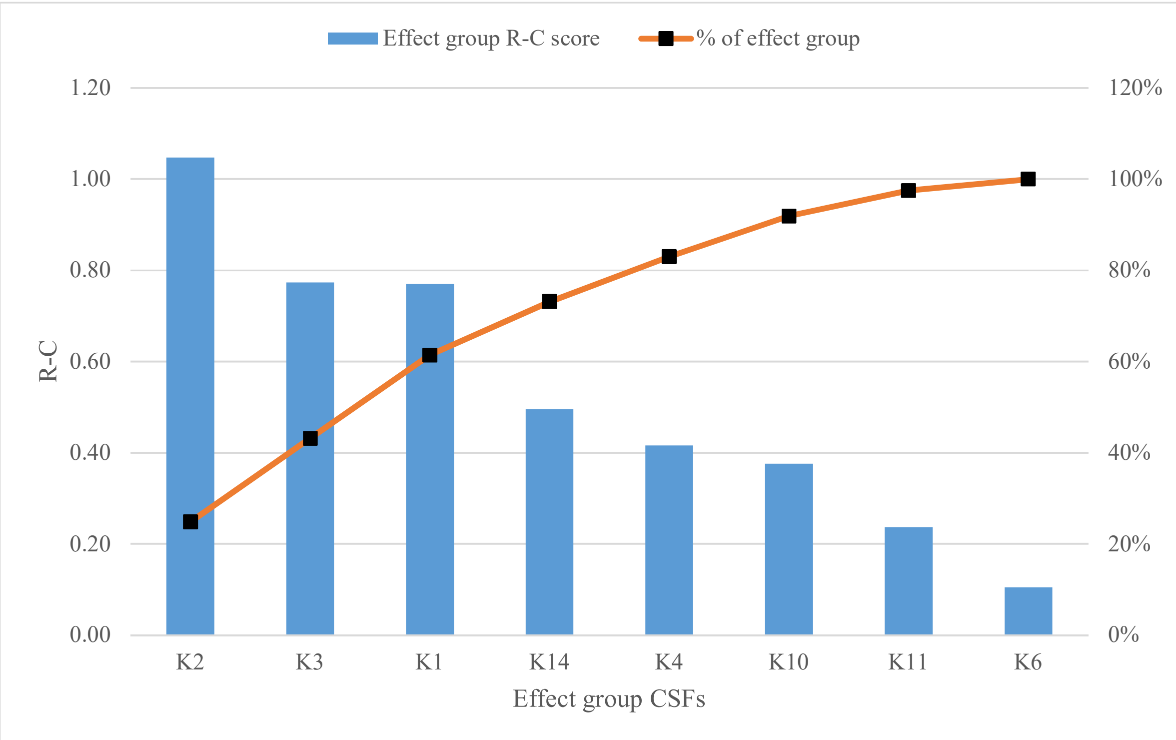


Figure 3.7: Effect group CSFs based on R – C value (values are negative)

Table 3.8: Effect group CSFs description

S.No.	Indicators check for effect group	Description
1	The highest degree of influential impact power of R	K4 - Environmental program has the highest degree of influential impact power R equals to 0.71, which means K4 has the most operative factors of the group.
2	Highest R – C score in the group	K6 - Training & empowerment has the highest value of R-C equals – 0.105, which indicates it is highly influenced by cause group CSFs.
3	Lowest R – C score in the group	K2 - Technology involvement has the least value of R-C equals to – 1.04, which indicates all other factors least influence K2.
4	Highest R+C score	K2 - Technology involvement has the highest R+C score equals to 2.30, and this CSFs is the most prominent factor among the other CSFs in the group.

3.5.3 Sensitivity analysis

In order to check the robustness of the cause and effect relationship, a sensitivity analysis is carried out using a scheme prescribed by Rajesh and Ravi (2015). For sensitivity analysis the weights of particular professional are varied, and the overall effect is analysed were changed at random. Here we present three cases of such changes are investigated by assigning new weights to expert's committee as same is presented in Table 3.9.

The cause and effect values and ranking of CSFs are obtained again and is tabulated in Table 3.10. Sensitivity analysis shows uniform ranking order (minimal variation in CSFs) is observed in each investigation. This implies robustness of the overall exercise and fidelity of the result and it is concluded that there is no significant bias in the expert's committee input.

Table 3.9: Assigned weights for three experts committees

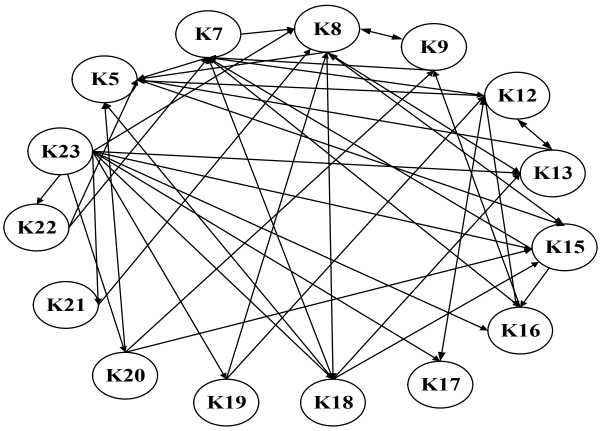
Experiment	Experts committee 1	Experts committee 2	Experts committee 3
Investigation 1	0.50	0.25	0.25
Investigation 2	0.25	0.50	0.25
Investigation 3	0.25	0.25	0.50

Table 3.10: Sensitivity analysis

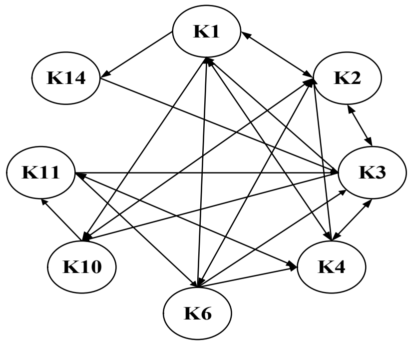
Ranking order	Investigation 1		Investigation 2		Investigation 3	
	CSFs	R-C	CSFs	R-C	CSFs	R-C
1	K23	1.467	K23	1.515	K23	1.572
2	K18	0.603	K18	0.617	K18	0.623
3	K22	0.427	K22	0.437	K22	0.436
4	K19	0.425	K19	0.428	K19	0.432
5	K9	0.358	K9	0.365	K9	0.385
6	K17	0.354	K17	0.358	K17	0.369
7	K20	0.196	K20	0.199	K20	0.211
8	K12	0.171	K12	0.165	K12	0.184
9	K21	0.142	K21	0.147	K21	0.169
10	K16	0.108	K16	0.110	K16	0.111
11	K5	0.076	K5	0.079	K5	0.079
12	K15	0.064	K7	0.075	K15	0.062
13	K7	0.055	K15	0.063	K7	0.055
14	K13	0.048	K13	0.047	K8	0.034
15	K8	0.032	K8	0.031	K13	0.029
16	K6	-0.161	K11	-0.162	K11	-0.145
17	K11	-0.183	K6	-0.194	K6	-0.190
18	K10	-0.388	K10	-0.402	K10	-0.385
19	K4	-0.499	K14	-0.521	K14	-0.554
20	K14	-0.522	K4	-0.531	K4	-0.559
21	K3	-0.834	K3	-0.855	K3	-0.881
22	K1	-0.870	K1	-0.896	K1	-0.958
23	K2	-1.067	K2	-1.073	K2	-1.080

3.5.4 Establishment of strategy interrelation map between causes and effects

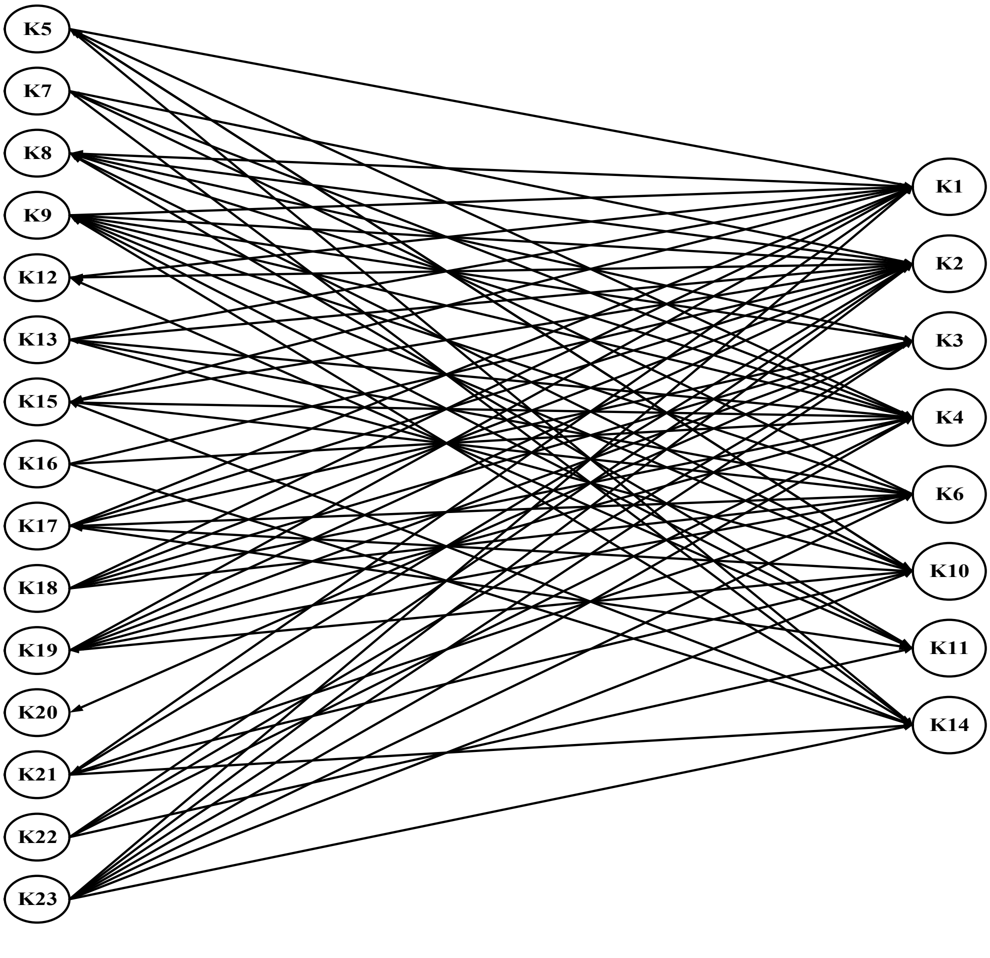
To develop the strategy interrelation map among the CSFs, the calculated threshold value (α) was obtained as 0.029 and computed using equation (14). This value is used to eliminate the weak interrelations among the CSFs and thereby highlight only those CSFs whose value in TRM is greater than the threshold value. A total of 146 interrelations are developed between CSFs based on their values. Since the number of interrelations is large, it is difficult to represent all the interrelations in one diagram. Therefore, strategy interrelations map is divided into three parts, one depicts interrelations between effects, the second shows interrelations between causes and third shows interrelations between causes (Figure 3.8). The number of interrelations among CSFs in the cause group is found more than that of the effect group. It is evident from Fig. 8, that Certification and Licensing (K23) has maximum number of connections and the same reveals that it affects maximum other CSFs. A few other CSFs such as stakeholder's awareness about circular economy (K9), Public ethics (K8), and Estimation of e-waste generation (K18) also show high number of interrelations with other CSFs. Luthra *et al.*, (2017) demonstrated through interrelation map structure that government regulation related to certification and licensing and circular supply chain had maximum interrelation among CSFs. In addition, Green practices (K1), Technology involvement (K2), Infrastructure development (K3), and Environmental programs (K4) are found to be highly dependent on other CSFs. Whereas, CSR (K14), Information visibility & transparency (K16) and Monitoring & enforcement (K20) emerge as the least connected CSFs, implying independent among the CSFs.



Inter-relationship between causes



Inter-relationship between effects



Inter-relationship between causes and effect

Figure 3.8: Strategy interaction map

3.6 Research implications

The research brings forth significant insight into the complex interrelation among various factors influencing e-waste collection policy and their implications, which can ultimately help frame appropriate policy. In the present study, twenty-three CSFs have been evaluated based on the input provided by an experts' committee. The study illustrates relations between the CSFs and establishes the prominence of CSFs in cause and effect sequence. A causal diagraph shows the connection among CSFs. The results are deemed helpful for policymakers and practitioners to comprehend the implications of policy design and implementation strategies for e-waste management. The prominent CSFs identified are discussed below:

- Technology involvement (K2) and green practices (K1) are identified as the most prominent factors in the research & development category. Similar findings are also supported in published literature (Kumar and Dixit, 2018; Wath *et al.*, 2010) as negative effect of lack of research & development in e-waste recycling are highlighted there. Garg (2021) drew a somewhat similar conclusion, who stated that technology and green innovation in recycling activities have raised awareness about sustainable issues. Need to invest on research in various areas related to these problems is underline. It recommended that the policymaker works with collectors and recyclers invest in innovation in technology for e-waste recycling activities and focus on designing appropriate e-waste collection policy.
- Environmental program (K4) emerge as an important option to spread e-waste awareness among consumers. A study by Parajuly *et al.* (2019) has pointed out that consumers are still not ready to change their consumption habits mainly because of a lack of awareness. This issue led to large e-waste storage in households and made

traceability difficult for stakeholders. The Government of India has started an awareness campaign named "Digital India Initiative" to address e-waste management issues. Learning from the same may important input for future of e-waste policy framework.

- Certification and licensing (K23) is found to have the highest degree of influence (R). This implies there is need to develop a provision for stakeholders to systematically and easily obtain e-waste authentication and license approval avoiding any entry barrier. However, the monitoring groups should implement tracking method to detect violations of compliance in their functioning subsequently. Wang *et al.* (2020) emphasised importance of direct monitoring of suspected policy violators and making such results public.
- It is found that Public ethics (K8) is one of the cause group factors with high relevance. Policymakers need to pay due attention to this factor, encourage the morality aspects, support responsible public behaviour, and increase e-waste disposal activity along with emphasis on continued education and improvement in policy framework.
- Stakeholder's awareness about the circular economy (K9) is also the most crucial factor, and this also provides a direct economic benefit. Therefore, the circular economy concept needs to be promoted and awareness to be increased and it is essential for a sustainable e-waste management (Singh, *et al.*, 2021). To ensure full utilisation of e-waste under reuse, reduce, recycle and recover under circular economy concept.

3.7 Sectional Summary

The design of an e-waste collection policy is challenging, especially for a country like India, where the economy is a developing state, and there is a large diversity in socio-economic factors. The e-waste collection policy impacts the various stakeholders such as the manufacturer, the raw material producers, the assemblers, the retailers, the generator (households and bulk consumers), the scrap dealers, the smelters, the recyclers, and the regulators. The salient points are summarized as follows:

- The design of an e-waste collection policy needs to consider the appropriate set of CSFs, which will maximise the e-waste collection providing business sustainability to the stakeholders while satisfying the environmental regulations in the operating locations.
- Twenty-three CSFs were identified and categorised into six implication dimensions for the e-waste collection policy framework based on a literature survey and expert's committee view.
- The fuzzy DEMATEL approach is employed to analyse the CSFs to design an e-waste collection policy in India from a comprehensive perspective.
- Cause and effect interrelationship is established among the CSFs, and also their impacts are evaluated to segregate the CSFs into cause group (prominent influencing and independent) and effect group (influenced and dependent).
- The CSFs such as technology involvement, green practices, environmental program, certification and licensing, public ethics and stakeholder's awareness for circular economy are prominent influencing CSFs for e-waste collection policy in India.

CHAPTER 4 EVALUATION OF SUSTAINABLE E-WASTE COLLECTION METHOD FOR URBAN AND RURAL REGIONS

Despite e-waste has become a significant issue due to the ever-increasing volume of generation coupled with inefficient collection and processing capacity. For various stakeholders, there is a need to select sustainable collection methods for hazard mitigation and active recovery of reusable materials from e-waste. This chapter purposes to understand the e-waste collection system of India including sustainability aspects, specifically urban and rural region. Keeping this as the strut of the research discussed, this chapter evaluates the e-waste collection methods for urban and rural region of India under the uncertain condition.

4.1 Introduction

E-waste is a stream of solid waste that needs to be handled separately from the MSW generated by the same households, business segment and public/private institutions. It consists of everyday items and parts such as computers, mobile phones, charging cables, televisions, kitchen appliances, imaging devices, toys, leisure, sports equipment and internet devices (Baldé *et al.*, 2017). E-waste is significantly different from other MSW because it has non-biodegradable material. Further, sparse amounts of valuable materials such as gold, silver, platinum and a large amount of copper, aluminium, steel and glass in pure form are available in it (Cucchiella *et al.*, 2015). There are also hazardous substances such as lead, mercury, brominated flame retardants, polychlorinated biphenyls, polybrominated biphenyls and polybrominated diphenyl ethers. Which must be isolated before dumping into a landfill (Zhang and Xu, 2016). If e-waste is not processed adequately before disposal, it can lead to contamination of soil, water and air producing adverse effect on the biosphere. Untreated e-waste that is kept at home or office also affects the value recovery chain (Ilankoon *et al.*, 2018). Further, it become untraceable. Accumulation of e-waste is rapidly becoming a challenge, particularly in India due to unavailability of low-cost aggregation and processing infrastructure. Recovery of material from e-waste is a lucrative secondary source of metal extraction that is called urban mining (Kang *et al.*, 2020). Urban mining can be profitable when collection activities provide a stable supply chain (Nowakowski, 2017). Therefore, a sustainable e-waste collection is a backbone to the ecosystem system of reuse, remanufacture and recycle.

E-waste recycling activities in India are governed by e-waste (management) rules which has introduced EPR concept. This regulation assigns mandatory responsibilities for the stakeholders (including collectors, producers, recyclers, importers, and manufacturers) to develop sustainable collection method, create environmental awareness programs and developed material recovery system that are economically meaningful without harming the environment. There is a prominent presence of both formal and informal sectors in e-waste collection and processing in India. The formal sector comprises of licensed recyclers, producers, retailers etc. While informal sectors include rag pickers, paddlers, scrap dealers and repair shops (Turaga *et al.*, 2019). Unfortunately, the informal sector dominates and it is estimated that nearly 95% of e-waste that is collected is processed by this sector (Kumar and Dixit, 2018). The informal sector is unregulated and allegedly do not follow scientific methods and safety standards. It is also perceived as a major threat to the sustainability of the formal sector. The authorised stakeholders face a tough challenge from the informal sector as the later conducts collection activities that bypass labour regulations and various safety standards and even engage in the unethical practices (Awasthi *et al.*, 2018). Currently, India has a projected e-waste production rate of more than 2 million tons per year which is roughly three times the installed capacity of formal recycling in the country (Baldé *et al.*, 2017). Further, there is also a large gap in the collection system and it is estimated that only about 40% of the total e-waste generated is channelized for recycling while the rest 60% remain untraceable (Rajya Sabha, 2011). Essentially the method of collection by organised sector has not been effective as the same is not commercially viable and as a result the growth remained stunted. While some of the developed countries like Switzerland, Japan etc. have successfully implemented sustainable formal collection schemes under the patronage of the government and public support.

To enhance the participation of stakeholders in e-waste collection, the benefits that it can provide to individuals, need to be adequately highlighted. For example, for a large producer, it can help to reduce the required investment of independently managing stipulated e-waste compliance. It can reduce the requirement of additional land for the landfill from the perspective of a municipal body, which can also reduce the impact on soil and water contamination potential. For Original Equipment Manufacturers (OEMs), there is an opportunity to benefit from re-use of material and also gain from improvement of organizational image and reputation. Promotion of e-waste collection can also help an Non-Government Organization (NGO) or business house to obtain a suitable pollution certificate from the government and/or obtain the benefit of subsidy. Collection of e-waste can also be viewed as an integral part of product recovery. Further, producers and recyclers may jointly deploy e-waste collection facilities across the country under government support and gain multi-pronged benefit from it. Before implementation of any e-waste collection options, however, the stakeholders must analyse the various options of e-waste collection in urban and rural areas. At present, there is lack of adequate understanding on the framework to effectively assess the potential e-waste collection scheme in an urban or rural setup.

Various e-waste collection methods have been attempted at various parts of the world, prominent among them are door to door collection, EEE retail store deposits, take back collection and curbside collection (de Souza *et al.*, 2016). Success is also reported about conducting seasonal campaign like special event (e-waste bin box) and fixed drop off location (Zbib and Wøhlk, 2019). These collection methods can be grouped under two categories stationary and mobile. The stationary collection provides easily identifiable and fixed container at a location near residential or industrial settlement to for collecting obsolete EEEs. Once containers are filled, these are sent to the recycling facility. A mobile facility on the other hand provides collection at the doorstep and on demand. A client can contact formal collectors through phone or some online platforms and schedule a collection. It is interesting to note here that a variation of this is a common practice by the informal sector. Another mobile collection method is curbside collection, where a temporary collection facility is set up at a regular interval or aligned with specific events, near residential or business hub (Nowakowski, 2017). The identified stakeholders for each of these methods are presented in Table 4.1.

Table 4.1: Types of e-waste collection methods and identified stakeholders

Collection types	**Collection Methods**	**Stakeholders**
Stationary	Fixed drop off location	Municipalities, recyclers
	Special event	Municipalities, authorised collectors
	Collection points	Producers, authorised collectors
	EEE Retailers (Take back)	Producer agents
Mobile	Door to door	Informal collectors or producer agents
	Curbside	Producers, authorised collectors
Source: (Elia *et al.*, 2018; Nowakowski, 2017)		

Further this study is grounded on application of Fuzzy-Multi Attribute Decision Making (MADM) techniques (i.e. Fuzzy AHP and Fuzzy VIKOR) for evaluation of e-waste collection methods in Indian locale, which is also another novelty.

The outcomes of the study are expected to help policymakers in developing appropriate e-waste collection method for different customer segments in India and also add valuable knowledge to e-waste management literature. The authors will like to specify knowledge addition components from this work as following:

a) Understanding the various customer segments' perspectives in India about successful adoption of e-waste collection method(s) along with various attributes and their sub-attributes.
b) Development of a structured methodology using Fuzzy AHP and Fuzzy VIKOR for evaluation and quantification of the impact of various attributes and sub-attributes to select suitable e-waste collection methods in different customer segments based on inputs from multiple Decision Makers (DMs).

4.2 Research questions

With above discussions, the following research question remains:

RQ1. How do people understand e-waste in urban and rural regions of India?

RQ2. What are various e-waste collection methods?

RQ3. Which sustainable attributes need to be considered for evaluating e-waste collection methods in urban and rural region of India?

RQ4: What are the best decision making approaches to evaluate sustainable collection methods?

In order to find a suitable answer to these issues and for identification of sustainable e-waste collection methods, further study is required. A stakeholder must analyse the various collection methods by assessing social, environmental and economic feasibility range for urban and rural regions of India to narrow down to a particular scheme. The stakeholders will implement a method to maximize their collection volume from specific regions to optimize profit. It is important here to note that the stakeholders not only need to consider social, economic and environmental sustainable attributes for evaluation of e-waste collection in specific regions but also need to be conscious about potential risk in various collection methods. Therefore, the current work establishes importance of e-waste collection methods towards the overall success in e-waste management. The work is focus on in Indian perspective and adoption of various e-waste collection methods in different customer segments.

4.3 Material and methods

4.3.1 Evaluation parameters of e-waste collection method

There are many factors needed to be considered in e-waste management (Wibowo and Deng, 2015). A review of the related literature is carried to determine the relevant attributes usable as a measure of sustainable e-waste collection. For example, Lin *et al.* (2010) adopted the Analytic Hierarchy Process (AHP) method to evaluate the performance of a new mandatory e-waste recycle policies in Taiwan. For this purpose, they identified six attributes, namely economic deterrent, availability of recycling technology, administrative feasibility, consumers' cooperativeness, e-waste volume and hazardousness. In order to priorities the attributes of e-waste recycling policies, they developed expert committees to evaluate each attribute and they concluded that the two attributes hazardousness and availability of recycling technology are the two most important ones.

Ciocoiu *et al.* (2011) in their study focused on five attributes that are political, economic, social, technical and environmental issues that can affect implementation of e-waste management systems. They presented an application of AHP for evaluating the implementation of e-waste management systems under these attributes. They concluded that this method is helpful for managers to comprehend the attributes that affect the implementation of overall e-waste management systems. Kim *et al.* (2013) reported an integrated approach of Delphi-AHP, which was used as a decision making tool in e-waste management processes. They evaluated the performance of ten EEE appliances that were regulated under EPR system in Korea. They selected four attributes that are: e-waste generation rate, recycling rate, collection system and recycling technology for prioritising the management of e-waste generated from appliances. For decision making, they selected a ten-member expert committee to evaluate each attribute and concluded that the "collection system" is the essential attribute. Singhal *et al.* (2019) analysed the factors that influence the remanufacturing opportunities of EEE in India. They used SWOT analysis for identifying the most important attributes and AHP method to evaluate the attributes. They concluded that environmental protection is the most important factor followed by public acceptability of remanufactured EEE items. Baidya *et al.*, (2020) proposed a holistic view for the improvement of e-waste supply chain to enhance the sustainability of e-waste management system in India. They identified four attributes that affect e-waste supply chain considering environmental, legislative, social and recycling plant capacity in India. For evaluation purpose, they used the AHP method and concluded that the most important attribute is the environmental compliance requirement, and the most important alternative is EPR system followed by formal e-waste collection.

However, AHP is not designed to handle the uncertainties and imprecision inherent in decision-making problems. To remove this disadvantage, Fuzzy-AHP (FAHP) was developed by Van Laarhoven and Pedrycz (1983). In order to synthesise the extended value of pairwise comparison matrices, Chang (1996) developed an extended analysis method for FAHP. Kaya (2012) employed the FAHP method to priorities and evaluate the attributes to select the most suitable e-waste outsourcing firm in Istanbul, Turkey. For this purpose, he identified five attributes that are quality, organisation, technology, cost and environment and established a four-member expert committee. Based on the study, the most important attribute determined was environment. While he also established rank of each e-waste outsourcing firm. Yeh and Xu (2013) proposed a fuzzy-Multi Attribute Decision Making (MADM) method to select the best sustainable planning of e-waste recycling activities for an e-recycling company. The proposed sustainability as an important criterion under the environmental, economic and social dimensions. They used FAHP method to propagate the sustainable e-waste recycling activities and proposed the e-waste recycling business to closely focus on the criteria to successfully implement a sustainable E-waste recycling policy. Wibowo and Deng (2015) presented an intuitive fuzzy multi-criteria group decision making approach for evaluating the performance of an e-waste recycling program under uncertain environment. They evaluated four important attributes: environmental impact, social responsibility, economic sustainability and technical feasibility that may affect the e-waste recycling programs of an organisation. For this purpose, they identified multiple experts from various departments to evaluate the performance of the e-waste recycling program and selected the best alternative under uncertainty. Bouzon *et al.* (2016) used a Fuzzy-Delphi method for solution finding and subsequently AHP method to identify the critical list of third party reverse logistics barriers in Brazilian EEE sector. They found that economic instability, followed by some identified supply chain issues as major barriers in reverse logistics. Shumon *et al.* (2016) reported application of FAHP in order to select the most beneficial e-waste collection system based on a reverse supply chain in Malaysia. They took help from a group of DMs to evaluate, based on various attributes such as economic, operational, strategic and social. They found door to door collection system to be the best suited for the given situation. Khoshand *et al.* (2019) developed a decision model for e-waste management system in Tehran, Iran. They applied FAHP method for e-waste management activity such as collection and processing system based on various attributes such as social, economic, environmental and technical. A group of DMs committee were enlisted for evaluating the attributes and ultimately rank the alternatives. Based on the study, they recommended permanent drop-off system as the best. Kumar and Dixit (2019) employed a hybrid approach of FAHP and fuzzy-VIKOR to select the e-waste recycler partners on the basis of various drivers of green competencies. They categorised problem in three phases. First, extensive literature review and discussed with experts then finalised seven main attributes and forty-eight sub-attributes. Secondly, FAHP is used to determine the weights of attributes and sub-attributes. Finally, these weights are used in fuzzy-VIKOR method to identify the rank of recycler partners under uncertainty.

The decision of choice ought to be a socially responsible, environmentally beneficial, economically sustainable and averse to potential risk. However, selecting an appropriate e-waste collection method is a challenging task for stakeholders, especially e-waste handlers, because of inexperience in the decision-making process (Kim *et al.,* 2013). In strategic decision making problems having multiple conflicting elements or objectives, the various attributes of the problem need to be taken into account for the decision making process. Fuzzy-MADM is a powerful tool and has been used to deal with mixed input data as well as conflicting elements (Kumar and Dixit, 2019). Here, we proposed to employ an integrated FAHP for determination of weights of attributes and finally is proposed, whereas Fuzzy-VIKOR technique for identifying the rank of the alternatives. Therefore, an integrated fuzzy-MADM approach is proposed to be introduced.

4.3.2 Research methods

Selection of an appropriate e-waste collection method is a challenging task for stakeholders, especially e-waste handlers, because of inexperience in the decision-making process (Kim *et al.,* 2013). In strategic decision making problems having multiple conflicting elements or objectives, the various attributes of the problem need to be evaluated scientifically for the decision making process. Fuzzy-MADM is a powerful tool and has been used to deal with mixed input data as well as conflicting elements (Kumar and Dixit, 2019). The proposed methodology of current study is presented in Figure 4.1.

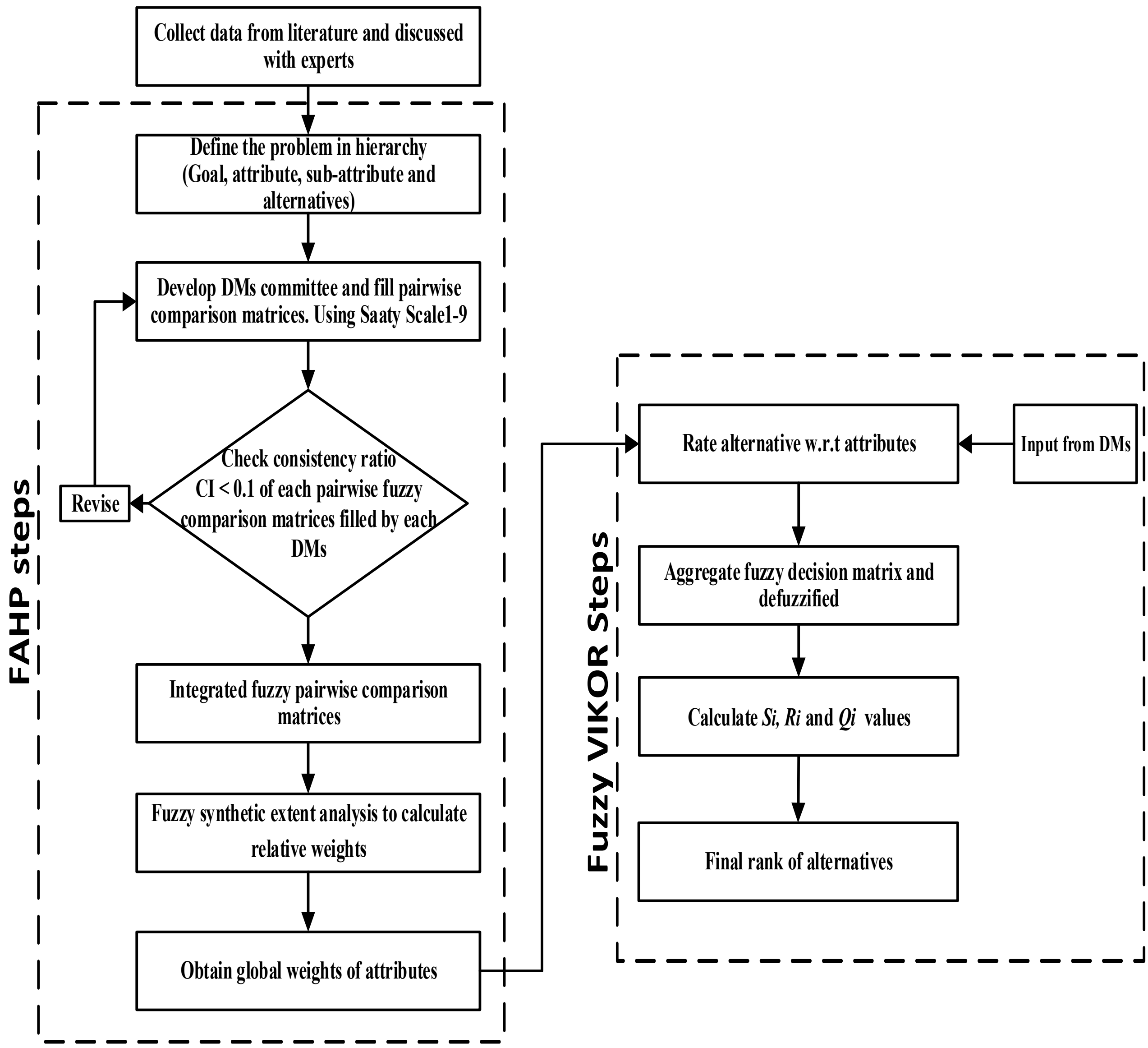


Figure 4.1: The flowchart of proposed methodology

4.3.2.1 Fuzzy AHP

In Fuzzy-AHP based computation, the following steps are identified:

Step 1: To develop a hierarchical decision structure

In order to develop a FAHP model, the first step is to breakdown the problem into a hierarchy of goal, attributes, sub-attributes and decision alternatives at three levels, as shown in Figure 4.2. Each level is consisting of 'n' number of decision elements. The first level of the hierarchy represents the overall goal, while the intermediate or second level of hierarchy embodies one or more of the decision attributes and sub-attributes, and the lower level consists of four possible alternatives.

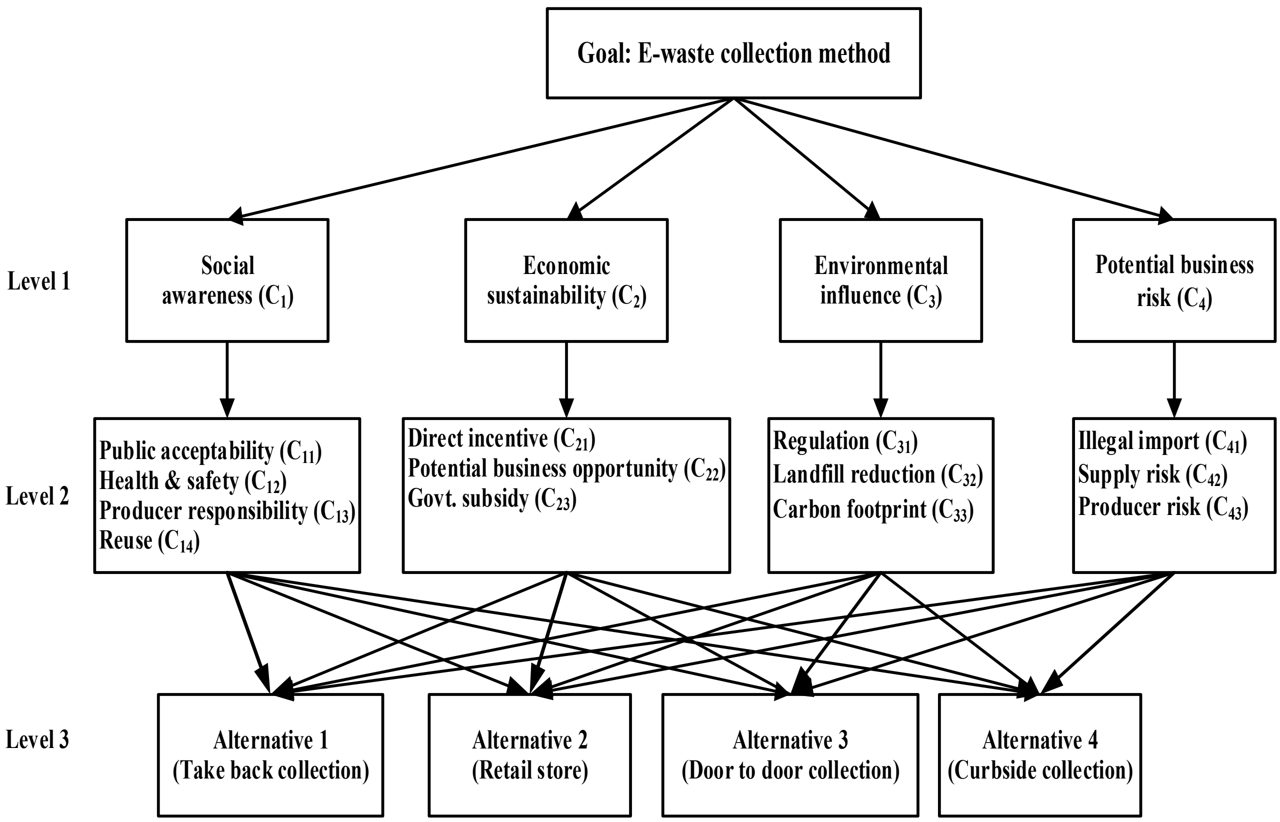


Figure 4.2: The hierarchical structure for decision making in e-waste collection method

Step 2: To construct a pairwise fuzzy comparison matrices $\widetilde{\mathrm{A}}$ for each DM

Based on input from DMs, a pairwise fuzzy comparison matrix $\widetilde{\mathrm{A}}$ is constructed which indicates the relative importance of various attributes. There after linguistic variables to the pairwise comparisons with n attributes are assigned, where the relative importance of attributes i to j is represented by TFN can be expressed as $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, where l is lowest value, m most likely value and u is highest value of any fuzzy event as presented in Figure 4.3. The fuzzy statement of mathematical operation between two TFNs, $\widetilde{\mathrm{A}}_1 = (l_1, m_1, u_1)$ and $\widetilde{\mathrm{A}}_2 = (l_2, m_2, u_2)$ is taken from Kaufmann and Gupta (1985).

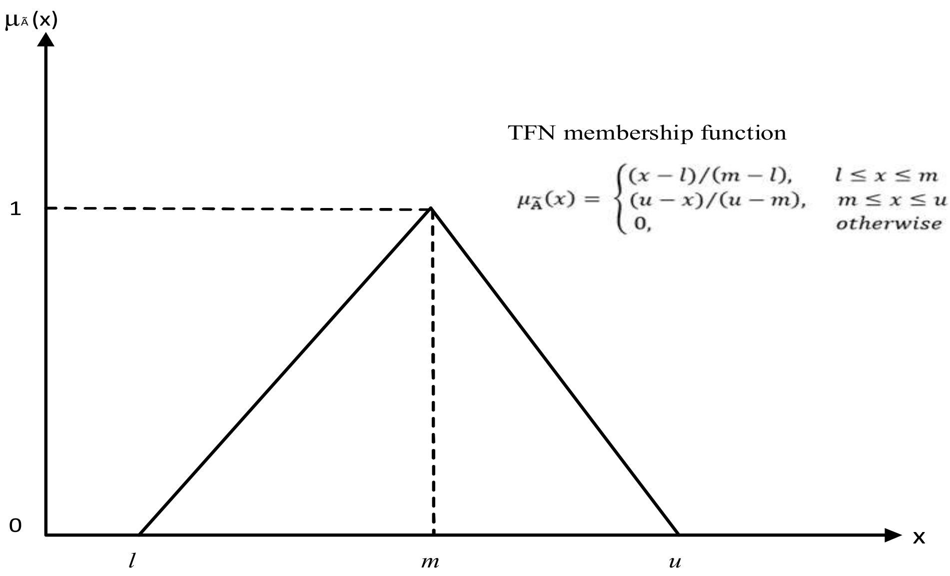


Figure 4.3: Triangular membership function

The expression of linguistic variables can be assessed using a Saaty nine-point scale ($\tilde{1} - \tilde{9}$) as presented in Table 4.2. This scale is used to evaluate the e-waste collection methods along with particular parameter of attributes.

Table 4.2: Linguistic variables using fuzzy scale (Saaty, 1994)

Definition of linguistic variables	**Intensity of fuzzy scale**	**TFN** (l, m, u)	**Reciprocal TFN** $(1/u, 1/m, 1/l)$
No influence (NI)	$\tilde{1}$	(1,1,1)	(1,1,1)
Weak (W)	$\tilde{2}$	(1,2,3)	(1/3 , 1/2 , 1/1)
Fair (F)	$\tilde{3}$	(2,3,4)	(1/4 , 1/3 , 1/2)
Preferable (P)	$\tilde{4}$	(3,4,5)	(1/5 , 1/4 , 1/3)
Good (G)	$\tilde{5}$	(4,5,6)	(1/6 , 1/5 , 1/4)
Strong (S)	$\tilde{6}$	(5,6,7)	(1/7 , 1/6 , 1/5)
Absolute (A)	$\tilde{7}$	(6,7,8)	(1/8 , 1/7 , 1/6)
Extreme (X)	$\tilde{8}$	(7,8,9)	(1/9 , 1/8 , 1/7)
Perfect (PE)	$\tilde{9}$	(8,9,9)	(1/9 , 1/9 , 1/8)

As in traditional AHP, the pairwise comparison matrix $\widetilde{A} = \{\tilde{a}_{ij}\}$ can be constructed as presented in Equation (4.1).

$$\widetilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (4.1)$$

Where

$$\tilde{a}_{ij} = \begin{cases} \tilde{9}^{-1}, \tilde{8}^{-1}, \tilde{7}^{-1}, \tilde{6}^{-1}, \tilde{5}^{-1}, \tilde{4}^{-1}, \tilde{3}^{-1}, \tilde{2}^{-1}, \tilde{1}^{-1}, \tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{5}, \tilde{6}, \tilde{7}, \tilde{8}, \tilde{9}, & i \neq j \\ 1 & i = j \end{cases}$$

Step 3: To check the consistency of DMs judgments

To ensure a certain quality level of a decision, the consistency of evaluation has to be analyzed. Saaty (1994) proposed a consistency index to measure the consistency of each pair-wise comparison matrices. The Consistency Index (CI) for a comparison matrix is computed using equation (4.2).

$$\text{CI} = \frac{(\lambda_{max} - n)}{(n-1)} \tag{4.2}$$

Where, λ_{max} is the largest Eigen-value of the comparison matrix and n is the size of the matrix.

The Consistency Ratio (CR) is calculated using Equation (4.3), which is defined as a ratio of CI of a given comparison matrix and Random Index (RI) of a consistency matrix. RI values are presented in Table 4.3.

Table 4.3: Random Index (Saaty, 1994)

Matrix size (n)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Random Index (RI)	0	0	0.52	0.89	1.1	1.25	1.35	1.40	1.45	1.49

$$\text{CR} = \text{CI/RI} \tag{4.3}$$

Recommended CR is less than 0.10, for the decision to be acceptable. Otherwise, the pair-wise comparison matrix should be improved to decrease inconsistency taking DMs' inputs.

Step 4: To integrate the judgment into the fuzzy pair-wise comparison matrices

The individual judgment matrix of DM represents the opinion of one DM. Aggregation is necessary to achieve a group consensus of DMs. Considering a group of k DMs providing individual judgment, which make a pair-wise comparison of n elements. After pair-wise comparison, k matrices are obtained as $\widetilde{A}_k = \{\tilde{a}_{ijk}\}$, where $\tilde{a}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$. It represents the relative importance of element i to j, assessed by the k DMs. The TFNs in integrated judgment matrix (L_{ij}, M_{ij}, U_{ij}) are computed by the geometric mean method as shown in Equation (4.4) and further the DMs inputs are aggregated into one fuzzy pair-wise comparison matrix.

$$\begin{aligned} L_{ij} &= \left\{\prod_{k=1}^{k} l_{ijk}\right\}^{1/k} \\ \tilde{a}_{ijk} = M_{ij} &= \left\{\prod_{k=1}^{k} m_{ijk}\right\}^{1/k} \\ U_{ij} &= \left\{\prod_{k=1}^{k} u_{ijk}\right\}^{1/k} \end{aligned} \tag{4.4}$$

Step 5: Determination of normalized weight using fuzzy synthetic extent analysis

Next step is conversion of fuzzy pair-wise comparison matrix into crisp value for normalization called Fuzzy Synthetic Extent (FSE) analysis and is carried out using Equation (4.5) as per (Chang, 1996).

$$\mathrm{F_i} = (\mathrm{m_i^-}, \mathrm{m_i}, \mathrm{m_i^+}) = \left\{\frac{\sum_{j=1}^{n} L_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} U_{ij}}, \frac{\sum_{j=1}^{n} M_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} M_{ij}}, \frac{\sum_{j=1}^{n} U_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} L_{ij}}\right\} \tag{4.5}$$

The degree of possibilities $\mu(\mathrm{F_i})$ is calculated using equation (4.6).

$$\mu(\mathrm{F_2} \geq \mathrm{F_1}) = \begin{cases} 1, & \mathrm{m_2} \geq \mathrm{m_1} \\ 0, & \mathrm{m_1^-} \geq \mathrm{m_2^+} \\ \frac{(\mathrm{m_1^-} + \mathrm{m_2^+})}{[(\mathrm{m_2} - \mathrm{m_2^+}) - (\mathrm{m_1} - \mathrm{m_1^-})]}, & otherwise \end{cases} \tag{4.6}$$

Therefore, normalization process determines the relative weights of attribute with respect to goal. Similarly, this process is repeated for all the sub-attributes with respect to their specific attributes. The global weights (W_j) are determined through multiplying the relative weights of attributes with respect to their sub-attributes. Further the global weights are utilized in Fuzzy VIKOR method to prioritizing the rank of alternatives.

4.3.2.2 Fuzzy VIKOR

Opricovic (1998) developed the VIKOR method expressed in Serbian name as 'VlseKriterijumska Optimizacija I Kompromisno Resenje'. This method is used in conjunction with multi-attribute optimization of complex systems for developing compromising ranking of solution. The compromising ranking solution, in particular, measures the closeness to the ideal solution. It ranks '0' as the best and '1' as the worst solution. The extension of VIKOR is the Fuzzy VIKOR (FVIKOR) method, where fuzzy linguistic variables are used as input data (Opricovic and Tzeng, 2007). In this method, the alternatives are denoted as $A = (A_1, A_2, \dots, A_n)$ that are assessed against a set of attributes indicated as $C = (C_1, C_2, \dots, C_m)$. The decision-makers $D_k (k = 1,2, \dots, k)$ evaluate each alternatives A_i with respect to attributes C_i using TFN that are represented by $\tilde{a}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$. The main steps of Fuzzy VIKOR based computation are listed below:

Step 1: To construct a fuzzy decision matrix $\widetilde{D}$ by each DMs as follows:

$$\widetilde{D} = \begin{matrix} & A_1 & A_2 & \cdots & A_n \\ C_1 & \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ C_2 & \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_m & \tilde{a}_{m1} & \tilde{a}_{m2} & \cdots & \tilde{a}_{mn} \end{matrix} \quad (4.7)$$

A nine-point linguistic scale is used for evaluation of alternatives (Table 4.2).

Step 2: To de-fuzzify the decision matrix into the crisp value (d_i) and to determine the best $f_j^* = \max(a_{ij})$ and the worst $f_j^- = \min(a_{ij})$ value of sub-attributes.

The inputs are aggregated in one fuzzy matrix as per Equation (4.4). Thereafter, fuzzy weights (L_{ij}, M_{ij}, U_{ij}) are converted into crisp weights using Center of Area (COA) method and computed using Equation (4.8).

$$d_i = \frac{L_{ij} + 4M_{ij} + U_{ij}}{6} \quad (4.8)$$

Step 3: To determine the value of S_i (utility measure) and R_i (regret measure), the recommended relations are shown in equation (4.9).

$$X_{ij} = W_j \left[\frac{f_j^* - a_{ij}}{f_j^* - f_j^-}\right], \text{ then } \quad S_i = \sum_{j=1}^{n} X_j \quad \text{and } R_i = max_j\left[X_j\right] \quad (4.9)$$

Step 4: To rank the alternatives for calculation of Q_i (ranking measure) value using Equation (4.10).

$$Q_i = \nu\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-\nu)\left[\frac{R_i - R^*}{R^- - R^*}\right] \quad (4.10)$$

Where, $S^* = min_i S_i;\ S^- = max_i S_i;\ R^* = min_i R_i;\ R^- = max_i S_i\ and\ \nu$ are defined as weight for the strategy coefficient of maximum group utility. The value of ν may vary from 0.1 to 0.9.

4.4 Modeling and evaluation of e-waste collection methods

The attributes and sub-attributes selected in the present study are derived from existing literature review presented in Table 4.4.

Table 4.4: Evaluation of attributes and sub-attributes for e-waste collection methods

Attributes	**Sub-attributes**	**Description**	**Authors**
Social awareness (C_1)	Public acceptability (C_{11})	General attitude/perception of public towards the specific e-waste collection program	Khoshand *et al.* 2019; Baidya 2016; Shumon *et al.* 2016; Wibowo and Deng, 2015; Temur *et al.* 2014; Kim *et al.* 2013
	Health & safety (C_{12})	Ensure the health and safety of societies and peoples	
	Producer responsibility (C_{13})	Stakeholders' satisfaction level regarding e-waste collection schemes	
	Reuse (C_{14})	Environmentally preferable options for managing e-waste	
Economical sustainability (C_2)	Direct incentives (C_{21})	Profitability gained through the effective implementation of e-waste collection schemes	Khoshand *et al.* 2019; Shumon *et al.* 2016; Wibowo and Deng, 2015; Temur *et al.* 2014; Kim *et al.* 2013
	Potential business opportunity (C_{22})	Benefit from markets exploited due to implementation of e-waste collection schemes	
	Govt subsidy (C_{23})	The system of incentives available for recyclers to increase the amount of e-waste collected in order to gain extra subsidies from government	
Environment influence (C_3)	Regulation (C_{31})	Level of commitment to compliance with appropriate environmental legislation and regulations for a specific collection schemes	Khoshand *et al.* 2019; Lee *et al.* 2018; Baidya 2019; Shumon *et al.* 2016; Wibowo and Deng, 2015; Temur *et al.* 2014; Kim *et al.* 2013
	Landfill reduction (C_{32})	Reduction of the amount of waste to be dumped in the landfill due to the adoption of a specific collection scheme	
	Carbon footprint (C_{33})	Emission occurring during the collection of e-waste	
Potential business risk (C_4)	Illegal import (C_{41})	Transfer/dumping of the e-waste from developed countries to developing countries for disposal, e-waste supply by illegal channels	Cucchiella *et al.* 2015; Salhofere *et al.* 2016; Zhang *et al.* 2016
	Supply risk (C_{42})	Insufficient collection of e-waste due to various reasons	
	Producer risk (C_{43})	Risk from change in government regulations and subsidy program as well as licensing	

4.4.1 Data collection

To validate these attributes and sub-attributes, the same has been discussed with the experts through several formal and informal interactions. The interaction was carried out over telephone, email, online meetings, webinars and face to face meeting. All experts are from waste management field and have subject knowledge in various e-waste management activities in Indian perspective such as environmental management, reverse supply chain and production planning. We asked them to rate the attributes and sub-attributes in the form of 'relevant or not relevant' for evaluation of e-waste collection methods. A total of 50 experts were consulted while responses were received from 35 (70%) experts. The responses received are from various stakeholders such as e-waste collectors (31.43%:11), recyclers (25.76%:9), environmental consultants (17.14%:6), educators (14.29%:6) and NGO persons (11.43%:4). The attributes and sub-attributes with 60% positive response rate are considered for the study. The expert responses are documented in Table 4.5.

Five experts are selected as decision-makers to provide inputs, and also results are discussed with them. The committee consists of two from industry, two from an academic background and a practitioner. The detailed information of selected DMs is presented in Table 4.6.

Table 4.5: Expert responses matrix

S.No	Attributes	Sub-attributes	No. of experts respondents (35)	Response rate (%)	Positive responses (21)	Positive response rate (%)
1	Social awareness (C_1)	Public acceptability (C_{11})	10	28.58	6	60
		Health & safety (C_{12})				
		Producer responsibility (C_{13})				
		Reuse (C_{14})				
2	Economical sustainability (C_2)	Direct incentives (C_{21})	9	25.72	4	44.44
		Potential business opportunity (C_{22})				
		Govt subsidy (C_{23})				
3	Environment influence (C_3)	Regulation (C_{31})	8	22.85	5	62.5
		Landfill reduction (C_{32})				
		Carbon footprint (C_{33})				
4	Potential business risk (C_4)	Illegal import (C_{41})	8	22.85	6	75
		Supply risk (C_{42})				
		Producer risk (C_{43})				

Table 4.6: Profile of selected DMs

DMs	Area/field	Designation	Experience
DM1	E-waste management	Manager	15 years
DM2	Waste management	Environment engineer	10 year
DM3	Industrial engineering	Professor	20 year
DM4	Mechanical engineering	Professor	30 year
DM5	Industrial engineering	Senior Research Fellow	5 years

4.4.2 Evaluation of attributes and sub-attributes of a specific region

The problem is defined as in hierarchical structure; next step is to determine the relative weights of attributes and their sub-attributes. The opinions of five DMs are received in the form of pair-wise comparison matrices. The rating scale is used to evaluate the e-waste collection methods along with the particular parameter of attributes in the form of Questionnaire provided in Table 4.7. The pair-wise comparison matrix of attributes of the urban region and rural region are separately provided in Table 4.8 and Table 4.9, respectively. During the evaluation process, the consistency is checked for all pair-wise comparison matrices. Therefore, pair-wise judgment has been found to be consistent and acceptable for further analysis. The next step is to aggregate the individual DMs input matrices into one fuzzy pair-wise comparison matrix presented in Table 4.10 for the urban region by using Equation (4.4).

Further, the FSE method is used to determine the relative weights of pair-wise comparison matrices by utilizing Equation (4.5) and (4.6). The FSE value is computed for the first-level hierarchy presented in Table 4.11. The final weights of the attribute are obtained as minimum value of the degree of possibilities $\mu(\mathrm{F_i})$. The obtained normalized weights of attribute of first level for the urban region are presented in Table 4.12.

Similarly, the calculation is repeated for second and third level hierarchy for the urban region. Finally, the relative weights of each attribute is multiplied by corresponding weights of sub-attribute to get the global weights W_j $(j=1,2,\ldots,n)$ as summarized in Table 4.13.

Table 4.7: Questionnaire

Importance/preference of one attribute over another, tick "√"																		
Attribute	Perfect (8,9,9)	Extreme (7,8,9)	Absolute (6,7,8)	Strong (5,6,7)	Good (4,5,6)	Preferable (3,4,5)	Fair (2,3,4)	Weak (1,2,3)	Equal (1,1,1)	Weak (1,2,3)	Fair (2,3,4)	Preferable (3,4,5)	Good (4,5,6)	Strong (5,6,7)	Absolute (6,7,8)	Extreme (7,8,9)	Perfect (8,9,9)	Attribute
C_1																		C_2
C_1																		C_3
C_1																		C_4
C_2																		C_3
C_2																		C_4
C_3																		C_4

Table 4.8: Input of five DMs for fuzzy pairwise comparison matrix (urban region)

With respect to goal	**C_1**					**C_2**					**C_3**					**C_4**				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C_1	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(0.33, 0.5, 1)	(1, 2, 3)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	(2, 3, 4)	(2, 3, 4)	(2, 3, 4)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(3, 4, 5)	(1, 2, 3)	(3, 4, 5)	(0.33, 0.5, 1)	(2, 3, 4)
C_2	(0.33, 0.5, 1)	(1, 2, 3)	(0.33, 0.5, 1)	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(2, 3, 4)	(1, 1, 2)	(3, 4, 5)	(2, 3, 4)	(4, 5, 6)	(3, 4, 5)	(0.25, 0.33, 0.5)	(4, 5, 6)
C_3	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(1, 2, 3)	(1, 2, 3)	(0.33, 0.5, 1)	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(0.5, 1, 1)	(0.2, 0.25, 0.33)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(1, 2, 3)	(0.2, 0.25, 0.33)	(3, 4, 5)
C_4	(0.2, 0.25, 0.33)	(0.33, 0.5, 1)	(0.2, 0.25, 0.33)	(1, 2, 3)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(0.167, 0.2, 0.25)	(0.2, 0.25, 0.33)	(2, 3, 4)	(0.167, 0.2, 0.25)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(3, 4, 5)	(0.2, 0.25, 0.33)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)

Table 4.9: Input of five DMs for fuzzy pairwise comparison matrix (rural region)

With respect to goal	**C_1**					**C_2**					**C_3**					**C_4**				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C_1	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(1, 2, 3)	(0.25, 0.33, 0.5)	(1, 2, 3)	(2, 3, 4)	(0.33, 0.5, 1)	(1,2, 3)	(1, 2, 3)	(3, 4, 5)	(3, 4, 5)	(0.25, 0.33, 0.5)	(2, 3, 4)	(0.25, 0.33, 0.5)	(5, 6, 7)
C_2	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(2, 3,4)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(0.2, 0.25, 0.33)	(2, 3, 4)	(2, 3,4)	(3, 4, 5)	(3, 4, 5)	(0.2, 0.25, 0.33)	(2, 3, 4)	(1, 2, 3)	(4, 5, 6)
C_3	(0.25, 0.33, 0.5)	(1, 2, 3)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(3, 4, 5)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(0.2, 0.25, 0.33)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(1, 2, 3)	(0.2, 0.25, 0.33)	(3, 4, 5)
C_4	(0.2, 0.25, 0.33)	(2, 3, 4)	(0.25, 0.33, 0.5)	(2, 3,4)	(0.143, 0.167, 0.2)	(0.2, 0.25, 0.33)	(3, 4, 5)	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(0.167, 0.2, 0.25)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(3, 4, 5)	(0.2, 0.25, 0.33)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)

Table 4.10: Aggregated fuzzy pair-wise comparison matrix (urban region)

With respect to goal	**Integrated fuzzy pair-wise comparison matrix**			
	C_1	C_2	C_3	C_4
C_1	(1, 1, 1)	(0.488, 0.803, 1.351)	(0.977, 1.465, 2.29	(1.431, 2.169, 3.129)
C_2	(0.74, 1.246, 2.048)	(1, 1, 1)	(1.783, 2.491, 3.594)	(1.888, 2.512, 3.245)
C_3	(0.435, 0.683, 1.024)	(0.278, 0.401, 0.561)	(1, 1, 1)	(0.903, 1.516, 2.141)
C_4	(0.32, 0.461, 0.699)	(0.308, 0.398, 0.53)	(0.467, 0.66, 1.108)	(1, 1, 1)

Table 4.11: FSE values of attributes (urban region)

Main attribute	$\sum_{j=1}^{n} L_{ij}$	$\sum_{j=1}^{n} M_{ij}$	$\sum_{j=1}^{n} U_{ij}$
C_1	3.896	5.437	7.777
C_2	5.411	7.249	9.887
C_3	2.616	3.600	4.726
C_4	2.095	2.519	3.336
Sum	**14.018**	**18.804**	**25.727**
Main attribute	m_i^-	m_i	m_i^+
C_1	0.151	0.289	0.555
C_2	0.210	0.385	0.705
C_3	0.102	0.191	0.337
C_4	0.081	0.134	0.238

Table 4.12: Degree of possibilities of attributes (urban region)

Main attribute	Degree of possibilities of attributes	Minimum degree of possibilities of attributes	Normalized weight of attributes
C_1	(0.781,1,1)	0.781	0.343
C_2	(1,1,1)	1	0.439
C_3	(0.655,0.395,1)	0.395	0.174
C_4	(0.358,0.099,0.703)	0.099	0.044

Table 4.13: Overall weights summary of attributes (urban region)

Attribute	**Relative weight**	**Sub-attributes**	**Relative weight**	**Global weight(W_j)**
Social awareness (C_1)	0.343	Public acceptability (C_{11})	0.4302	0.1475
		Health & safety (C_{12})	0.0217	0.0074
		Producer responsibility (C_{13})	0.3476	0.1192
		Reuse (C_{14})	0.2006	0.0688
Economical sustainability (C_2)	0.439	Direct incentives (C_{21})	0.2400	0.1053
		Potential business opportunity (C_{22})	0.4670	0.2050
		Govt subsidy (C_{23})	0.2930	0.1286
Environment influence (C_3)	0.174	Regulation (C_{31})	0.3981	0.0692
		Landfill reduction (C_{32})	0.2030	0.0353
		Carbon footprint (C_{33})	0.3989	0.0694
Potential risk (C_4)	0.044	Illegal import (C_{41})	0.2214	0.0097
		Supply risk (C_{42})	0.3954	0.0173
		Producer risk (C_{43})	0.3833	0.0168

Following similar steps for the rural region, DMs' input is captured (Table 4.9). The summary of relative weights of attributes obtained after step by step processing is as tabulated in Table 4.14.

Table 4.14: Overall weights summary of attributes (rural region)

Attribute	**Relative weight**	**Sub-attributes**	**Relative weight**	**Global weight(W_j)**
Social awareness (C_1)	0.3368	Public acceptability (C_{11})	0.3695	0.12445
		Health & safety (C_{12})	0.2317	0.07804
		Producer responsibility (C_{13})	0.0858	0.02890
		Reuse (C_{14})	0.3130	0.10542
Economical sustainability (C_2)	0.3214	Direct incentives (C_{21})	0.2409	0.07743
		Potential business opportunity (C_{22})	0.4458	0.14328
		Govt subsidy (C_{23})	0.3133	0.10069
Environment influence (C_3)	0.2159	Regulation (C_{31})	0.4459	0.09627
		Landfill reduction (C_{32})	0.2545	0.05495
		Carbon footprint (C_{33})	0.2997	0.06471
Potential risk (C_4)	0.1259	Illegal import (C_{41})	0.2200	0.02768
		Supply risk (C_{42})	0.3230	0.04063
		Producer risk (C_{43})	0.4571	0.05750

The individual inputs of five DMs are captured and analyzed in AHP and FAHP. In AHP, the weightage of sub-attributes is calculated considering each DM's input. The average weightage calculated using AHP and weightage calculated using FAHP for sub-attributes are presented in Table 4.15. It was observed that there is a difference in average weightage of sub-attributes calculated using AHP and FAHP. As there is no option available in AHP to check the consistency of average weightage, it was decided in consultation with DMs that the results of FAHP should be considered for further analysis which checks the consistency of the combined opinion.

Table 4.15: Comparison of AHP and FAHP result

Sub-attribute	**Urban region**		**Rural region**	
	AHP	**FAHP**	**AHP**	**FAHP**
Public acceptability (C_{11})	0.1087	0.1475	0.1348	0.1245
Health & safety (C_{12})	0.0482	0.0074	0.0726	0.0780
Producer responsibility (C_{13})	0.0715	0.1192	0.0563	0.0289
Reuse (C_{14})	0.0676	0.0688	0.0676	0.1054
Direct incentives (C_{21})	0.1017	0.1053	0.0849	0.0774
Potential business opportunity (C_{22})	0.1230	0.2050	0.1114	0.1433
Govt subsidy (C_{23})	0.1439	0.1286	0.0957	0.1007
Regulation (C_{31})	0.0691	0.0692	0.1002	0.0963
Landfill reduction (C_{32})	0.0498	0.0353	0.0408	0.0550
Carbon footprint (C_{33})	0.0499	0.0694	0.0608	0.0647
Illegal import (C_{41})	0.0661	0.0097	0.0664	0.0277
Supply risk (C_{42})	0.0565	0.0173	0.0437	0.0406
Producer risk (C_{43})	0.0438	0.0168	0.0642	0.0575

4.4.3 Determine ranking of alternatives using Fuzzy VIKOR

The sustainable e-waste collection method(s) among the four alternatives for a specific region is determined in this step. The FVIKOR method is utilized to determine the rank of alternatives. Firstly, a fuzzy comparison matrix is constructed utilizing input from five DMs with the help of a defined linguistic scale (Table 4.2). The constructed fuzzy comparison matrix of each DM is presented in Tables 4.16 and 4.17 for the urban and rural region, respectively. The next step is to aggregate the individual DMs opinion in one fuzzy matrix using equation (4). The aggregated matrix is presented in Supplementary Tables 4.18 and 4.19 for the urban and rural regions. After that, the fuzzy values are converted into crisp values using equation (8). As an example, sub-attribute C_{11} for the urban region, which is computed as $d_i = ((6.76 + 4 * 7.765 + 8.58)/6) = 7.734$. Likewise, the best and the worst values of all sub-attributes are calculated; the same is presented in Supplementary Tables 4.20 and 4.21 for the urban and rural region, respectively. Further, S and R values of alternatives are computed by using equation (9), shown in Table 4.22 for urban and rural region. Finally, the Q values for alternatives are computed using ν = 0.5 which varies from 0.1 to 0.9 as discussed earlier. The Q values are sorted in ascending order to rank the alternatives for the urban region and rural region, and the final evaluation is presented in Table 4.23.

Table 4.16: DMs input in linguistic term for alternatives (urban region)

Sub-attributes	**A1 (Take back)**					**A2 (Retail store)**					**A3 (Door to door)**					**A4 (Curbside)**				
	D1	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**
C_{11}	X	A	A	X	PE	PE	X	PE	S	A	S	A	A	S	X	F	G	F	S	P
C_{12}	G	S	P	G	A	G	G	P	G	F	A	S	P	A	A	W	P	P	G	S
C_{13}	X	PE	PE	PE	PE	S	PE	G	A	A	P	G	P	G	P	P	G	P	G	P
C_{14}	A	A	G	G	G	X	A	G	G	S	F	F	G	P	W	A	F	G	P	S
C_{21}	S	A	X	S	PE	S	A	G	S	G	S	A	G	S	G	P	P	G	S	G
C_{22}	X	X	PE	PE	A	X	A	PE	S	A	P	S	S	G	G	S	S	S	S	S
C_{23}	S	S	X	X	PE	P	G	P	X	F	P	P	F	W	F	P	G	F	G	S
C_{31}	X	A	X	PE	X	S	S	G	P	A	S	A	X	A	S	A	A	X	A	S
C_{32}	X	PE	PE	A	A	S	A	S	A	A	F	A	X	G	S	A	A	X	G	S
C_{33}	X	PE	PE	A	A	S	A	G	A	A	P	P	W	P	W	A	P	A	P	A
C_{41}	A	S	G	P	S	W	NI	W	W	W	W	NI	W	W	W	A	G	P	G	A
C_{42}	A	G	S	G	S	W	NI	W	G	W	P	NI	W	P	W	P	F	F	P	F
C_{43}	S	PE	P	S	G	G	S	P	F	G	G	F	P	F	F	G	S	P	F	P

Table 4.17: DMs input in linguistic term for alternatives (Rural region)

Sub-attributes	**A1 (Take back)**					**A2 (Retail store)**					**A3 (Door to door)**					**A4 (Curbside)**				
	D1	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**
C_{11}	P	P	P	G	P	PE	X	PE	X	A	P	P	F	P	G	S	G	P	F	S
C_{12}	G	S	P	G	A	S	G	P	G	S	P	S	P	G	S	A	G	A	G	S
C_{13}	X	PE	PE	PE	PE	S	PE	G	A	PE	P	W	P	F	W	A	X	G	A	P
C_{14}	S	G	S	S	S	X	A	A	X	A	F	F	F	P	W	A	S	G	P	S
C_{21}	F	G	G	G	P	S	A	S	S	A	F	P	G	S	G	A	S	G	S	G
C_{22}	G	P	S	S	G	X	A	PE	X	X	F	S	P	G	F	X	S	A	S	A
C_{23}	S	S	A	S	S	S	A	S	X	S	W	P	F	W	F	F	G	F	G	S
C_{31}	A	S	G	A	X	S	S	G	P	A	A	A	S	A	S	X	A	X	A	A
C_{32}	P	A	P	A	P	S	A	S	A	A	P	W	G	G	W	A	A	X	S	A
C_{33}	S	PE	S	A	A	S	A	S	S	S	S	P	G	P	G	P	G	A	S	F
C_{41}	G	F	G	P	F	S	A	S	P	P	A	G	G	G	A	F	W	F	G	F
C_{42}	S	G	S	G	S	A	P	F	G	A	P	G	G	P	G	P	F	P	P	G
C_{43}	S	G	P	S	G	G	S	P	F	G	G	P	P	S	G	F	F	P	F	P

Table 4.18: Aggregation of DMs input in one fuzzy matrix (urban region)

Sub-attributes	**A1 (Take back)**			**A2 (Retail store)**			**A3 (Door to door)**			**A4 (Curbside)**		
	D1	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
C_{11}	6.760	7.765	8.586	6.694	7.708	8.360	5.753	6.760	7.765	2.993	4.043	5.073
C_{12}	4.282	5.305	6.320	3.288	4.317	5.335	5.036	6.069	7.090	2.825	3.949	5.008
C_{13}	7.789	8.790	9.000	5.650	6.673	7.529	3.366	4.373	5.378	3.366	4.373	5.378
C_{14}	4.704	5.720	6.732	5.073	6.093	7.108	2.169	3.245	4.282	3.728	4.789	5.827
C_{21}	6.093	7.108	7.950	4.743	5.753	6.760	4.743	5.753	6.760	3.728	4.743	5.753
C_{22}	7.160	8.165	8.790	6.320	7.331	8.165	4.129	5.144	6.153	5.000	6.000	7.000
C_{23}	6.284	7.300	8.139	3.471	4.536	5.578	2.048	3.104	4.129	2.862	3.898	4.919
C_{31}	7.384	8.386	9.000	4.478	5.502	6.518	5.753	6.760	7.765	6.188	7.189	8.191
C_{32}	7.160	8.165	8.790	5.578	6.581	7.584	4.416	5.502	6.554	5.502	6.518	7.529
C_{33}	6.943	7.950	8.586	5.335	6.346	7.354	1.933	3.031	4.076	4.547	5.596	6.629
C_{41}	4.789	5.827	6.853	1.000	1.741	2.408	1.000	1.741	2.408	4.441	5.471	6.491
C_{42}	4.743	5.753	6.760	1.320	2.091	2.766	1.552	2.297	2.954	2.352	3.366	4.373
C_{43}	4.743	5.785	6.673	3.438	4.478	5.502	2.491	3.519	4.536	3.245	4.282	5.305

Table 4.19: Aggregation of DMs input in one fuzzy matrix (rural region)

Sub-attributes	A1 (Take back)			A2 (Retail store)			A3 (Door to door)			A4 (Curbside)		
	D1	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
C_{11}	3.178	4.183	5.186	7.160	8.165	8.790	2.930	3.949	4.959	3.594	4.644	5.674
C_{12}	4.282	5.305	6.320	4.129	5.144	6.153	3.898	4.919	5.933	4.919	5.933	6.943
C_{13}	7.789	8.790	9.000	5.985	7.017	7.708	1.783	2.862	3.898	4.967	6.010	7.039
C_{14}	4.782	5.785	6.787	6.382	7.384	8.386	1.888	2.930	3.949	4.478	5.502	6.518
C_{21}	3.288	4.317	5.335	5.378	6.382	7.384	3.438	4.478	5.502	4.743	5.753	6.760
C_{22}	4.129	5.144	6.153	6.971	7.975	8.790	2.993	4.043	5.073	5.753	6.760	7.765
C_{23}	5.186	6.188	7.189	5.547	6.554	7.560	1.644	2.702	3.728	3.170	4.227	5.261
C_{31}	5.502	6.518	7.529	4.478	5.502	6.518	5.578	6.581	7.584	6.382	7.384	8.386
C_{32}	3.959	5.004	6.034	5.578	6.581	7.584	2.169	3.314	4.384	5.966	6.971	7.975
C_{33}	5.908	6.921	7.765	5.785	6.787	7.789	4.076	5.102	6.119	4.043	5.073	6.093
C_{41}	2.862	3.898	4.919	4.227	5.261	6.284	4.704	5.720	6.732	2.000	3.064	4.095
C_{42}	4.573	5.578	6.581	3.866	4.939	5.985	3.565	4.573	5.578	2.930	3.949	4.959
C_{43}	4.129	5.144	6.153	3.438	4.478	5.502	3.728	4.743	5.753	2.352	3.366	4.373

Table 4.20: Crisp decision matrix (urban region)

Sub-attributes	**Crisp value**				$f_j^* max$	$f_j^- min$
	A1	**A2**	**A3**	**A4**		
C_{11}	7.7340	7.6479	6.7593	4.0395	7.7340	4.0395
C_{12}	5.3034	4.3152	6.0670	3.9380	6.0670	3.9380
C_{13}	8.6585	6.6451	4.3730	4.3730	8.6585	4.3730
C_{14}	5.7196	6.0924	3.2388	4.7855	6.0924	3.2388
C_{21}	7.0792	5.7522	5.7522	4.7420	7.0792	4.7420
C_{22}	8.1017	7.3011	5.1427	6.0000	8.1017	5.1427
C_{23}	7.2708	4.5321	3.0986	3.8955	7.2708	3.0986
C_{31}	8.3213	5.5002	6.7593	7.1894	8.3213	5.5002
C_{32}	8.1017	6.5813	5.4962	6.5168	5.4962	8.1017
C_{33}	7.8879	6.3452	3.0225	5.5934	3.0225	7.8879
C_{41}	5.8254	1.7288	1.7288	5.4691	1.7288	5.8254
C_{42}	5.7522	2.0752	2.2826	3.3648	2.0752	5.7522
C_{43}	5.7594	4.4750	3.5175	4.2798	3.5175	5.7594

Table 4.21: Crisp decision matrix (rural region)

Sub-attributes	**Crisp value**				$f_j^* max$	$f_j^- min$
	A1	**A2**	**A3**	**A4**		
C_{11}	4.1823	8.1017	3.9474	4.6407	8.1017	3.9474
C_{12}	5.3034	5.1427	4.9178	5.9321	5.9321	4.9178
C_{13}	8.6585	6.9601	2.8547	6.0076	8.6585	2.8547
C_{14}	5.7850	7.3840	2.9263	5.5002	7.3840	2.9263
C_{21}	4.3152	6.3815	4.4750	5.7522	6.3815	4.3152
C_{22}	5.1427	7.9435	4.0395	6.7593	7.9435	4.0395
C_{23}	6.1878	6.5540	2.6966	4.2234	6.5540	2.6966
C_{31}	5.0011	5.5002	6.5813	7.3840	7.3840	5.0011
C_{32}	7.7340	6.5813	3.3018	6.9710	3.3018	7.7340
C_{33}	6.8926	6.7874	5.1002	5.0714	5.0714	6.8926
C_{41}	3.8955	5.2595	4.7459	3.0585	3.0585	5.2595
C_{42}	5.5777	4.9348	3.7978	3.9474	3.7978	5.5777
C_{43}	5.1427	4.4750	4.7420	3.3648	3.3648	5.1427

Table 4.22: Values of $\boldsymbol{S_i}$, and $\boldsymbol{R_i}$ (urban region and rural region)

Region	**Measure**	**A1**	**A2**	**A3**	**A4**	**Max**	**Min**
Urban	S_i	0.0116	0.4138	0.8064	0.7658	0.8064	0.0116
	R_i	0.0090	0.0844	0.2050	0.1475	0.2050	0.0090
Rural	S_i	0.5068	0.1996	0.8633	0.4859	0.8633	0.1996
	R_i	0.1174	0.0761	0.1433	0.1037	0.1433	0.0761

Table 4.23: $\boldsymbol{Q}$ values and rank of alternatives for urban and rural region

Measure	A1	A2	A3	A4	Alternative ranking (ascending order)
Q_i	0	0.4454	1	0.8278	A1>A2>A4>A3 (urban region)
Q_i	0.5389	0	1	0.4209	A2>A4>A1>A3 (rural region)

4.5 Results and discussions

The outcome of detailed analysis is summarized in Table 4.23, which concluded that 'take back' mode of collection is the one most suited for urban regions in India, while 'retail store' based collection is most suited for rural region. It is also interesting to note that 'door to door' collection is adjudged as the worst option in both cases. The result is compared and contrasted with previously published studies, one from Iran (Khoshand *et al.,* 2019) that recommended permanent 'drop box', while the study in Malaysia (Shumon *et al.*, 2016) selected 'door-to-door'. The differences in decision are due to socio-economic factors that have profound effects on the collection system to be chosen and its sustainability.

For urban region, the 'economical sustainability' attribute has the highest influence with relative weightage 0.439, followed by 'social awareness' (0.343). While the 'potential business opportunity' sub-attribute (C_{22}) is the most important factor having weightage 0.2050 followed by 'public acceptability' (C_{11}) 0.1475 in rural India. The study also concludes that collection strategy(s) need to be selected based on socio-economic background of the region.

4.5.1 Research implications

Based on the analysis, the current study has obtained several theoretical implications. The proposed work identified four attributes and thirteen sub-attributes based on literature review and discussions held with various stakeholders. This study uses MADM methods to evaluate the sustainable e-waste collection methods in urban and rural regions of India. However, validation of attributes and sub-attributes are empirically approved for the study based on the expert's responses and also expertise in e-waste management and sustainability. Thereafter, an integrated FAHP and FVIKOR approach is applied to evaluate the e-waste collection method for both the regions under uncertainty and qualitative information. A fuzzy set is found particularly suitable for handling DM's input. Inclusion of potential business risk as an attribute and rural India as an application domain are novelty in this current work. From academic's point of view, this paper provides a detailed demonstration of theoretical analysis and an effective application of MADM approach, which advantageously deals with vagueness in attributes and multiple conflicting evaluation criteria.

Based on the outcomes, managerial implications have also been suggested from the stakeholder point of view. The e-waste collection is a statutory requirement and it also delivers reusable materials, job opportunity, improved sustainability index and reduced impact on the environment and human health. An appropriate e-waste collection method can provide sustained benefit for all stakeholders such as the increase in efficiency, enhancement of collection, fulfilling collection targets, increase in awareness and improvement in environmental performance culminating into economic benefit. For managers, this approach provides an efficient tool to deal with the vagueness in DM's perceptions and linguistic inaccuracies to choose the most suitable and sustainable e-waste collection method(s) counting the potential risk and sustainability factors.

4.6 Sectional summary

This chapter describes that e-waste is one of the most challenging waste streams to manage. It has become a significant concern in developing countries due to the ever-increasing volume of generation coupled with deficient growth in collection and processing infrastructure. The salient points are summarized as follows:

- It is a paramount importance to adopt a robust and sustainable collection method for hazard mitigation. The prevalent e-waste collection methods are categorized under four major heads i.e. take back, retail store, door to door, and curbside collection.
- The e-waste collection problems are analysed from various perspectives, based on literature that cited developing country-specific survey and data that includes India. Economic sustainability and potential risk are included as attributes in the evaluation scheme.
- Fuzzy-AHP is used to determine the importance of various attributes and sub-attributes, while fuzzy-VIKOR is used to determine the rank of the alternatives.
- Based on the analysis, ‘take-back collection’ and ‘retail store based collection’ are found most suitable options for urban and rural regions respectively.
- Implementation of a collection method is an expensive activity and the proposed fuzzy MADM attempts to capture various attributes and their complex interplay to arrive at a decision on optimum e-waste collection option(s) in a specific locality.

CHAPTER 5 EEE CONSUMPTION PATTERN AND E-WASTE DISPOSAL BEHAVIOUR OF INDIVIDUALS AND HOUSEHOLDS IN INDIA

Understanding consumer perception about e-waste disposal and its flow holds a vital role in efficient e-waste management in a developing nation like India, where e-waste generation is rapidly increasing. This chapter determines the perception of consumers and conducts a nationwide survey on consumer consumption patterns, awareness and disposal behaviour through empirical investigation.

5.1 Introduction

The mounting global population has witnessed a rise in demand for EEE, causing a consequential increment in the generation of e-waste. In the year 2019, the amount of e-waste produced globally was 53.6 MMT, with a per capita share of 7.3 kg (Forti *et al.,* 2020). The EEEs plays an important role in improving the standard of living and safety for human being. However, the disposal behaviour of consumers and the ever-shrinking useful life span of consumer durable category EEEs is a significant concern. The e-waste, unless processed scientifically, has enormous potential for contaminating the biosphere. New inventions, increase in disposable income and growth in population are driving up the consumption of EEE, while peer pressure, penchant for an improved lifestyle and other factors are lowering the useful life span of EEE.

India is currently undergoing a digital revolution, which is fuelling an increase in the consumption of electronic devices in the country. This growth is primarily attributed to the country's growing middle-class population, rising disposable income in 2021 of US$ 3003 billion, and declining electronics prices (Disposable Personal Income, 2021). Furthermore, due to an increase in per capita disposable income and consumption over the last decade, India has become one of the largest consumers of electronic products, particularly in the Asia-Pacific region. Similarly, India's high internet penetration rate and position as the world's second-largest smartphone manufacturer boosted electronic product penetration (Kwatra *et al.*, 2014). With this surge in demand in various sectors such as electronic products, electronics systems, and electronics design, the consumer durables market in India is expected to reach US$ 220 billion by 2025, growing at a 16.1% compound annual growth rate (CAGR) between 2019 and 2025 (ESDM, 2020). With increasing consumption of EEE, consumers have no intention of reusing them after a time span, and that time span is shrinking. This is resulting in a spiralling rise in the rate of e-waste generation. There is a need for a thorough look at consumer behaviour and disposal habits to align the mitigation policies to combat hazards from e-waste (Bovea *et al.*, 2018).

However, despite the policy being updated regularly, there is still a gap in awareness among communities regarding e-waste collection and handling of discarded EEE. E-waste collection is a complex task, the success of which depends upon consumer awareness, consumer behaviour, the extent of law enforcement, collection, processing and infrastructure (Singh, *et al.*, 2021b). One of the brightest examples of e-waste management in the recent past has been the construction of all the medals of the recently concluded "Tokyo Olympic Games 2020" from recycled e-waste (Hameed *et al.*, 2020). The collection campaign was a huge success, with 90% of municipalities across Japan conducting a voluntary campaign to collect e-waste from residents, and a total of 78,985 tons of e-waste was collected (Indian, 2019). A campaign of such a scale must have generated a high level of awareness, motivation and pride among the fellow citizens. It also contributed toward building trust in sustainable business models using circular economy concepts and also helped to develop a robust closed-loop supply chain system (Tong *et al.*, 2018).

Global warming awareness and pro-environment behaviour among consumers and OEM led to initiatives for sustainable e-waste collection implementation (Kumar et al., 2022). This prompted the scientific academician to understand the attitude of consumers toward the e-waste disposal system to address the critical e-waste collection issues while developing an implementation plan for a sustainable e-waste collection system for residents (Chandra *et al.*, 2022; Gilal *et al.*, 2021; Thukral *et al.*, 2022). However, it is observed from the literature that only a few studies have been conducted to analyse the consumer behaviour of e-waste in India (Awasthi and Li, 2017; Borthakur and Govind, 2018; Borthakur and Singh, 2021). The studies are generally restricted to a few aspects such as demand estimation, consumer behaviour, organized sector and education level. These aspects are mostly taken in isolation and are far from comprehensive.

The novel contribution of this study attempts to fill the gap and is expected to be a valuable knowledge enhancement. Consequently, empirical research is being conducted to better understand consumption patterns such as EEE volume, length of ownership, and e-waste disposal constraints, with a focus on individuals and households in India. In addition, the current e-waste disposal system in rural and urban areas of India is examined. The study examines the current state of the e-waste material flow in India, as well as the relevant policy framework and current practices.

5.2 Research questions

The research question of this study is as follows:

- What is the current e-waste flow in India for consumers and bulk consumers?
- How do individuals and households use their various EEE for analysing the consumption patterns in terms of EEE quantity and replacement time?
- What are the factors affecting consumer disposal behaviour and examine the various e-waste disposal methods and which are currently most commonly used in disposal activity?

5.3 Materials and methods

India is the third-largest e-waste producer in the world, estimated to have generated 3.2 MMT of e-waste during 2019 and the second largest in Asia after China (Forti *et al.,* 2020). Due to the large population and increasing disposable income, the demand for electronic devices is increasing day by day in urban and rural areas. The End-of-Life (EoL) management of EEE has become more complex with an improper reverse supply chain. As per the e-waste policy of India, two types of consumers are identified, bulk consumers and individual consumers. The bulk consumers include public and private companies/institutions and multinationals. As part of the e-waste policy, formal collectors, dismantlers, and recyclers frequently provide services to bulk consumers to depose their e-waste under EPR schemes. Bulk consumers send their e-waste to authorised refurbishers or recyclers via proper channels. Recyclers disassemble the product and subject it to scientific treatment in order to recover valuable material from the e-waste and dispose of the remainder in an authorized landfill. While refurbishers try to salvage useful components and send the rest of them to recyclers. One other category of an organization is the PRO, it is a professional organisation authorised or financed collectively or individually by producers, which can take the responsibility for collection and channelization of e-waste generated from the 'end-of-life' of EEE products. It provides compliance services to the bulk consumers, including the collection and channelization of e-waste generated from the EoL to formal recycling facilities, as well as the administration of awareness campaigns. Thus e-waste flow for bulk consumers can be summarised in Figure 5.1.

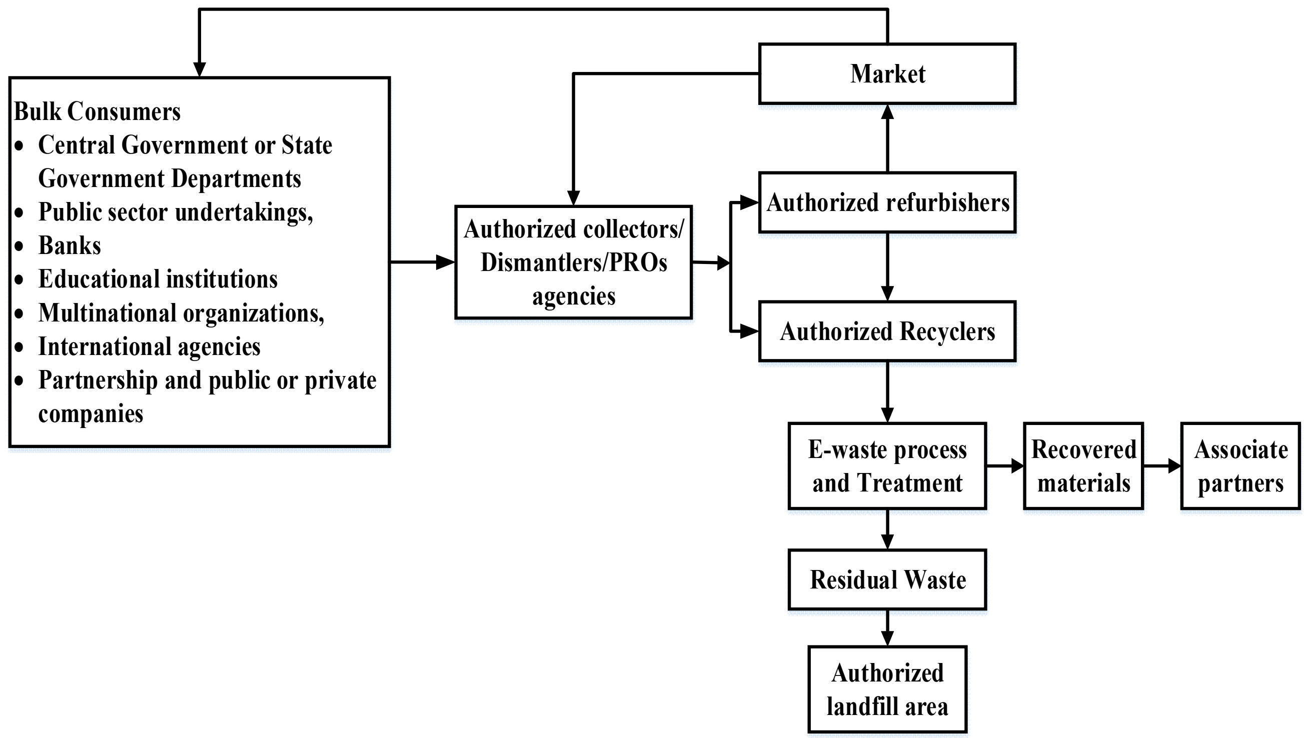


Figure 5.1: General e-waste flow of bulk consumers in India

The e-waste collection from individual consumers is more varied than that from bulk consumers. Further, the e-waste disposal culture of India's rural and urban consumers also differs (Singh *et al.,* 2021a). Urban consumers mostly discard e-waste or sell it, which feeds the affordable old market (Nowakowski, 2017). Unlike in the west, most urban consumers are unaccustomed to schemes where disposal costs money or requires extra consumer responsibility. Many formal e-waste collection agencies are established and provide facilities in urban regions. However, the same is virtually absent in rural areas. The formal sectors offer many options to retail consumers to dispose of their e-waste. These are door-to-door collection, take-back collection, e-retailer (electronic retailer) option, exchange, curbside collection, and community collection drives conducted by municipalities or individual producers under the EPR system. An e-waste exchange scheme refers to an independent market instrument that provides services for the sale or exchange of discarded EEE, providing some of the benefits like vouchers/coupons for further purchases (Sabbir *et al.*, 2022). Exchange schemes are not available very often, they are mostly available during the festive season or special promotional events. Take-back collection system refers to a guaranteed facility through an authorized retailer/dealers or a collection centre and drop-off bins facility linked with the authorized collection centres for deposing the e-waste by consumers and most commonly related to bulk consumers (Rasnan *et al.*, 2016). Door-to-door collection refers to the collection of e-waste on-demand from retailers or consumers who call an online service by an authorized collector to pick up large size obsolete EEE devices (Gu *et al.*, 2016). At the residential level, there is also a prominent presence of the informal sector as kawadiwalas, who collect e-waste along with various other types of recyclable waste from the residents and, in return, provide monetary benefit. In the rural region, services by the informal sector are hardly observed. The informal sector is a vast network of door-to-door collections that caters to the extended mainstream residences (Sharma *et al.*, 2021). The e-waste flow for individual consumers can be summarised in Figure 5.2.

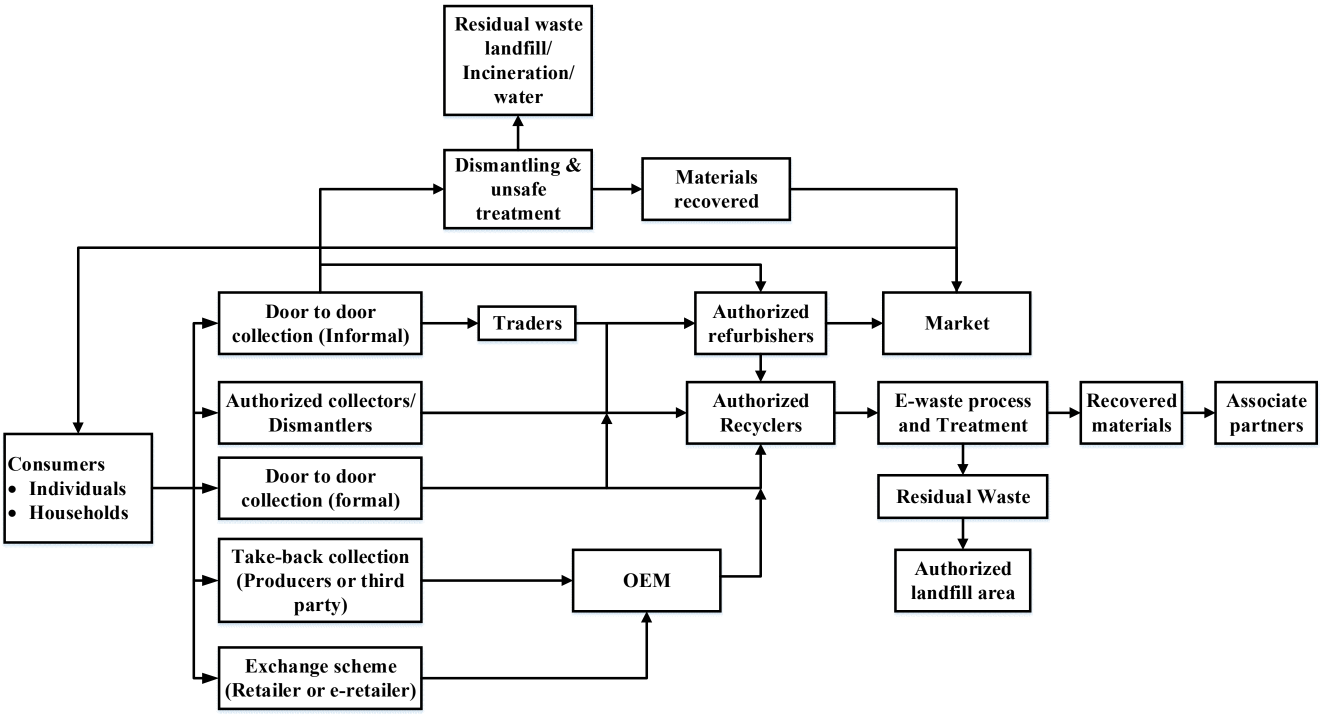


Figure 5.2: General e-waste flow for individuals and households in India

5.3.1 Study locale and representative population

The study has been conducted across India to reach out to consumers in urban, semi-urban and rural regions. The main focus is on individual consumers and families as a unit. Consumers are the target population as their behaviour cause replacement of EEE devices at ever-shrinking intervals as the technology updates or as disposable income increases. According to the 2011 Census of India, the total population is 1.2 billion, out of which half of the population is 18 to 60 years of age (First post, 2016). 31% of the population lives in an urban area while 69% live in a rural area and the proportion of households in urban and rural areas are 32% and 68%, respectively (Census data, 2011). India is the second largest populous country in the world and the consumption of EEE at the domestic and commercial levels are increasing at an increasing rate at present. Therefore, large amount of e-waste is generated and significant portion of that is unaccounted for or finds place in informal sector for processing.

The study is focused on young consumers and working people as the target population whose age is above 18 years and up to 60 years, both individual, and family are surveyed with income level above ₹5 lakhs. The main reason for that same is that this population is long-time EEE users and are perceived to be the most appropriate target of this study. Young consumers have a strong affinity towards EEE consumption and also have awareness about updated technologies (Ramzan *et al.*, 2019). While the employed population are expected to have least some awareness about environmental issues and regulations (Dasgupta *et al.*, 2001). It is important for such consumers to have understanding of the e-waste management system and make themselves responsible to bringing in societal behaviour change in the near future.

5.3.2 Questionnaire design for the survey

For the descriptive analysis, a survey questionnaire (available in secondary data) was developed in English from an in-depth review of the literature relating to e-waste issues and after discussion with professionals, including academics and practitioners. Questionnaires have different sections such as demographic characteristics, ownership, knowledge of EEE, information about e-waste disposal behaviour, knowledge of e-waste policy and awareness of e-waste disposal systems or collection modes. Since the questionnaire was to be self-administered, basic instructions on how to complete it were also included. A pilot study is conducted with 30 respondents based on feedback received, and data collection is restricted to respondents whose annual income level is above ₹5 lakhs. Also, nine questions were dropped as they were deemed confusing or incomplete, and finally, 21 valid questions were finalized for the survey, presented in Appendix A.

5.3.3 Sample size and data collection

In order to select a random sample from the population, many researchers use the sample size formula to determine the minimum sample size required for statistical analysis (Afroz *et al.*, 2013; CRC, 2010) as follows in Equation (5.1):

$$n' = \frac{Z^2(P\,(1-P))}{d^2} \tag{5.1}$$

Where: n' is the sample size, z = z value (e.g. 1.96 for 95% confidence level); P = 0.5 (Assuming that 50% of population are known about e-waste management) and d is the confidence interval or margin of error (d = 5%). The minimum sample size is found as 384 which is sufficient for data collection. (Kotrlik and Higgins, 2001) endorsed that a sample size of 384 is sufficient for survey analysis. Another study by (Hair *et al.*, 2013) pointed out that the number of valid responses should be at least five times of total survey questions. The survey was conducted online via email and social media from 01/10/2021 to 30/10/2021 throughout India. A sample of 1500 possible respondents was drawn for the survey from Educational Institutes, Government and Private organizations. A follow-up email was sent as a reminder after 07 days. Finally received 491 valid responses with an effective rate of 32.73%. The representative sample comfortably satisfies these yardsticks and is considered valid. Furthermore, information about the collection mode and business model of a small number of informal collectors (Kawadiwala) from the Rajasthan region of India is gathered.

5.3.4 Data analysis

IBM Statistical Package for the Social Sciences (SPSS) version 25 is utilised for data analysis. Descriptive analysis is carried out on demographic characteristics and survey questions to determine the frequency of responses. The data are categorical (i.e. Nominal or Ordinal), and the chi-square (χ^2) test was employed to check the significant relationship between variables. Another appropriate analysis, the Friedman test, was used to analyse the rank preferences of the e-waste disposal method and to assess whether there would be a significant relationship between those methods.

5.4 Results and discussions

The study aims to understand the respondent's consumption patterns, including EEE quantity and replacement period, and its disposal behaviour. It is also observed that the respondents are less aware of the e-waste policy. Therefore, priorities and ranking of e-waste disposal methods were identified, which are essential for the consumer's landscape.

5.4.1 Geographic and demographic characteristics of respondents

Geographic and demographic characteristics influence the consumer's e-waste disposal behaviour (Hansmann *et al.*, 2006). Figure 5.3 represents the responses received state-wise on a map of India. Most of the responses were obtained from the southern region (48%), with the majority of respondents being from Tamil Nadu (21.4%), Karnataka (11.8%) and Telangana (5.7%), followed by Western Region (18%) including Maharashtra (11.8%) and Gujarat (4.5%). The Northern Region from Rajasthan (11.4%), Central Region (11%) include Uttar Pradesh (5.1%) and Chhattisgarh (2.4), Eastern Region (5%) mainly from Jharkhand (2.4%)

and North-eastern region (1%) from Assam (1%). The socio-demographic characteristics composition is listed in Table 1, in which 59% male and 41% female. In total, 41% of the sample fell into each age group 18-27 years of age, and 38% were between 28-37 years of age, respectively. In contrast, only 16% were between the ages of 38-47, and the rest, 5%, were below 57 years of age. Most respondents were graduates (63%), followed by postgraduate and above (29%). In total, 69% of respondent's professions were from private organizations, followed by 23% were students, 5% were government employees, and 3% were running their own businesses as entrepreneurs.

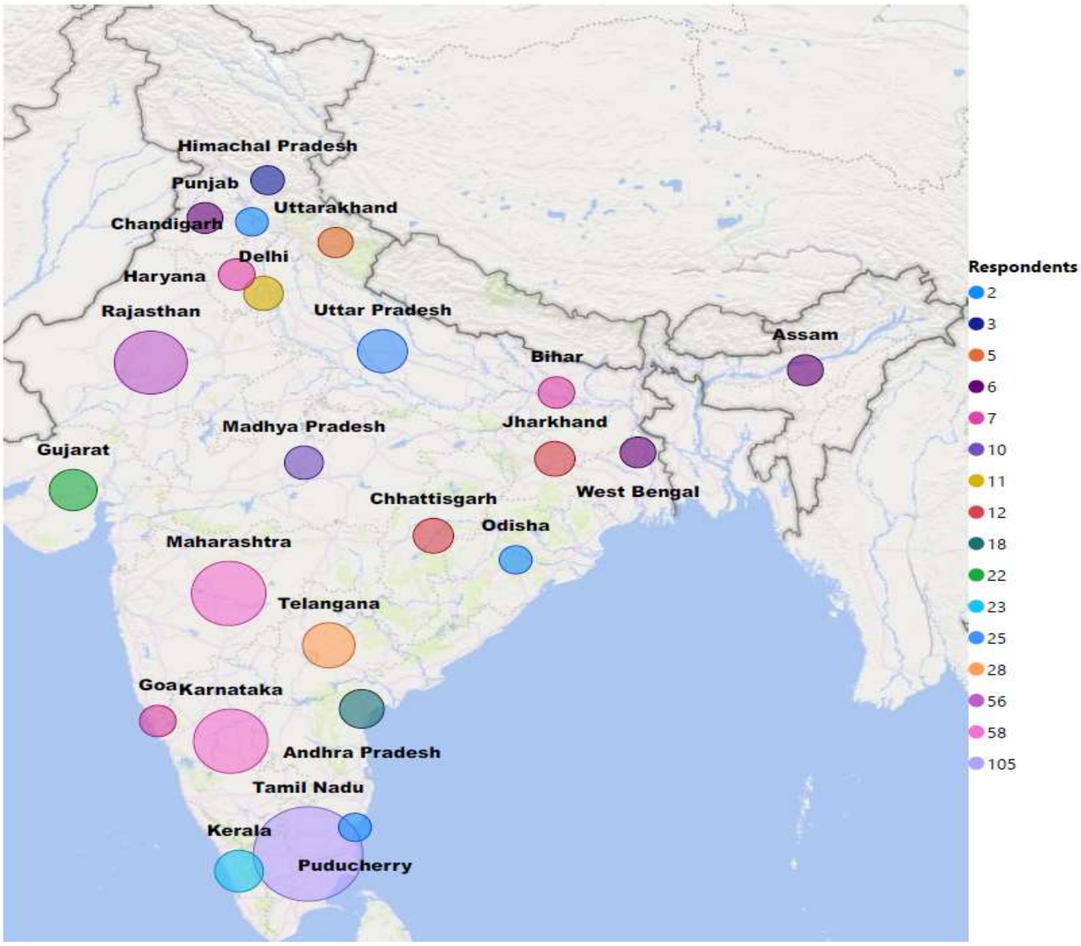


Figure 5.3: Individual responses received from various states

Similarly, analysis of the survey data, the majority of respondent's income levels were found between ₹5 lakhs - ₹10 lakhs, consisting of 40%, and the remaining is 60% (i.e. ₹11 lakhs – ₹15 lakhs:29%; ₹16 lakhs – ₹20 lakhs:22% and ₹21 lakhs – ₹25 lakhs:9%). Lastly, 66% of respondents lived in the urban region, 24% were in the semi-urban region, and 9% were in the rural region. In addition, there are 2315 persons living in 491 households, and the average number of members in the household is 5. The different household members were accounted for through a survey that included 15% teenagers, 39% between 18-36, 33% between 37-57 and 13% over 58 years. The frequency of family income and living area are also determined and mentioned in Table 5.1.

5.4.2 EEE quantities and consumption pattern

The current study indicates that a significant percentage of respondents have at least one laptop (68.0%), mobile phone (67.2%), and Bluetooth speakers/headphones (56%). About 72% reported that no one used a desktop or a tablet. The percentage of EEEs currently owned by the respondents and their family members is shown in Table 5.2 and Table 5.3, respectively. Comparison of other studies, a study in Spain revealed that 50% of individuals used at least one and 30% used more than one EEE such as mobile, tablet and speakers, respectively (Bovea *et al.,* 2018). However, about 45% of individuals in the Midwestern region of the USA currently owned at least two EEEs like mobiles, laptops, computer accessories, stereo and other small devices (Arain *et al.,* 2020).

Table 5.1: Demographic results

S.No.	Demographic variables		No. of respondents	%
1.	Age	18-27	201	41
		28-37	186	38
		38-47	79	16
		48-57	25	5
2.	Gender	Male	289	59
		Female	202	41
3.	Education Level	Graduate	309	63
		Post Graduate and above	143	29
		Other (High school, School, Diploma)	39	8
4.	Annual income level	₹5 lakh–₹10 lakhs	198	40
		₹11 lakh – ₹15 lakhs	143	29
		₹16 lakh – ₹20 lakhs	108	22
		₹21 lakh – ₹25 lakhs	42	9
5.	Profession	Student	113	23
		Govt. employee	25	5
		Private employee	338	69
		Entrepreneur	15	3
6.	Living Area	Urban	324	66
		Semi-urban	117	24
		Rural	50	10
7.	Family size (numbers)	Single	30	1
		2-4	930	40
		5-8	1166	50
		9-12	175	8
		Above 12	12	1
8.	No. of family members (age wise)	below 18	241	15
		18-27	277	17
		28-37	342	22
		38-47	182	11
		48-57	335	21
		Above 58	211	13
9.	Household income	Personal income	50	10
		₹11 lakh – ₹15 lakhs	178	36
		₹16 lakh – ₹20 lakhs	161	33
		₹21 lakh – ₹25 lakhs	102	21
10.	Family Living Area	Urban	311	63
		Semi-urban	119	24
		Rural	61	12

Table 5.2: Percentage of current EEE owned by respondents (N=491)

Type of EEE	**EEE quantity owned by respondents (%)**			
	UUT	**1**	**2**	**More than 2**
Mobiles	0.4	67.2	16.5	15.9
Laptops	7.3	68.0	19.6	5.1
Tablets	72.9	24.2	1.4	1.4
Desktops	72.5	25.3	1.8	0.4
Accessories	24.2	50.7	16.3	8.8
Bluetooth speakers	9.8	55.6	22.2	12.4
Smartwatches	58.5	34.4	5.1	2.0

Table 5.3: Number of current EEE owned by respondent's family (N=491)

Type of EEE	**EEE quantity owned by family member [other than respondent] (%)**				
	UUT	**1**	**2**	**3**	**More than 3**
Mobiles	4.3	18.7	23.8	27.1	26.1
Laptops	32.4	35.6	19.8	7.1	5.1
Desktops	75.8	20.8	2.2	0.6	0.6
TVs/Monitors	6.3	59.7	26.9	4.9	2.2
Refrigerators	4.9	79.8	13.2	1.6	0.4
Washing machines	11.6	79.2	8.4	0.6	0.2
Microwaves	47.0	49.5	3.1	0.4	0.0
Air conditioner (AC)	27.5	32.6	19.1	12.0	8.8

In total, 3090 EEE items were currently used by 491 individual respondents. The mean was 6.2 EEEs per respondent, meaning each respondent is presently in use around 6 EEEs. The most common type of EEE is a mobile phone, Bluetooth speakers, laptops, and computer accessories, with mean values of 1.48, 1.37, 1.22, and 1.10, respectively. It means respondents have more than one of these EEEs. Other EEEs include smartwatches, tablets and desktops, each with a mean value of 0.51, 0.31 and 0.30, respectively, which means every two/third respondent has at least one EEEs. However, in Australia, younger people use more laptops than desktop computers for studying or working (Islam *et al.*, 2021). Similar situation in China, where younger people use mobile phones and laptops (Zhu *et al.*, 2017). As a result, younger people possess more mobile and laptops than ordinary residents. This is confirmed by Zhang *et al.*, (2019), younger people's ownership of EEE such as mobile phones, laptops and stereo systems was higher than other people based on a capita basis. The study also found a similar pattern for mobile phones, Bluetooth speakers, laptops, and computer accessories.

A survey conducted in Brazil revealed that 50% of families have more than 2 EEEs like mobiles, TVs and tablets respectively. However, 40% reported having at least one EEE, including refrigerators, washing machines, stereo systems and other items (Rodrigues *et al.,* 2020). Whereas in Spain, 85% of households have at least two mobile phones, 20% have at least five mobile, and 11% of households have at least four MP3 players at home (Bovea *et al.,* 2018). In the current study in India, most of the respondent's families (annual income level above ₹5 lakh) are using at least one EEE, such as a refrigerator (79%), washing machine (79%), TVs/monitor (60%), microwaves (50%), laptops (35%) and ACs (32%), respectively. It was observed that the respondent's family primarily utilized more than two EEEs (i.e. mobile phones: 80%; ACs:44% and laptops:32%). Whereas, many respondents' families still do not use a single EEE, mainly desktop (76%), microwave (47%), laptops (32%) and AC (27%), respectively.

In total, 2315 dwellers currently use 8134 EEEs in the household. The mean was 4 EEE items per household. Compared to other country studies, such as Jordan, 6.7 EEE/households were acquired (Hamdan and Saidan, 2020), Brazil identified 5.3 EEEs in the household (Rodrigues et al., 2020) and the United Kingdom users have 25 EEE/household (Cooper and Mayers, 2000). The EEE items that are currently used per household are more than one (i.e. mobile phones: 2.52; ACs:1.42, TVs:1.37, laptops:1.17, refrigerators:1.17 and washing machines:1). Other EEE items include desktops (0.30/household) and microwaves (0.50/household) are used in homes. While Islam *et al.* (2021) identified that in Australia, households currently use TVs 2.76 EEE/household and desktops are 1.3 EEE/household. However, in the present study, the number of TVs and desktops per household is found to be lower than in Australian households.

5.4.3 EEE replacement time

The replacement time represents the length of ownership for various types of EEE reported by respondents and their families, as presented in Figure 5.4 and Figure 5.5. Several respondents and their families indicated that the EEE has been kept for more than three years. It has been found that smaller EEEs such as mobile phones, laptops, Bluetooth speakers and smartwatches are willingly replaced between 2-3 years, while larger EEEs such as refrigerators, washing machines, TVs and ACs are replaced after three years. A similar study was conducted in the USA, which specified that 80% of the respondents had replaced their EEE such as mobiles, laptops and computer accessories in more than two years, respectively (Arain *et al.,* 2020).

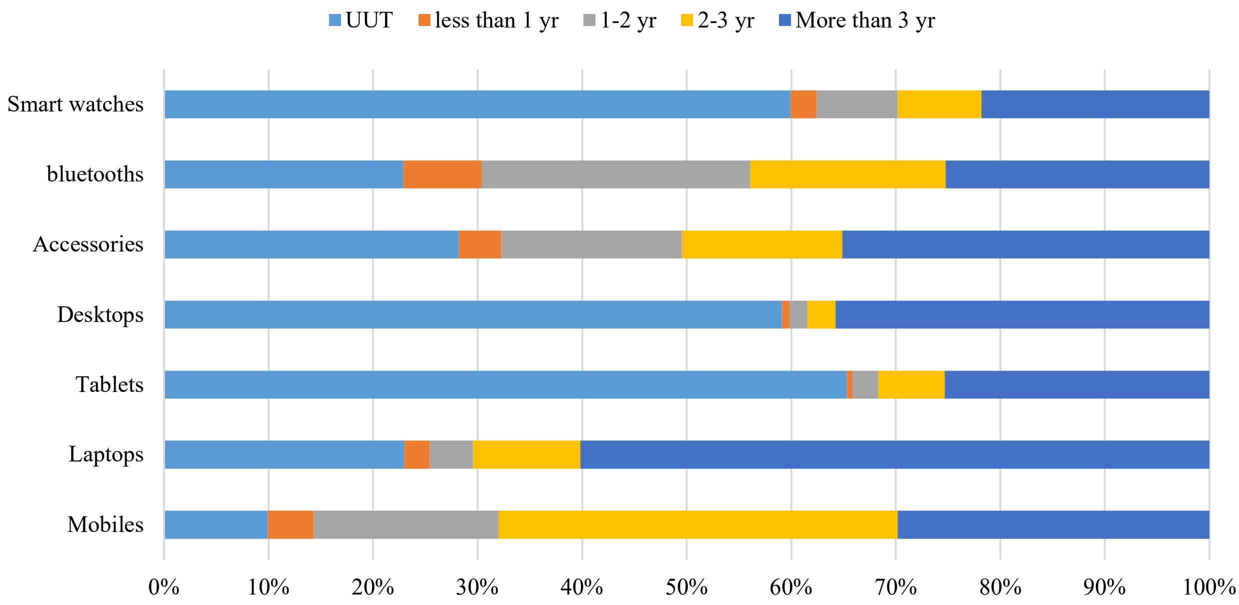


Figure 5.4: EEE replacement time for respondents (UUT: unutilized EEE; Yr: the period of EEE replacement, in year)

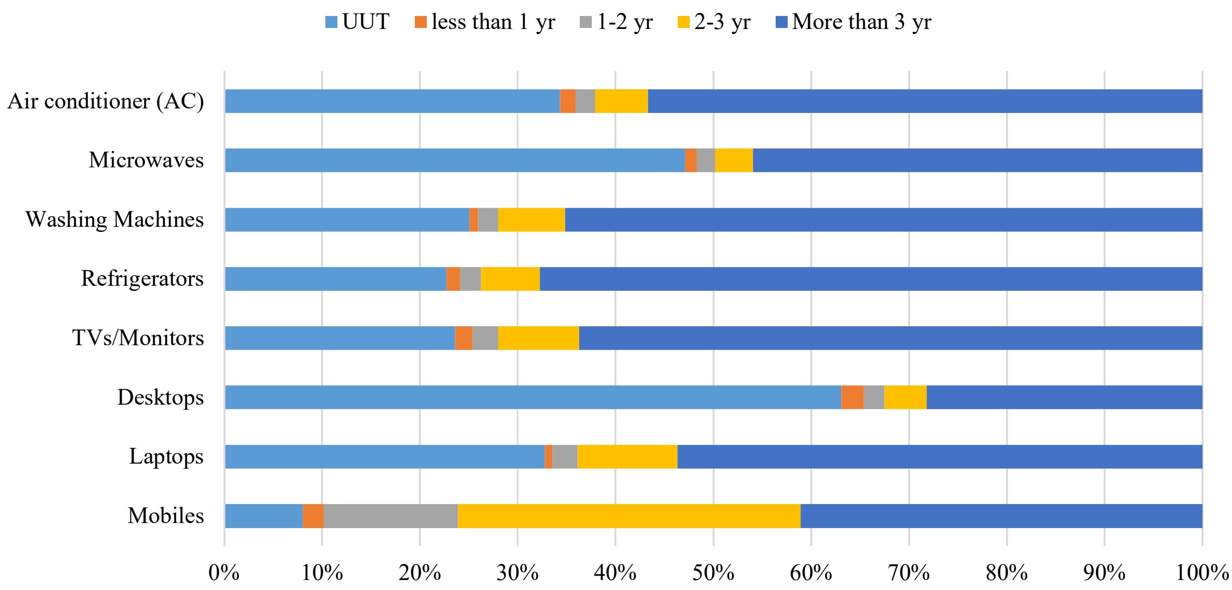


Figure 5.5: EEE replacement time for respondent’s family

The replacement time for the different EEE items varied considerably. Alternatively, EEE replacement results in a disposal pattern of EEE, indicating that lifespan is an essential attribute of e-waste production. The result is consistent with a similar study conducted in China and America. In China, consumers have replaced their small EEE between 2-3 years (Yin *et al.*, 2014), while in America, the replacement period is between 1-2 years for small EEEs, mainly mobiles and Bluetooth speakers (Arain *et al.,* 2020). Large EEE like refrigerators, washing machines, and AC have been acquired for over three years. However, Islam and Huda (2020) revealed that in Australia, the average life of such TV, Desktops and Laptops varies from 3.5-13 years, 3-8.4 years and 2 to 9.1 years, respectively. In the case of a refrigerator, in India, a person had it acquired for 10-15 years normally, same for washing machines and ACs. For instance, the viewpoint of a respondent in our study sample describes the usage and disposal of the refrigerator as follows,

"I had purchased a refrigerator from a Godrej company in 1999. It worked fine, and some issues came in the compressor in 2008. I went to the nearest repair shop, and they charged ₹1000 for repairs. I agreed, and they repaired the compressor. Finally, I used its facility until 2013 and replaced the refrigerator in the exchange offer, and its exchange price was ₹3000. I got a new refrigerator with an upgraded version at the best price".

This storyline is the same in most cases, with some variation in repair and purchase. In the Indian scenario, large EEE such as refrigerators, microwaves and ACs, the consumer has bought for a more extended period, which can be at least ten years. Repair options are an important reason for the increasing EoL. In contrast, small EEE mobile phones, smart watches etc., must be bought frequently or replaced after some time. The respondents are categorized based on age and profession to determine the essential causes of EEE replacements. For instance, the age groups, i.e. 18-27 years and 28-37 years, willingly replace their EEE items with a focus on possible causes. The comparison within professional categories reveals that private employees are more passionate about replacing their EEE devices. In contrast, government employees are unwilling to replace their EEEs on regular periods. In the case of students, the most important cause for replacement is that possessing the latest model will increase status in society among the peers in specific.

5.4.4 Awareness of e-waste and its disposal behaviour

This section describes the consumer's awareness level in terms of EEE replacement, reason for not disposing e-waste, knowledge of e-waste policy and preferences of e-waste disposal methods.

5.4.4.1 Probable cause of EEE replacement

The researchers mentioned that the prominent reasons for replacement are the respondent buying EEE with updated features (Herat, 2007) and decreasing the EEE life span or non-functional (Williams *et al.*, 2008). Another study by Islam *et al.* (2016) mentioned that prominent replacement reasons such as EEE became obsolete, existing EEE items had outdated additional features, and respondents bought new EEE items with a recommendation from peers or a new product launch. Whereas in Malaysia (Afroz *et al.*, 2013) and the UK (Ongondo and Williams, 2011) has major reason is of EEE replacement is damaged, outdated and non-functional. The current study respondents were asked to state the main reasons for replacing their EEE devices. Respondents have answered in “Yes” and “No” option, as presented in Figure 5.6. It was reported that the primary potential reasons for replacement were the old one has become non-functional (72%). The old one cannot be repaired (57%), considering the cost of maintenance, it is wiser to buy a new one than to repair the old one (52%), and the latest models have attractive features (26%). The probable reasons, such as a monetary gain from selling old ones (5%), and possessing the newest model, will increase my status in society (3%). While all my colleagues/friends are buying the latest models, so do I (1%), was the least affected reasons by the respondents.

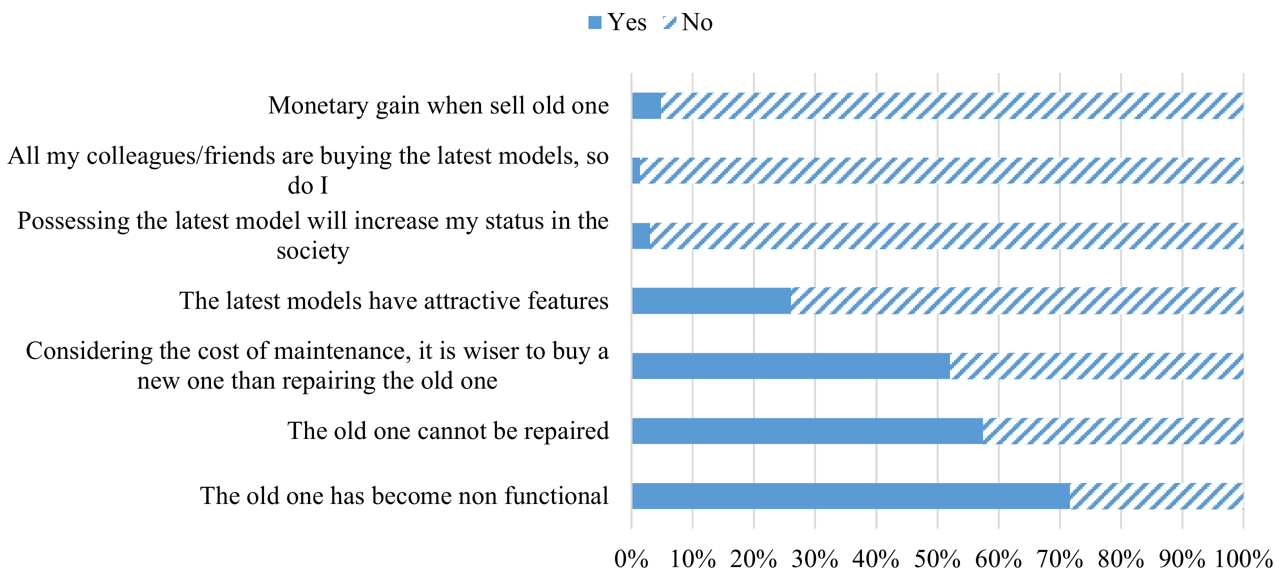


Figure 5.6: Probable causes of replacement

Few studies have indicated that socio-demographic is linked to consumer behaviour towards e-waste disposal. Song *et al.* (2012) stated that an increase in the level of education and household income found a significant impact on e-waste disposal behaviour. Another study by Milovantseva and Saphores (2013) revealed that individuals with higher education are more knowledgeable about pro-environmental protection and positively influenced e-waste disposal behaviour. For this, the chi-square ($\chi 2$) test was conducted to check the significant association between the probable causes of replacement and socio-demographic variables, as listed in Table 5.4. It was observed that the increase of income and profession level had developed a significant relation with the probable cause of replacement such as EEE has non-functional, cannot be repaired, latest models have attractive features and considering the cost of repairing and will increase status in the society. Whereas age and education level showed the least significant association with a possible reason for replacement.

Table 5.4: Cross tabulation analysis for probable cause of replacement

Probable cause of replacement	**Age**	**Income**	**Profession**	**Education**
The old one has become non-functional	13.284**	5.162	7.553**	6.529*
The old one cannot be repaired	7.333	11.767**	7.148	11.587**
Considering the cost of maintenance, it is wiser to buy a new one than repairing the old one	12.625**	7.781*	24.911**	2.43
The latest models have attractive features	0.741	9.87*	7.853*	2.528
Possessing the latest model will increase my status in the society	2.748	3.877	8.546*	2.073
All my colleagues/friends are buying the latest models, so do I	0.994	11.639**	1.107	1.687
Monetary gain when sell old one	5.371	5.449	1.005	0.243
*P ≤ 0.05; **P ≤ 0.01				

5.4.4.2 Reason for not disposing e-waste

In a developed country such as Spain, 28% of the respondents kept EEE with them and did not know where to dispose of them (Bovea *et al.,* 2018). While in the USA, 44% reported having no idea how to recycle them, 26% mixed their e-waste in the solid waste bin, and 12% stored them as a sense of belongingness (Arain *et al.,* 2020). Another reason for not disposing of e-waste has been determined through observation, such as concern regarding data security, location of collection centres and lack of knowledge about e-waste collection options (Ramzan *et al.,* 2019). While outcomes are consistent with a similar study done in a specific city in India, 59% reported that they kept discarded EEEs at home and about 95% of respondents mentioned that they did not know the presence of any authorized collection centres in the city (Borthakur and Govind, 2018). There is a lack of information about e-waste management facilities. So, discarded EEEs are primarily being stored at home. The result of the current study on these aspects is presented in Figure 5.7. It shows that 52% of respondents thought I keep as I do not know how to and where to dispose of them, followed by 36% give away to children/relatives/domestic servants, and 32% of respondents said that I leave them at the store when buying a new one. In contrast, 20% indicated that they disposed of their e-waste in the mixed waste bin, and 16% of the respondents keep it as I have a sense of belonging with them.

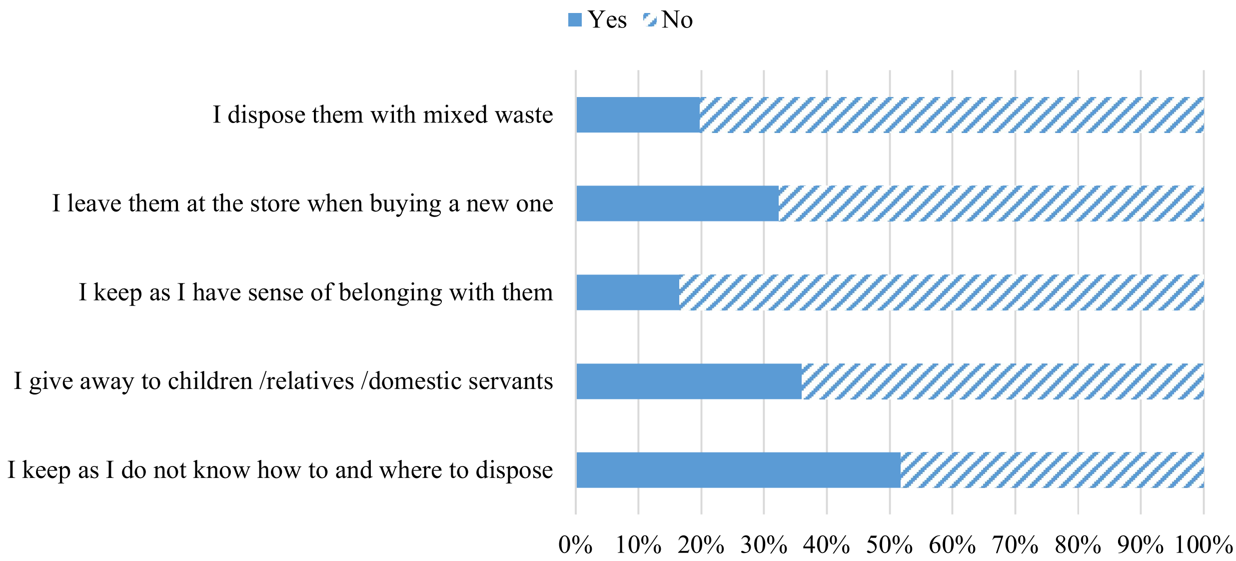


Figure 5.7: Reason of not disposing e-waste

The chi-square ($\chi 2$) test was also conducted to check if any significant relationship exists between the reason for not disposing of e-waste and socio-demographic variables, as listed in

Table 5.5. The analysis revealed that age and education significantly correlate with the reasons for the non-disposal of e-waste in the Indian scenario. It means do not know where to dispose, a sense of belonging mixed with solid waste and give it away to others or store it at home. While prima facie implies that people who are older or more educated are concerned about their e-waste and are aware of environmental regulations. However, the disposal rate is low in India due to a lack of formal e-waste collection facilities. Many people are uncomfortable disposing of e-waste in the informal sector, so they either store it at home or wait for better deals.

Table 5.5: Cross-tabulation analysis for e-waste disposal reasons

Reason for not disposing of e-waste	**Age**	**Income**	**Profession**	**Education**
I keep as I do not know how to and where to dispose	11.250**	3.201	4.191	1.519
I give away to children/relatives/domestic servants	11.553**	4.833	5.653	9.790**
I keep as I have a sense of belonging with them	9.18*	5.915	17.217**	8.250*
I leave them at the store when buying a new one	7.184	11.407**	3.574	4.272
I dispose of them with mixed waste	1.698	6.31	1.696	7.826*
*P ≤ 0.05; **P ≤ 0.01				

If not disposing of the e-waste, some respondents favour leaving them at the store while buying a new one. It could be an attribute of buy-back offers and exchange schemes during festive seasons. While some have no idea how and where to dispose of e-waste, they keep a sense of belonging with them. It could attribute to a low level of awareness and lack of infrastructure in collection centres and stakeholder involvement. However, many respondents are unaware of India’s e-waste policy. Hence, as a result in India, the scope of e-waste issues in the public domain concerning family, peers and neighbours is largely insufficient to influence the intention of their actual disposal. The selection of e-waste disposal options is important which methods are choosing for e-waste disposal. There are different types of e-waste disposal or collection methods in which exchange schemes (online or retailer stores) are most popular among consumers, especially for urban and semi-urban ones. The plan is limited to small EEEs such as mobile phones.

5.4.4.3 Information about e-waste term

Responses to awareness and knowledge of the term e-waste are presented in Figure 5.8. In the current study, 65% of respondents reported having heard the term e-waste from school or college, followed by social media (57%). Also, various respondents had heard from TVs (27%), print media (24%), public domain (21%) and Government-sponsored initiatives (19%). The result with consistent with another study, (Ramzan *et al.,* 2019) stated that 45% of respondents heard the e-waste term from social media platforms, followed by print media (29%) and by the internet (26%). Regarding the knowledge of e-waste policy, 79% of the respondents mentioned that they are unaware of any e-waste-related policy. Only 21% of the respondents said that they are aware of the e-waste policy, presented in Figure 5.9. This percentage will decrease significantly if the study is extended to respondents below ₹5 lakh income level. Another study in India estimated that about 90% of respondents did not become aware of the e-waste policy in India (Borthakur and Govind, 2018). Consumer behaviour is significantly influenced by specific knowledge of environmental policy, and it has been discovered that people who are more informed about the environment have a greater tendency to behave in a more ecological manner (Pérez-Belis *et al.*, 2015).

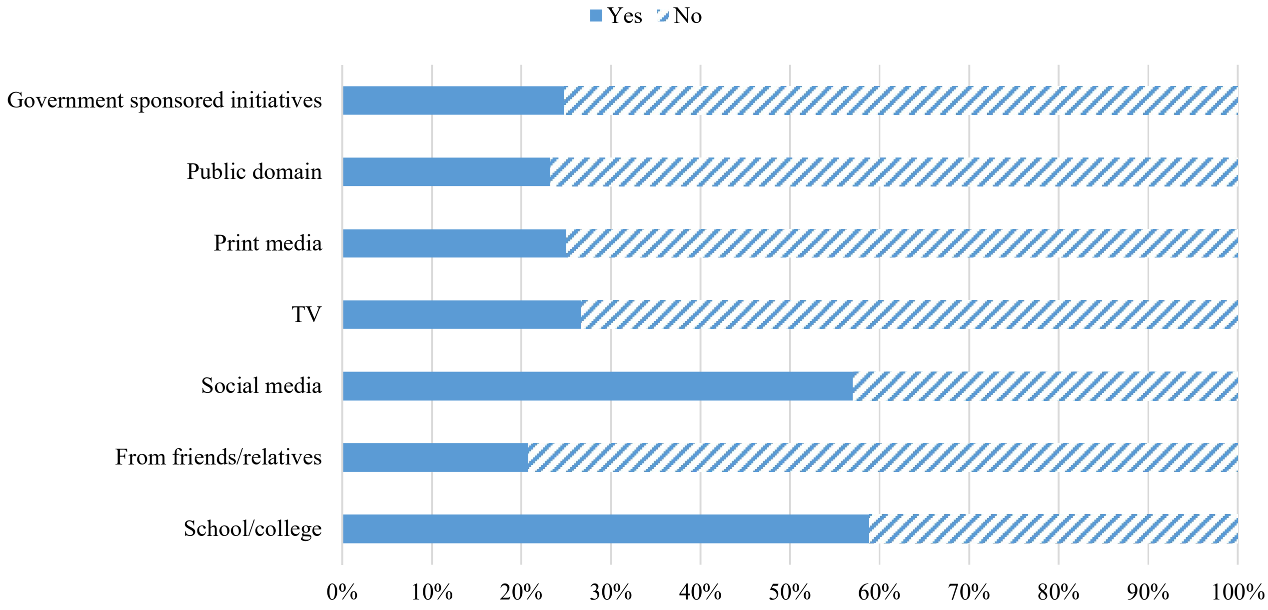


Figure 5.8: Respondents heard e-waste term

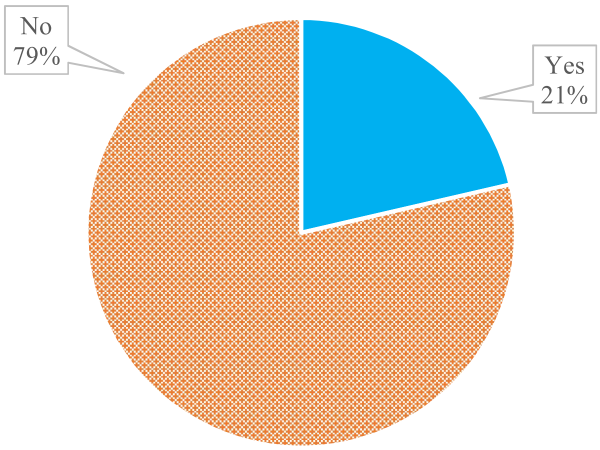


Figure 5.9 Respondents frequency for e-waste policy

5.4.4.4 Selection of e-waste disposal methods

A study in China revealed that 39% of respondents sold their e-waste to informal collectors (Chi *et al.*, 2014). Like Bangladesh, 50% of the respondents have opted for informal e-waste disposal collection (Islam *et al.,* 2016). The current study, Figure 5.10, shows the respondent's willingness to choose their e-waste collection method for e-waste disposal. About 2/3 of respondents preferred the exchange scheme by retail store/online mode. In contrast, 40% of respondents still use the door-to-door collection service from kawadiwalas/rag pickers.

When asked to assess and rank e-waste disposal options as listed in Table 5.6, about 49% of respondents reported that they prefer the exchange scheme option by retail store/online mode. While 34% preferred take-back collection, 30% preferred door-to-door collection (formal), and 26% chose door-to-door collection in the informal sector. Also, it was observed that the least preferred method was curbside collection (10%).

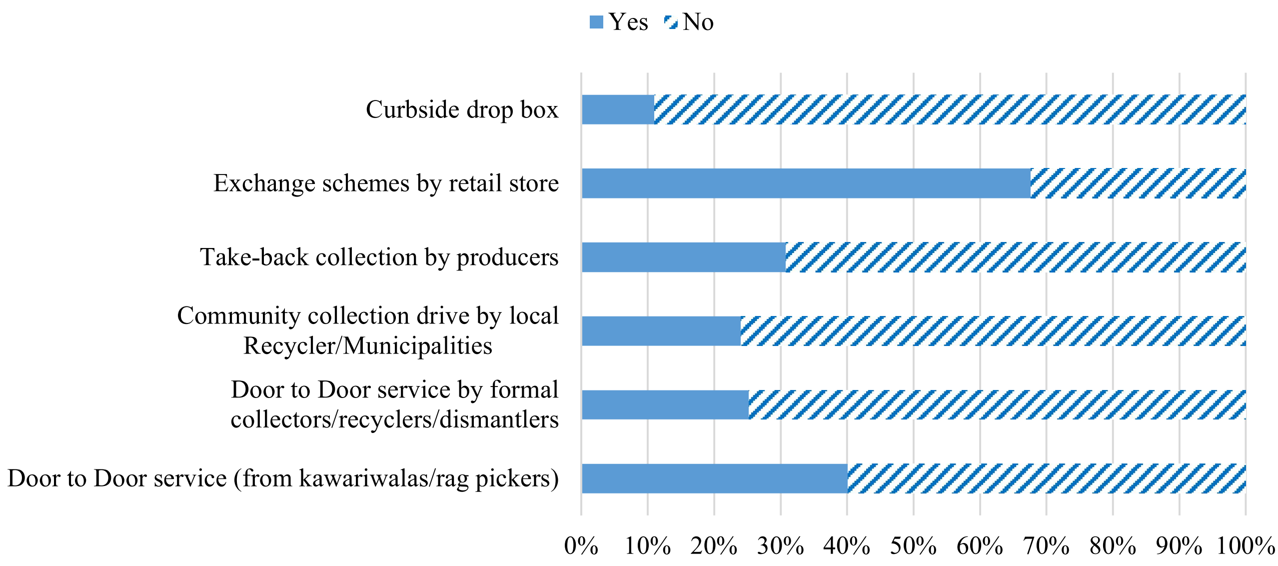


Figure 5.10: Preferences of e-waste disposal methods

Table 5.6: Rank of e-waste disposal method(s)

E-waste disposal method(s)	**Rank preference (%)**					
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**
Door to Door service (from kwadiwalas/rag pickers)	26%	14%	13%	6%	14%	27%
Door to Door service by formal collectors/recyclers/dismantlers	31%	21%	15%	15%	11%	7%
Community collection drive by local Recycler/Municipalities	24%	22%	24%	15%	8%	8%
Take-back collection by producers	36%	25%	15%	12%	7%	5%
Exchange schemes by retail store/online	49%	22%	10%	7%	8%	4%
Curbside drop box	10%	15%	15%	8%	14%	32%

While the unorganized sector is also actively collecting e-waste from the consumers, the kawadiwalas or scrap dealers are the two active players. They have a vast network and use door-to-door collection facilities for e-waste. Instead, they provide some monetary benefit to the consumers. As discussed with one of the Paddlers, how to collect e-waste, as described below,

"I have been serving as a peddler for the last five years and collecting e-waste from the household. I am collecting only e-waste items like PCBs, TVs, plastic cabinets, mobile phones, inverters, electric wires, batteries etc. I am collecting e-waste from rural and semi-urban areas and some urban area. We are using a cycle or pushcart as logistics service and go from street to street and shout, and you can sell me discarded mobiles, TV etc., at a reasonable price. Instead, we offered customers to take money or get other items like toys and kitchen utensils. The collected e-waste was dismantled from plastics, metals and PCBs. These items are then sold to the related traders at a specified price".

The above person's experience suggests that they may not be aware of the harmful effects of e-waste on human health, and e-waste treatment practices are operated in an unsustainable manner. However, consumers are selling their e-waste as a commodity and are not interested in what they will do with their discarded EEE. Door-to-door collection (formal sector) and take-back collection services are primarily used in the urban area. Distinctive consumers use these services because they have pro-environmental knowledge about e-waste issues. While other methods, such as community collection drive and curbside collection, are still in the pilot phase in India. These methods are organized as special events for households in order to raise environmental awareness and encourage them to dispose of their discarded EEE in the proper and appropriate locations.

Although determining the overall rank of the e-waste disposal option using the Friedman test to analyze the ranked data by the mean score for 'n' variables, the importance of variables is more when the mean rank is less. The outcomes of the Friedman test are shown in Table 5.7, the preferred e-waste collection method(s) in the exchange scheme based on mean rank. Followed by take-back collection, door-to-door collection (formal sector), community collection drive and the least effective option are a door-to-door collection (informal sector) and curbside collection. However, most of the respondents did not opt for informal door-to-door collection as it is not deemed to be a safe practice for the environment. While informal collectors are not even aware of the harmful effects of e-waste on health and the environment in general. Whereas the significance value of alpha is set to 0.001, the chi-square ($\chi 2$) value 356.14, df = 5, $p < 0.001$. The null hypothesis has been rejected, meaning a significant difference exists in the ranking distribution for e-waste disposal methods.

Table 5.7: Friedman test result for an e-waste disposal option

e-waste disposal option	**Overall rank**
Door to Door service (from kawadiwalas/rag pickers)	5
Door to Door service by formal collectors/recyclers/dismantlers	3
Community collection drive by local Recycler/Municipalities	4
Take-back collection by producers	2
Exchange schemes by retail store	1
Curbside dropbox	6

5.5 Study implications

The subject is of contemporary relevance and is evident from the respondent's interest in their daily use of the EEEs. The authors focused on the e-waste disposal behaviour of consumers across India with one set of questionnaires. In contrast, prior research focused on empirical analysis of various issues of e-waste collection, disposal and recycling for other countries or a limited geographic region within India (Arain *et al.,* 2020; Rodrigues *et al.,* 2020). A wide and country-specific result on consumer's perception of e-waste disposal behaviour is obtained, which is valuable. The outcome is expected to help stakeholders such as the government and e-waste recyclers develop the right strategy(s). The strategies may include the adoption of e-waste collection method(s) concerning the type of EEE, location (areas), customer segments, customer awareness and various motivation factors for e-waste disposal. The complex relationship between successful mitigation of e-waste related issues and customer disposal behaviour is attempted to maximize e-waste collection.

This survey provided primary data for various statistical analysis and it is suitable for the research. The inability to trace domestic EEE flows is a significant challenge for identifying how much EEE is currently in use and how much is discarded. The national data presented, reflect some estimation of e-waste generated, which is about 2.4 kg per capita. That is either stored or discarded and did not determine how much EEE is currently held by individuals and households. Another notable point from the responses is the identification of the main reason for replacement/reuse of EEE. This study also pointed out the prominent e-waste pile-up at the household level due to the fact that people do not know how to safely dispose of or where to dispose. Additionally, due to inadequate formal collection infrastructure, consumers sell/dispose discarded EEE to the informal sectors. Further, consumers are keen to keep the same with a sense of belonging and are mixed with the solid waste stream. These reasons are more prominent in developing countries such as India when there is a lack of awareness and knowledge on the environmental effect of e-waste at the household level. Hence, there is high scope for the involvement of academicians, NGOs and practitioners to elaborate on e-waste disposal issues and behaviour, region-wise. The managerial level implications for e-waste disposal problems are important for establishing sustainable e-waste collection methods across the country. Although the use of EEEs in India continues to grow, the e-waste disposal system, on the other hand, still faces challenges in establishing a robust reverse supply chain. The authorized stakeholders, including recyclers, producers and collectors, are utilizing the EPR system for e-waste collection for bulk consumers. The take-back collection, door-to-door collection and exchange schemes (by online/retail store) are also used by organized sectors mainly to collect the discarded EEEs from consumers. Further, these methods are used primarily for e-waste collection in urban areas, whereas kwadiwalas/peddlers mainly serve semi-urban and rural areas.

Consumers are able to exchange or sell their mobile phones to formal collectors with a monetary benefit. While other small EEEs, like Bluetooth speakers/headsets, laptops etc., are not frequently exchanged or sold due to the selective nature of formal collectors who provide these offers only occasionally. It leads to mainly three situations: store & forgets; donate or sell in second-hand markets. Similarly, large-size EEE-like home appliances such as refrigerators and washing machines are used for a long time until they become obsolete. In this case, the reverse logistics facility will provide particular e-waste disposed of at the collection centre. Consumers face hurdles regarding where and how to dispose of their discarded EEEs. As a result, consumers gave it to the local peddlers instead of a little money. Therefore, stakeholders need to improve their reverse supply chain and develop a collection system across the country that is easily accessible across various regions to cover all demographics.

India's e-waste policy is well defined and clarifies the roles and responsibilities of stakeholders for regulating e-waste collection from consumers. The policy also described important terminologies such as EPR, PRO, deposit refund schemes and collection targets for collectors, recyclers and manufacturers. To fulfil these schemes, the authorized stakeholders primarily focus on the bulk consumers. The latter dispose of their discarded EEEs by following the appropriate channels (reverse supply chain) as described in the policy. The stakeholders do not adequately cover the domestic e-waste collection as such collections are costly. Consumers are unaware of the e-waste policy and its harmful impact on the ecosystem and are, therefore, not ready to put effort into voluntary disposal. It is not feasible to stop the collection of e-wastes by the informal sector for their non-compliance because of their vast network and the employment they provide. However, the Government should develop guidelines and provide training with incentives for its operations. It will make the unorganized sector move towards an organized sector with compliance. Also, learn lessons from developed and developing countries successfully implementing e-waste policies and regulations. NGOs can also play an active role with the various stakeholders by conducting awareness campaigns, pilot projects, skill training and seminars to disseminate knowledge about e-waste related issues at the household level in urban, semi-urban and rural areas.

Moreover, various extended stakeholders such as Government, media houses, social platforms and organized sectors should also contribute to enhance customer awareness regarding the importance safe disposal practices. Such campaigns by the stakeholders will definitely strengthen the e-waste collection and boost business sustainability. The current study indicates that about 40% of the respondents prefer the informal disposal method, and about 79% reported that they were unaware of the e-waste policy. Various NGOs such as The NEPRA (Nepra, 2022) and KARO SAMBHAV (Karo Sambhav, 2022) have been working with recyclers and collectors in recent years, and the involvement of more NGOs is necessary for such activities. NGOs can aim to educate the informal sector, such as rag pickers and peddlers, while also building long-term relationships with the formal sector, which may provide gainful employment. Furthermore, on an open platform, one can provide consultancy services to stakeholders and conduct training programs at educational institutions to create a workforce for the future.

5.6 Sectional summary

This chapter presents an empirical assessment of the e-waste disposal behaviour of consumers living in India's urban, semi-urban and rural areas. It analyses the various aspects of e-waste, including consumption quantity, length of ownership, reason for replacement, reason for not disposing e-waste, the status of policy awareness and preference of e-waste disposal methods. The salient points are summarized as follows:

- A survey questionnaire was developed to study these dimensions, and primary data were collected to elucidate e-waste flows from individuals and households.
- As per the survey, the average individual and household in India currently own 6 EEE as individuals and 4 EEE as households, respectively, with an average per capita income level of ₹5 lakhs to ₹25 lakhs ($6289 to $31295).
- Interestingly, many respondents informed that they attempted to replace an EEE when the same became non-functional or not repairable, however, the reason for not disposing off the same is that majority had no idea how to and where to dispose. Therefore, they gave it away to others or stored it.
- This is perceived to be a prominent reason why the informal sector thrives at the cost of the formal sector.
- Not only the education and awareness of e-waste is insufficient, but also the implementation plan of the e-waste disposal system at the upstream level are important.
- The policymakers should work with stakeholders and NGOs to identify the causes of particular e-waste disposal behaviour and establish a visible and robust e-waste collection system or plan for the general public.

CHAPTER 6 CONSUMER BEHAVIOUR TOWARDS E-WASTE DISPOSAL MODE: AN APPLICATION OF THE THEORY OF PLANNED BEHAVIOUR

This chapter describes and evaluates the consumer behaviour towards e-waste disposal mode through statistical analysis. The investigation of the psychological factors is carried out employ Theory of Planned Behavior (TPB) which contributed to diagnose the potential factors of e-waste disposal among consumers. For this, a model is established to examine the various hypothesis through Structural Equation Modeling (SEM).

6.1 Introduction

The demand of EEE has been increasing exponentially due to advertisement pressure, frequent technology appearance, high obsolescence rate, improving lifestyle, increased household income and, early EEE disposal behaviour (Koshta *et al.*, 2022). In recent years, there has been a rapid growth in EEE consumption, contributing to the cumulative rise in waste generated from the obsolete EEE, referred to as e-waste/WEEE. E-waste comprises a wide variety of products that contain PCBs circuitry or EEE components that require power or battery supply to perform their functions. Once EEE is discarded by its owner without the intention of reuse, it becomes e-waste (Forti *et al.,* 2020). A report shows that the e-waste stream is growing much faster than other solid waste streams, with an annual rate of 5-10 % (Masud *et al.*, 2019). E-waste is non-biodegradable waste and requires proper supply chain management for collection, recycling, and safe disposal (Shreyas Madhav *et al.*, 2021). There is significant potential to conserve natural resources which contain many rare earths and valuable added materials having vast economic potential as well as highly toxic substances (Arya and Kumar, 2020). Valuable material may be recovered and reused by using proper treatment methods. Hazardous substances present in e-waste may pose a severe threat to the environment and human health due to pilferage and also during the recycling process (Corsini *et al.*, 2015).

Most of the countries have an e-waste policy and rules in place but at different maturity levels. The policy essentially obliges producers and manufacturers to take responsibility for each EEE for the entire life cycle under EPR (Khetriwal *et al.*, 2009). Other authorised stakeholders such as collectors, remanufacturers, and recyclers are responsible for setting up collection centres, establish collection channels, and recycling units for material recovery and developing reverse logistics networks to maximise e-waste collection (Guarnieri *et al.*, 2016; Islam and Huda, 2018). Consumer involvement is crucial for the successful implement an e-waste collection system, particularly in developing nations. Lack of consumer awareness in disposal activities is a significant impediment to the e-waste collection system as illustrated by 75% of discarded EEE such as mobiles and laptops being stored at home rather than returned to the stakeholders (Kumar, 2019). Another research showed that consumers in developing nations like India store their discarded EEE for up to 10 years (Borthakur and Govind, 2018). Thus, there is a need to actively encourage consumers and adequately support the e-waste disposal system.

The socio-cultural factor is the indispensable parameter for any country to implement a successful e-waste collection system, especially for the emerging nations (Ananno *et al.*, 2021). Gilal *et al.*, (2021) also pointed out that consumer's disposal behaviour plays a significant role, in being willing to return their discarded EEE through a formal e-waste collection system. Another scholar (Aboelmaged, 2021) argued that consumer habits and intentions influenced e-waste disposal systems. Therefore, a prominent factor for understanding the disposal trend of e-waste is observing the consumer's behaviour and intention. For this, there is a need to assess the prevailing disposal practice, engage the consumer through awareness camps and also know the consumer habits. This will help to identify relevant vulnerabilities for improving the collection system and encourage the consumers to choose a suitable disposal mode. Meanwhile, to the best of our knowledge, research on predicting consumer behaviour towards e-waste disposal systems is in infancy and very limited work is available, especially in developing economies like in India.

This study explores consumer behaviour related to the e-waste disposal system for to popularize its adoption. Furthermore, the investigation of the psychological factors is carried out employing TPB which contributed to diagnose the potential factors of e-waste disposal among consumers. TPB is a well-established and accepted behavioural theory that precisely assesses the socio-physiological variables, including attitude, subjective norms and perceived behaviour control in consumer behaviour (Ajzen, 1985). In the domain of pro-environment behaviour, many scholars utilised the TPB model to understand whether consumers intend to perform environmentally friendly. The TPB revealed that the consumer's attitude, control over their actions, and the group of people close to them, form an association with their willingness to engage in the behaviour (Ajzen, 1991). Acknowledging the effectiveness of TPB in explaining individual intention-behaviour, researchers stress that the framework does not contain context-specific factors, which play an essential role in individual decision making (Dhir *et al.*, 2021). It is, therefore, important to modify the basic TPB framework to improve its explanatory predictive power according to the problem statement (Kim *et al.*, 2013). The present study proposes a model for e-waste disposal behaviour in the context of e-waste disposal modes using the TPB approach. The questionnaire on consumer behaviour has been developed considering the above aspects, Responses have also been collected across India in terms of attitude, social pressure, and Perceived Behavioral Control (PBC). The key factors are identified that influence consumer decision-making while selecting the e-waste disposal system in the context of India. The survey data is utilized to evaluate and analyze the results to improve the e-waste collection system.

In the current chapter, a Structure Equation Modelling (SEM) based on the TPB framework is proposed while reporting these research questions. The proposed model stipulates that consumer attitudes, subjective norms (social pressure), PBC, and influencing consumer decision factors contribute to an intention towards a particular behaviour. According to TPB, this intention is expected to convert into behavioural practice in the near future. In addition, the factor influencing consumer decision is included as a mediator to improve the proposed model's predictive ability and model statistical power.

6.2 Research questions

The present study proposes objectives in the form of the following research questions.

- What are the psychological factors that explain and affect the consumer's disposal behaviour?
- What is the influence of various psychological factors on the e-waste disposal system?
- How do the context-specific factors such as cost transparency, proximity, incentives for future purchases and documentation & legalization influence consumer decisions when choosing an e-waste disposal mode?

6.3 Materials and methods

6.3.1 Hypothesis development

The current research model is based on the TPB framework to observe and examine consumers' intention toward e-waste disposal in India. TBP is a well-established and widely accepted framework among researchers for developing a conceptual framework that focuses on predicting behaviour related to the intention to perform a given trait in specified contexts (Ajzen, 1991). It is well exploited in social science, especially to predict psychological behaviour. The TPB model basically examines the individual's behavioural intention based on three independent predictor/construct variables: attitude, social pressure, and PBC.

Attitude refers to an individual's positive or negative belief about performing a specific behaviour (Ajzen, 1985). It focuses on moral responsibility or the feelings of people themselves. In other words, as the effect associated with the action becomes more favourable, the likelihood of people having a strong intention to perform the behaviour increases. In this regard, Park *et al.*, (2020) stated that individual attitudes positively impact e-waste disposal behaviour. In contrast, Dhir *et al.,* (2021) reported that a particular attitude shares a constructive relation with e-waste recycling intention. Similarly, Koshta *et al.,* (2022) observed that the general attitude of consumers showed positively towards e-waste recycling intention.

Social pressure refers to the belief of the relevant individuals that the behavioral option should be selected (social pressure) at the time of the willingness to obey that expectation. It derives from the norms known to individuals such as colleagues, friends and family members (Ajzen, 1985). A prior study reported that e-waste rules and regulations and their related propaganda have impact on individual's e-waste disposal behaviour. Yu *et al.*, (2014b) reported that social pressure plays an essential role in changing individual habits toward e-waste disposal. Koshta *et al.,* (2022) asserted that social pressure positively influences particular disposal intentions.

PBC refers to an estimate of an individual's ability to believe how easy or difficult it is to perform a specific behaviour. Wan *et al.*, (2014) found that PBC positively influences personal recycling intent. Another study by Kumar (2019) suggested that the PBC shares a positive relationship with e-waste recycling whereas, Park *et al.,* (2020) believed that the individuals showed positive attitudes about e-waste disposal. Therefore, the following research hypothesis are proposed:

H1a. Attitude positively affects the individual's behaviour towards e-waste disposal.

H1b. Social pressure positively affects the individual's behaviour towards e-waste disposal.

H1c. Perceived behaviour control positively affects the individual's behaviour towards e-waste disposal.

Behaviour intention indicates how hard individuals are willing to try and how much effort they are planning to exert to perform the behaviour. These three psychological predictors explain individual behaviour. An upsurge in intentions is more likely to transform into actual behaviour, showing a positive association between intentions and behaviour. Borthakur and Govind, (2017) reported that understanding an individual's behaviour is positively associated with e-waste disposal. Gilal *et al.,* (2021) argue that individual awareness about e-waste disposal behaviour significantly developed a relationship with psychological predictors and environmental variables. Park *et al.,* (2020) reported that the individual disposal behaviour showed a significant impact on intention to select e-waste disposal modes whereas, Aboelmaged, (2021) argued that the role of disposal habits positively impacts individual consumer behaviour. Similarly, Islam *et al.*, (2021) pointed out that the individual disposal behaviour significantly correlates with awareness level and knowledge about the e-waste disposal system in terms of disposal methods. Based on the above discussion, we defined individual behaviour of e-waste, which directly influences intention towards selecting e-waste disposal modes as the second research hypothesis.

H2. Individuals' e-waste disposal behaviour directly influences intention towards selecting e-waste disposal modes.

There are various attributes that indirectly affect the individual decision to select e-waste disposal modes. The attributes are cost transparency, proximity, incentives for future purchases and documentation & legalization. These attributes are also discussed in the intention to a selection of e-waste disposal modes. Transparency in the cost mechanism for e-waste sales is a significant variable which can affect the e-waste disposal system. Wang *et al.*, (2012) reported that the importance of e-waste disposal cost influences consumer behaviour when selecting disposal options. It can be said that the disposal price is one of the significant determinants of the willingness and ultimate action of individuals in choosing the e-waste disposal option. Proximity refers to individual's ease of access to the e-waste disposal facility or service with comfort. Tan *et al.*, (2018) indicated that many residents had changed their selection behaviour based on the distance to e-waste collection sites indicating the importance of proximity for individual decisions towards various e-waste disposal services. Providing incentives in future purchases also reflect in e-waste disposal behaviour when consumers safely discard their e-waste at the disposal facility. Ongondo and Williams, (2011) pointed out that economic benefits such as cash payments and coupons exert the most significant influence on an individual's willingness to participate in e-waste disposal services. In comparison, Mishima and Nishimura, (2016) reported that cash payment alone is not a sufficiently strong driving force for disposal behaviour. While the potential discount service on the next purchase of new products associated with the return of e-waste can be an effective tool to encourage a specific disposal behaviour that promotes e-waste disposal. Documentation & legalization as the fidelity of data protection of e-waste disposal also influence individual disposal behaviour. People are concerned about information leaks and data security issues when disposing of a certain variety of e-waste, such as mobile phones, laptops etc. at the disposal facility Thukral *et al.*, (2022). These are essential attributes for decision making in the selection of disposal modes. Collectors and recyclers should ensure proper documentation when collecting e-waste. It also important to clarify that it is legally authorized to provide an e-waste collection service. Tan *et al.,* (2018) argued that proper authorization/certification of e-waste disposal facilities might accelerate and it has been reported as the most crucial factor influencing individual preference for certain e-waste disposal services. Chi *et al.,* (2014) pointed out that due to peculiar characteristics of selected e-waste, the collector characteristics may become a primary factor that is considered other by an individual to make a decision. Based on the above arguments, we suggested a hypothesis:

H3. Factor affecting consumer decisions mediates the association between e-waste disposal behaviour and the intention to select an e-waste disposal mode.

Based on the prior literature review, it can be recognized that TPB theory can very well capture such behaviour. The focus is on the various predictors that affect the e-waste disposal behaviour among individuals. The research framework using TPB theory is presented in Figure 6.1.

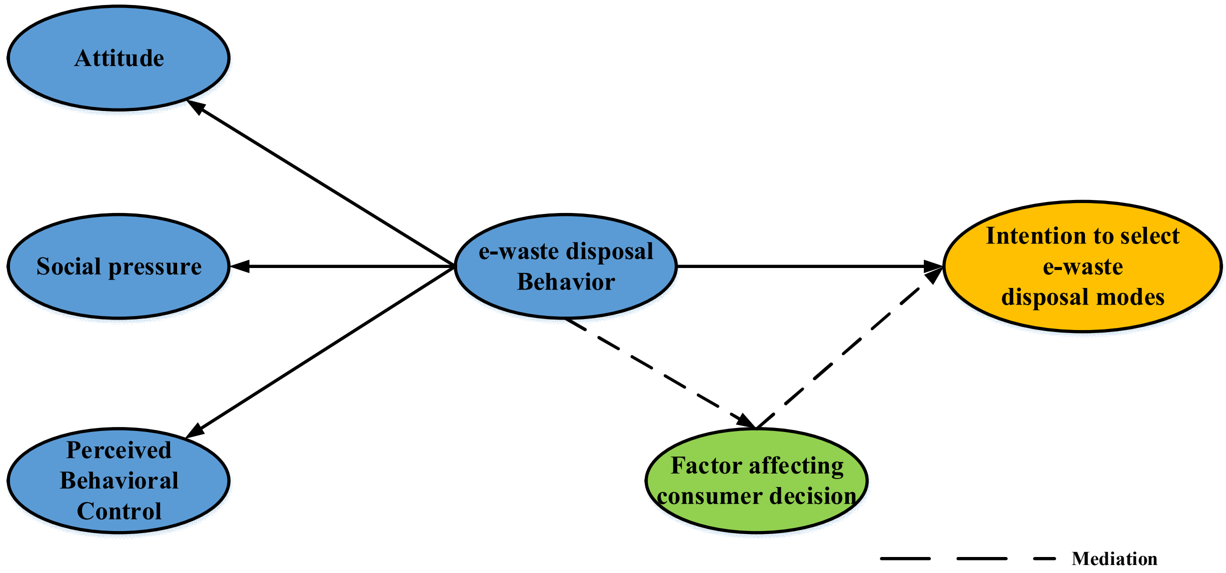


Figure 6.1:Research framework of e-waste disposal behaviour

6.3.2 Instrument design

After reviewing the literature, a self-administered instrument (questionnaire) was developed to collect survey data to test the proposed model. A set of survey questionnaires has been developed from a modified version of the questionnaire used in previous studies related to the e-waste management (Kumar, 2019; Wan *et al.*, 2014). The instruments are organized into two sections: the first section comprises the respondent's demographic profile, including gender, age, education level, annual income level and living area (see Chapter 5, section 5.3.2). The second part focused on measuring the modified TPB constructs, including attitude, social pressure, PBC and factors affecting consumer's decisions and intention toward selecting e-waste modes. Each construct has four to five sets of indicators in a survey instrument, which measure different constructs from different angles. A five-point Likert scale (1 - strongly disagree; 2 - agree; 3 - neutral; 4 - agree; 5 - strongly agree) is utilized to measure the various indicators of the proposed model.

An expert team was formalized to analyze the content validity of questionnaires derived from existing literature. The team is comprised of four experts (two academicians, one practitioner and one environment consultant) who have knowledge of the e-waste management field and have experience of more than five years. The questionnaire was updated as per the suggestions received from the expert team. A pilot test has been conducted to finalize the survey questionnaire. Thirty respondents were randomly selected from among the population to fill out the survey through the online platform. The respondents have raised no issue as all questionnaires are well defined and understandable, as presented in Appendix A.

6.3.3 Data collection

The survey was conducted online mode and was distributed covering most of the states of India. A sample of 1500 potential respondents for the survey was drawn from a random population. Potential respondents were contacted through email and social media and were invited to fill up online forms, which may reduce the social desirability bias to some extent. The survey data is obtained, see chapter 5, Table 5.1.

6.3.4 Data analysis

The maximum likelihood estimation approach was used for SEM analysis. This approach maximises the probability (likelihood) that the observed co-variances are drawn from the population assumed to be the same as that reflected in the coefficient estimates. The SEM analysis estimates the unknown coefficients of casual relation among latent (construct) variables and specifies how observed variables indicate the hypothetical constructs. Two popular statistical tools, such as SPSS 25.0 and AMOS 25.0, are employed to test the hypothesis of the proposed model. A two-step research methodology is utilised for SEM data analysis. In the first step, the CFA was performed to analyse the adequacy and quality of the measurement model whereas to examine the reliability, convergent validity and discriminant validity are performed for the constructs. In the second step, all proposed research hypotheses were evaluated using the SEM approach. Finally, the mediation analysis was carried out to examine the indirect effect among hypotheses H2 and H3.

6.4 Results analysis

6.4.1 Measurement test

The measurement model in SEM is a confirmatory factor model. It empirically measures the relationships between the latent (construct/unobserved) variables and the observed (item/indicator) variables. As part of the CFA analysis, the factor loading was assessed for each item, and each item has higher loadings (< 0.704), while communality describes variation in the indicators explained by the construct, referred to as variance extracted from the indicators.

6.4.1.1 First order test

First-order factor loading and communality are presented in Table 6.1 and correlation among latent variable presented in Figure 6.2. First-order measurement model assessment includes construct reliability, convergent validity, discernment validity, and Average Variance Extraction (AVE) of the given model. Construct reliability measures the inter-consistency of the indicators within the same constructs, and it was assessed using Cronbach's Alpha (α) and Composite Reliability (CR). Cronbach Alpha for each construct in the study was found over the required limit of 0.70 (Nunnally, 1994). CR ranged from 0.887 to 0.930, above the 0.70 benchmark (Hair *et al.*, 2013). The convergent validity extent measures the correlation among indicators within the same construct, and it is assessed by AVE (Fornell and Larcker, 1981), whereas discriminate validity is the extent to which a construct is truly correlated but distinct from other constructs. It can estimate as the square root of AVE and is greater than the correlated value. Hence, reliability and validity were established for first-order CFA in the study, as listed in Table 6.2.

The model fit measures were used to assess the model overall goodness of fit, the ratio of chi-square value and degree of freedom ($\chi 2/df$), Normal Fit Index (NFI), Comparative Fit Index (CFI), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), Standardized Root Mean Square Residual (SRMR) and Root Mean Square Error of Approximation (RMSEA) were used. A good fit model should have the values of GFI, CFI, NFI, TLI and AGFI close to 1 or ≥ 0.9 (Byrne, 2013; Kline, 2015) and the values of RMSEA and SRMR ≤ 0.08 (Schermelleh-Engel *et al.*, 2003). The four model yield good fit for the data: $\chi 2/df$: 1.924, GFI: 0.955, AGFI: 0.937, CFI-0.984, NFI: 0.968, TLI-0.981, SRMR:0.0341 and RMSEA-0.043. All values of model fit were within their respective acceptable levels.

Table 6.1: Factor loading and communality of measurement model

Latent variables (Constructs)	Manifest variables (Indicators)	Factor Loadings	Commonalities
Attitude (ATT)	ATT_1	0.725	0.526
	ATT_2	0.836	0.699
	ATT_3	0.862	0.743
	ATT_4	0.827	0.684
Social Pressure (SP)	SP_1	0.816	0.666
	SP_2	0.891	0.794
	SP_3	0.861	0.741
	SP_4	0.777	0.604
PBC	PBC_1	0.817	0.667
	PBC_2	0.892	0.796
	PBC_3	0.871	0.759
	PBC_4	0.708	0.501
Intention towards selection of e-waste disposal modes (INT)	INT_1	0.893	0.797
	INT _2	0.901	0.812
	INT _3	0.844	0.712
	INT _4	0.869	0.755
Factor affecting consumer decisions (CDs)	CDs_1	0.773	0.598
	CDs_2	0.853	0.736
	CDs_3	0.824	0.678
	CDs_4	0.716	0.512

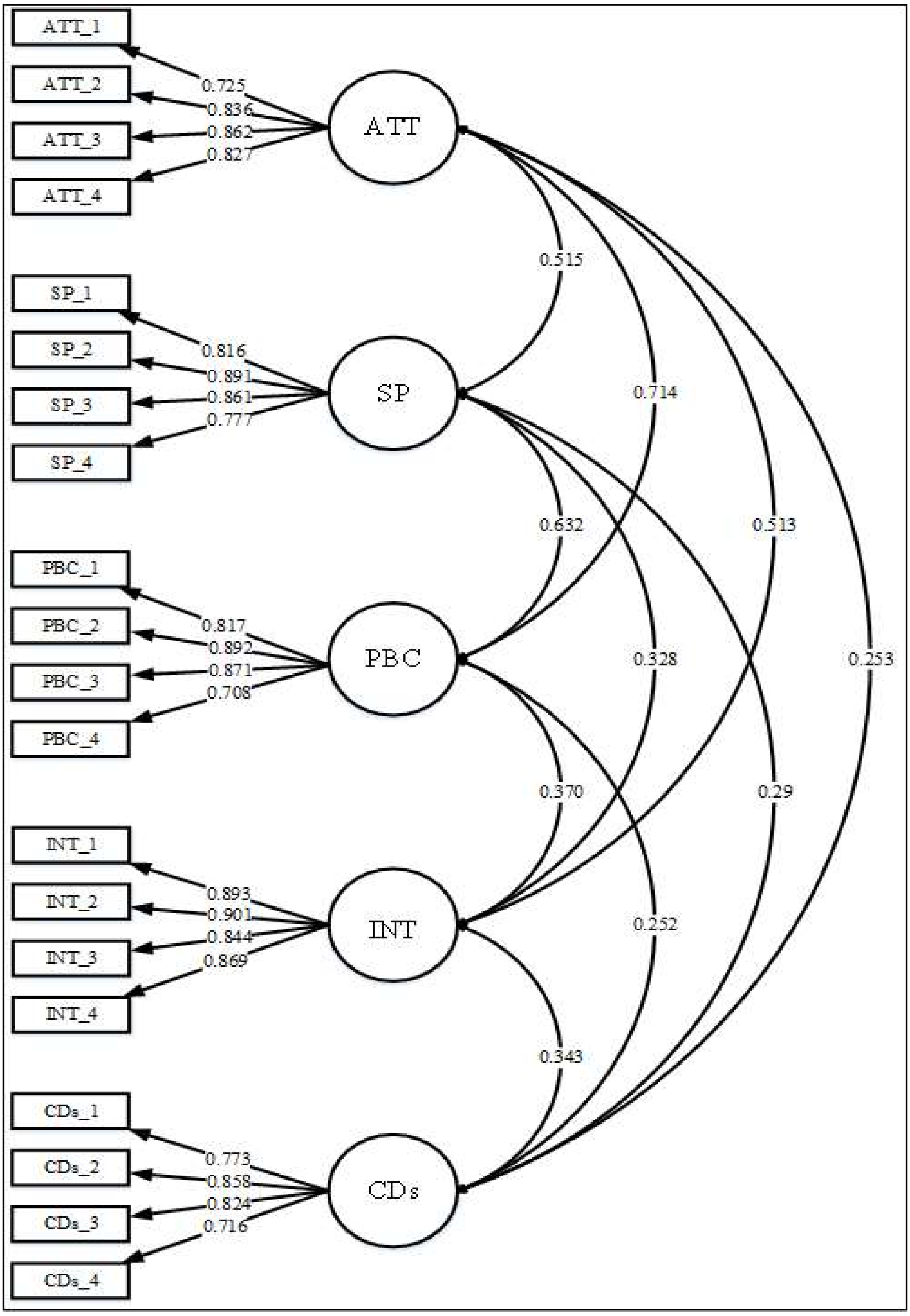


Figure 6.2: First order measurement model

Table 6.2: Reliability, validity and correlation of first order CFA

Constructs	α	CR	AVE	MSV	ASV	ATT	SP	PBC	INT	CDs
ATT	0.884	0.887	0.663	0.509	0.275	**0.814**				
SP	0.901	0.903	0.700	0.400	0.214	0.516***	**0.837**			
PBC	0.887	0.894	0.681	0.509	0.277	0.714***	0.632***	**0.825**		
INT	0.929	0.93	0.769	0.263	0.156	0.513***	0.328***	0.370***	**0.877**	
CDs	0.867	0.874	0.584	0.117	0.082	0.253***	0.289***	0.252***	0.342***	**0.764**
α = Cronbach's Alpha, CR = Composite reliability, AVE = Average variance extraction, MSV = Maximum shared variance, ASV = Average shared variance, ***correlation values ≤ 0.001										

6.4.1.2 Second order test

It was observed that the high correlation among constructs in the first-order measurement model is visible (see Table 6.2). The higher-order model is suitable for this study, i.e. second-order model is employed. The second-order CFA refers by the researcher to confirm that the theorized construct in a study loads into a certain number of underlying sub-constructs (Tanwar and Prasad, 2017). The main construct has become second-order while sub-constructs become the first-order constructs. Therefore, a construct is added, "*E-Waste Disposal Behavior*" (EDB) to explain the three constructs as sub-construct, a correlation of second order is presented in Figure 6.3 Similarly, the quality and adequacy of the second-order measurement model are tested. The CR and AVE values are 0.838 and 0.635, respectively, and values are within the permissible limit. All values of model fit were within their respective acceptable levels. The result of model fit is: $\chi2$/df: 2.168, GFI: 0.949, AGFI: 0.930, CFI-0.980, NFI: 0.963, TLI-0.976, SRMR:0.0485 and RMSEA-0.049.

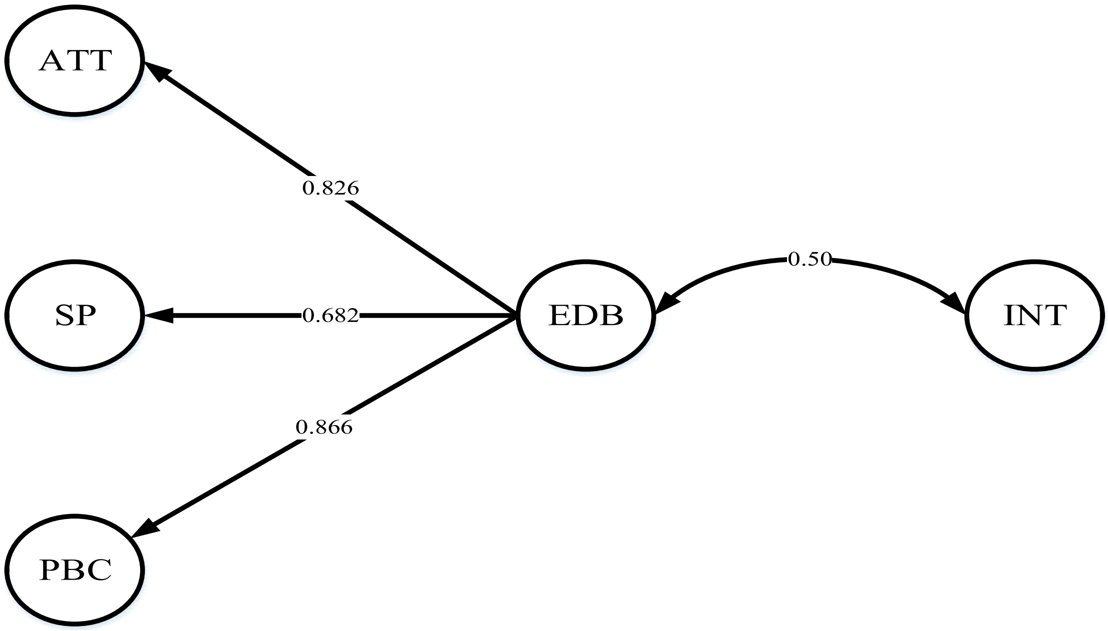


Figure 6.3:Second order measurement model

6.4.2 Structure equation modeling

The structural equation model examines the path analysis and assesses the relationship between constructs (i.e. independent constructs influence dependent constructs). In order to assess the physiological factors of consumer disposal behaviour and e-waste disposal intention relationship, it was imperative to create a second-order structural model. A second-order latent construct, *E-Waste Disposal Behavior* (EDB), was created using a reflective construct model in the structural model. The primary condition for this type of modelling is that all first-order latent variables should have a significant correlation (Collier, 2020). The SEM with AMOS 25 was used to test the path coefficient (β) of the relationship between constructs in the proposed research model.

The second-order SEM model introduce to compute model fit values are $\chi2$/df: 1.725, GFI: 0.972, AGFI: 0.957, CFI-0.991, NFI: 0.978, TLI-0.988, SRMR: .0237 and RMSEA-0.038 and all values are found in acceptable limit. The e-waste collection mode construct was also subjected to CFA and was also satisfactory. The proposed model was found to be appropriate for model fit indices values $\chi2$/df: 1.961, GFI: 0.954, AGFI: 0.937, CFI-0.983, NFI: 0.967, TLI-0.980, SRMR: .0477 and RMSEA-0.044. All standardized path coefficient values of the proposed hypothesis of the structural model were significant at $p < 0.001$ and are presented in Table 6.3. The study assesses the impact of e-waste disposal behaviour on e-waste disposal mode. The relationship between constructs found positive and significant value (β=0.51, t=9.020, p-value=0.00). The square multiple correlation (R2) was 0.26 for e-waste collection modes. The structural model explained a 26 % variance in e-waste disposal behaviour towards e-waste collection mode, as presented in Figure 6.4. Hence, it can be concluded that the psychological factors of disposal behaviour are positively associated with the e-waste disposal modes for collection.

Table 6.3: Result of proposed hypothesis

Hypothesis	**Path**	**Path coefficient (β)**	**t- value**	**S.E.**	**P-value**	**Results**
H1a	ATT<---EDB	0.826	11.756	0.088	0.00	Supported
H1b	SP<--- EDB	0.685	10.605	0.074	0.00	Supported
H1c	PBC<--- EDB	0.865	Reference point		0.00	Supported
H2	INT<--- EDB	0.510	9.020	0.070	0.00	Supported

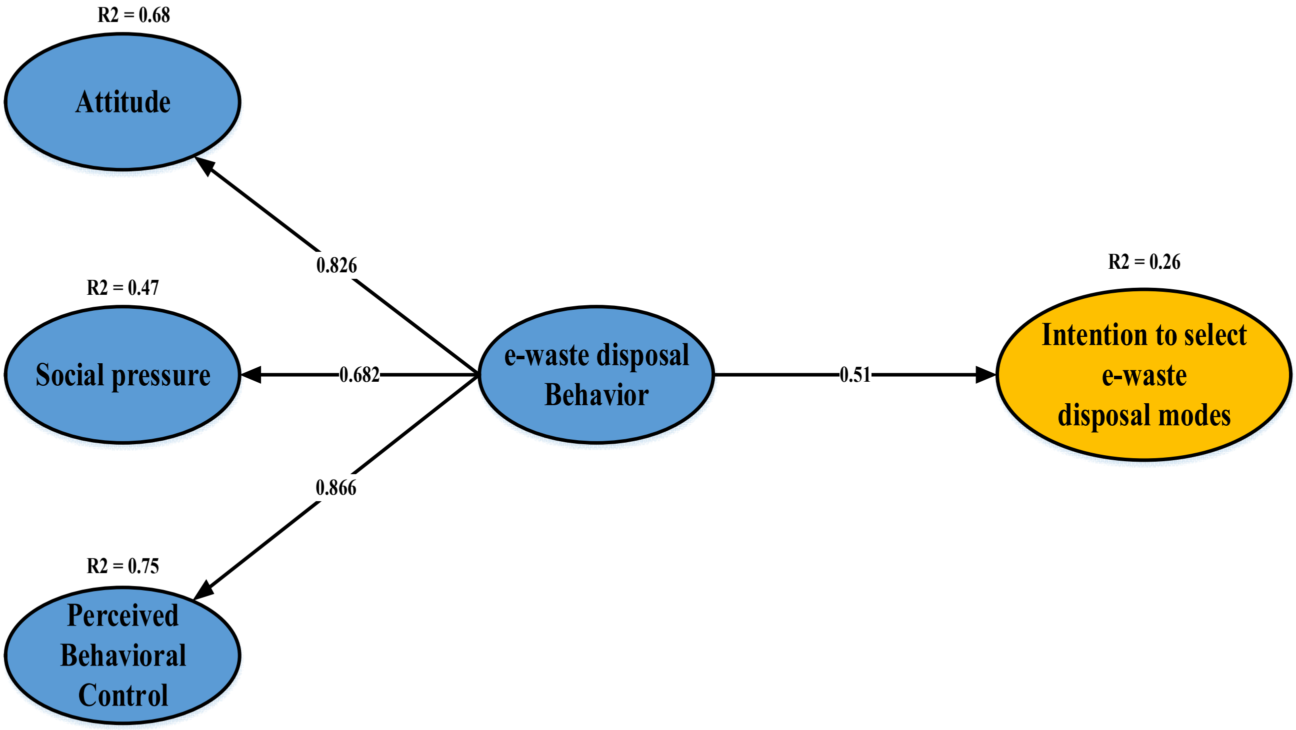


Figure 6.4:Result of the proposed model

6.4.3 Mediation analysis

The study assessed the mediating role of factors affecting consumer decisions in the relationship between e-waste disposal behaviour and e-waste collection modes. The results revealed that an indirect effect of e-waste disposal behaviour on e-waste collection modes was positive and significant (β = 0.082, t = 6.70, p = .002), supporting H3. Furthermore, the direct effect of e-waste disposal behaviour on e-waste collection modes in the presence of the mediator (factor affecting consumer decision) was also found significant (β = 0.441, t = 7.819 p = 0.000). Hence, factors affecting consumer decisions partially mediated the relationship between e-waste disposal behaviour on e-waste collection modes. The mediation analysis summary is presented in Table 6.4. Sobel's test statistic for a path is 3.486, with p = 0.00, which shows that the indirect effect is significant. The model was found to be appropriate for all quality measures. Model fit indices values are $\chi 2$/df: 1.742,

GFI: 0.948, AGFI: 0.932, CFI-0.983, NFI: 0.960, TLI-0.979, SRMR: .0485 and RMSEA-0.039. The overall result indicates that the square multiple correlation (R2) value was 0.30 and significantly explained the variance 30%, as shown in Figure 6.5. It means that adding a construct as a mediator improves the prediction of the model compared to the previous model.

Table 6.4: Mediation analysis summary

Relationship	Direct effect	Indirect effect	Confidence interval		p-value	Conclusion
			Lower bound	Upper bound		
EDB – CDs - INT	0.441 (0.00)	0.082	0.025	0.166	0.002	Partial mediation

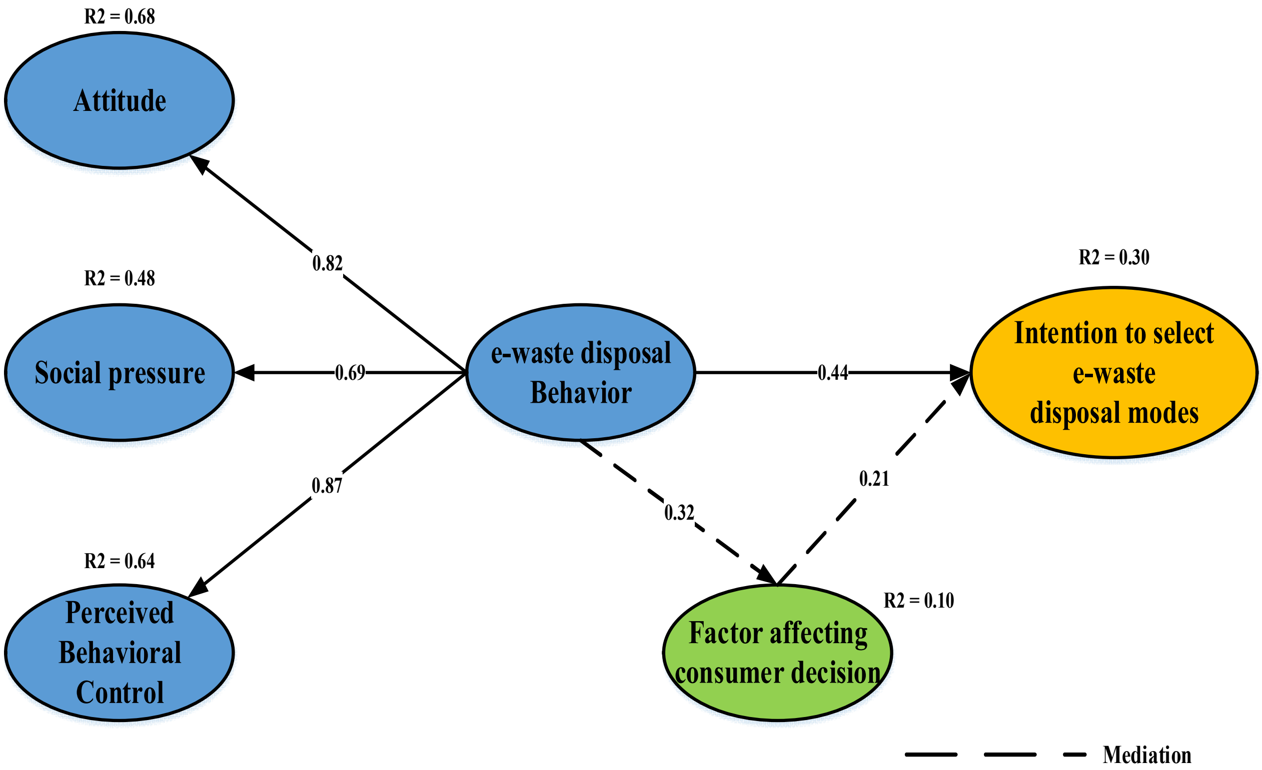


Figure 6.5:Result of the purposed model with mediation

6.5 Discussion

The motivation of this study is to understand consumer's disposal behaviour towards e-waste disposal mode. In other words, the study was conducted to examine the various psychological factors that determine the behaviour of consumers associated with the disposal of e-waste. The research emphasizes the importance of consumer behaviour toward e-waste disposal to participate in the e-waste disposal mode. However, previous studies have mainly concerned the determinants of consumer's behavioural intent of recycling e-waste without paying much attention to the important factors influencing consumer disposal behaviour in the context of e-waste disposal mode and reverse logistics. This type of research can help developing countries such as India those face problems mainly due to the lack of collection infrastructure and e-waste disposal actively undertaken by the informal sector. Therefore, the present study is a pioneering attempt to fill this research gap. For this purpose, a research hypothesis was developed focusing on consumer behaviour using the TPB framework and SEM was employed to assess the developed model.

The result suggested that hypotheses H1a, H1b, and H2c were found to be true concerning the disposal behaviour of the respondent. In other words, consumer disposal behaviour is significantly defined by attitude, SP and PBC and accounted for 68%, 48% and 87%, respectively. The findings are in line with Wang *et al.* (2018) and Park *et al.* (2020). The possible explanation is that a positive attitude is conducive to e-waste disposal behaviour and it is believed that adopting an organized disposal system would be beneficial. Similarly, among various psychological factors of disposal behaviour, social pressure contributes to respondents' behaviour. The persons have received positive responses from a society whose opinions are valuable to them. It means the social circle is essential to change the perception of disposal behaviour (Koshta *et al.*, 2022). While also, e-waste rules and regulations significantly affect individual disposal behaviour and enforce participation in disposal activities. PBC is a positive influence on the respondent's disposal behaviour. One possible explanation is that the government and stakeholders should develop a robust disposal system where it is easy for consumers to dispose of their e-waste at collection centres. Conversely, informal sectors dominate in developing countries such as India. To change the behaviour of Indian residents in the current study, stakeholders such as authorized collectors and recyclers, with the help of government officials, launched community collection drives. In which they organized an environmental awareness program and explained how to dispose of their e-waste through formal channels. It will certainly motivate the residents to adopt a sustainable practice for e-waste disposal.

The result further supports hypothesis H3, that consumer disposal behaviour has positively associated with the intention to select e-waste disposal modes. The outcomes are consistent with previous studies suggested that there is positive influence of psychological factors of disposal behaviour on intention to select disposal modes (Nduneseokwu *et al.*, 2017; Park *et al.*, 2020). Disposal modes such as take-back collection and door to door pick up services are operated by producers as they are responsible for the entire life cycle of the EEE under EPR. In the present scenario, the urban people of India recognize these disposal methods as potential due to social media and publicity campaigns. The findings also indicate that a factor influencing consumer decision-making is a mediator between consumer behaviour and selecting an e-waste disposal mode. These factors are proximity, cost transparency, incentives for future purchases and documentation & legalization influencing consumer disposal behaviour while selecting disposal mode. The outcomes are consistent with Shevchenko *et al.* (2019) and they stated that the bonus for future purchasing and legal documentation for data security is essential when selecting an e-waste disposal mode. Therefore, stakeholders should focus on these influencing factors while reviewing the disposal modes to satisfy the consumers. For this, consumers should adopt the appropriate mode as per their convenience.

6.6 Theoretical and practical implications

The theoretical implications of this study significantly corroborated with the past literature on e-waste disposal and its behaviour. Various academicians, in supply chain management, primarily focused on designing and optimizing efficient collection routes of e-waste disposal methods for a specific region. However, consumer behaviour is the key point for e-waste management, especially the collection process. It has not attracted sufficient support from the supply chain management academia. To the best of the authors' knowledge, no attempt has been made to analyse consumers' behaviour towards e-waste disposal systems in the context of selecting disposal mode. This study model and measures influencing factors of consumer's behaviour and willingness to select e-waste mode. The present study also significantly explored subjective knowledge from literature and theory to develop hypotheses using the TPB framework to improve the explanatory power. This method examines the determinants of consumer behaviour related to the e-waste disposal system. Also, this study has examined the mediating role of influence factors that affect consumer decisions such as proximity, cost transparency, incentives for future purchases and documentation and legalization. Another theoretical contribution of this study is to provide critical insight into the determinants of the disposal behaviour of the Indian EEE users and their intention towards the selection of the disposal mode. India is the third-largest producer of e-waste globally and still has minimal knowledge regarding the consumer's willingness to support e-waste collection methods for disposing of its e-waste systematically. These research findings should motivate academicians and practitioners to extend similar types of studies and add more determinants focused research on the e-waste disposal system among different geographical settings (urban and rural) to enrich the understanding of the topic.

The current study proposes major practical implications for the e-waste disposal system. The results may be helpful for policymakers, EEE manufacturers, collectors and recyclers particularly in developing countries to formulate sustainable strategies for reverse logistics in the e-waste disposal domain that can be accomplished by strengthening consumer practices. The stakeholders can better understand the influencing factors that impede the consumer decision to participate in the e-waste disposal system. The psychological factors such as attitude, SP and PBC are positively explained by consumer behaviour. Consumers are keen to dispose of their e-waste through a proper collection system in the present scenario (Alblooshi *et al.*, 2022). Indian customers do not have easy access to collection infrastructure due to the lack of convenient formal disposal channels and standard practices. Furthermore, lower compensation provided to consumers forces them to dispose of their e-waste in the informal sector. Therefore, it is essential to empower people with the necessary information on how to systematically engage in pro-environmental activities to dispose of the e-waste. Practitioners can use alternative communication such as social media, print media and the public domain to disseminate information whereas, government officials should invert on vendor development and equip them with documentation and standard practices. The same integrated plan for may also be developed the informal and formal sectors to improve the collection rate by incorporating a joint disposal system for residential. Another practical implication is that the consumers are hesitant to dispose of their e-waste due to the data security, lack of proximity, cost transparency, incentives for future purchases and documentation & legalization. It is a great opportunity for policymakers to address such issues in public policy. The results also support that recyclers and collectors must overcome the factors influencing consumer decisions. It will lead to higher collection rates and increased participation in the e-waste disposal system, improving the reverse logistic network and supporting a circular economy and sustainable society.

6.7 Sectional summary

This chapter analyses the intent of consumers towards the e-waste disposal system in the Indian context. The research mainly focuses on the post-consumption disposal behaviour, which is related to sustainability and the circular economy concept. Research is conducted to identify important consumer psychological determinants of e-waste disposal behaviour. The current study uses a TPB framework to evaluate the resident disposal behaviour towards the e-waste disposal system using the survey method. The proposed model is assessed using SEM with survey data from 491 Indian residents. The results highlight that the attitude and perceived behavioral control are important psychological constructs of disposal behaviour that significantly impact the selection of e-waste disposal modes. Consumer decisions (i.e. proximity, cost transparency, incentives for future purchases and documentation & legalization) act as mediators and significantly influence disposal behaviour and intention to select e-waste disposal mode. As consumers are of utmost importance for success of any e-waste disposal scheme, it can be suggested, based on this study, that e-waste disposal infrastructure directly influences behaviour as well as affect intention. Therefore, organizations must take the initiative to design infrastructure that facilitate the disposal modes.

CHAPTER 7 DEVELOPMENT OF E-WASTE COLLECTION SYSTEM USING VEHICLE ROUTING OPTIMIZATION

This chapter develops an intelligent e-waste collection model i.e. 'On Demand Service'. A genetic algorithm is being used to identify the number of vehicles needed whereas with an ant colony optimization algorithm being developed to optimize the shortest path to specific locations for vehicle routing.

7.1 Introduction

India has introduced various policies and amendments of policies of e-waste in 2018 setting higher levels of collection targets for stakeholders. It specifies 10% yearly incremental of collection of EEE that is generated in the market. The aim of this policy 70% collection target of WEEE can be achieve by till 2023 (CPCB, 2018). It is an ambitions target and there are various factors that can contribute toward achieving the set target of collection and improve collection rates. At one end of the spectrum it can viewed in terms of requirement of robust reverse logistics infrastructure, at other, there end it involve intensive customer engagement to change customers' attitude towards disposal behaviour of WEEE.

The stakeholders involved in e-waste collection activities generally adopt a mixed model, with pre-notified schedule for WEEE collection. The collection companies inform clients about the collection schedules. However, this depends upon the consumer's/end users behaviour. When, how and where they would like to dispose WEEE. For this, the e-waste policy implementation regulations need to be strong, designed to cover collection related issues minimising the adverse effect on eco system (Wath *et al.,* 2010). Generally, authorised collection companies provide the service and they maintain logistics facility for e-waste collection and transportation to recycling facility, where disassembly and material recovery take place under compliance with environmental standards. One major factor is deciding how many vehicles are required for e-waste collection. Improper collection schedule of vehicle or allocation of non-optimum number of vehicles lead to increase in cost as well as increase in Green House Gas (GHG) emission (Nowakowski *et al.,* 2017).

The formal collectors are authorized by the government to collect WEEE from various consumers. However, formal collectors in India face serious challenge in business sustainability owing to uncertainty in steady supply chain, limited business opportunity, absence of robust collection mechanism, high operational cost and customer attitude and indifference (Imran *et al.*, 2017). Informal sectors, taking advantage of lack of enforcement of labour regulations as well as environmental regulations thrive and poses serious challenge to the formal sector.

The estimated of e-waste production of India in 2020 is 5.2 million tons according to a joint study by ASSOCHAM and EY. A previous study also noted that the formal recyclers are handling a proportion of around 5% of the overall e-waste recycled in India, while the remaining proportion is being recycled by informal recyclers (Khattar *et al.*, 2007). Around 70% of the total e-waste in India is generated in households. According to CPCB, there are total 312 authorized e-waste dismantlers/recyclers with a total capacity of 0.78208 million tons per year. Rajasthan has 26 formal recycling units with total capacity 90769 metric tons per annum, out of which six recycler units are located in Jaipur city with a capacity of 27405 MT (CPCB, 2018).

India government has made the EEE producers are solely responsible for collection and channelization of e-waste after their 'EoL' under EPR (Nnorom and Osibanjo, 2008). The producers either can setup their own collection center with suitable take back system, or the producers can tie-up with third party called PRO for EoL e-waste collection.

Collection of E-waste can be classified into stationary or mobile (Nowakowski *et al.,* 2017). In stationary mode of collection, the collection centers can be setup at appropriate places in residential areas or supermarkets. Containers can also be placed at different places for collection of WEEE. When the containers are filled, they shifted to a nearby collection center. These collection centers can be setup by individual producers (Król *et al.*, 2016).

In case of mobile collection, container vehicles can be used to pick-up the e-waste from households or business center and gather them at collection centers. The pick-up can be fixed scheduled or dynamic (Nowakowski *et al.,* 2017). The advantage of this method over stationary collection is that pick-up takes place at the premises of user and if possible, at their convenient time. The collection centers may use Geographic Information Systems (GIS) and optimization models to maximize amount of e-waste collection from a certain location in a time frame.

The objective of this study is to construct an intelligent and responsive vehicle routing model collection 'on demand service'. This model can be beneficial for formal collection sector for determination of waste collection rout for multiple vehicle on daily basis. In order to schedule a pick up facility for waste disposal, customers have multiple choice to call the collectors through a mobile application, call or through website mentioning their location, time for pickup, amount of waste and type of waste. The model work on an average delay and maximum delay of waste collection and Capacitated Vehicle Routing Problem (CVRP). The hybrid evolutionary genetic algorithm is combination of Simple Genetic Algorithm (SGA) and Ant Colony Optimization (ACO) is used to optimize rout selection and length for multiple vehicles. The model can be help in reducing collection cost and emission while achieving the collection targets.

7.2 Research problem

This study is aimed at creating route optimization models for collection centers, such that maximum amount e-waste is collected by employing minimum time and resources. The authorized e-waste collection company name X, situated in Vishwakarma Industrial Area (VKI), Jaipur, Rajasthan. The study map area is presented in Fig 4. The company is authorized as PRO and collected from bulk consumers as well households. The company tie up with various producers like Havel's, Sony Erikson, Acer, LG, Samsung, Dell and many more. The company wants to implement an 'on demand service' where the customers can schedule for discarded EEE collection by using online platform. The company is using five vehicles for collection operation. For a given data of location or GIS, amount of load and average speed of vehicle, minimize the travelling distance while having constraints on capacity of vehicle. The results should be the order in which the customers are to be serviced and optimum number of vehicles required for the objective. The route for travelling between any two locations is optimized based on the shortest path algorithm which helps in reducing the fuel consumption.

7.3 Material and methods

A CVRP model is applied to solve the e-waste collection rout optimization problem. The detail of CVRP model and hybrid SGA-ACO algorithm are discussed here.

7.3.1 CVRP model

The concept of vehicle routing problem is to serve a group of customers, each with a certain demand level and to find the least total travel distant routes from starting to returning at depot (Fidanova *et al.*, 2014). When capacity of the vehicle is considered, it becomes the CVRP. The objectives of the CVRP model is considered to minimize the distance travelled by vehicles to service all the customers and to determined number of vehicles required for the corresponding minimum distance. Assumption made for modelling are:

- Vehicle is always empty when it leaves the depot.
- The waste from customer is always acquired completely. It is never acquired partially even if the current load in vehicle has not exceed the maximum capacity.
- All the customers are always serviced, and time required for servicing and unloading is not considered.
- Each customer is always serviced exactly once using only one vehicle.
- Volume of waste at any instance in the vehicle does not exceed maximum capacity of the vehicle.
- Vehicles always start and end at the depot.

A graphical representation of problem is shown as in Figure 7.1. Where all the customers and the main depot are represented as nodes. Each node is connected to every other node by an edge. Blue nodes represent the customers to be serviced and black node represents the main depot. Route for a vehicle consists of a collection of edges which start and end with the main depot.

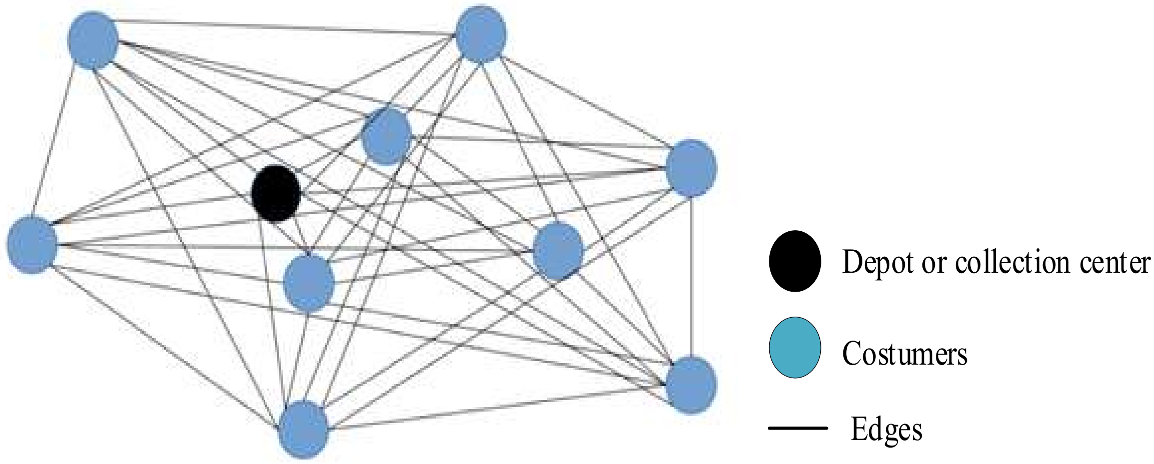


Figure 7.1: Representation of the location of customers, depot and edges

Consider a graph $G = (N, E)$ where N is the set of customers and depot and E is the set of edges connecting the nodes.

- $N = \{i \mid i \in \mathbb{Z} \text{ and } 0 \leq i \leq n\}$ represents that there are n customers. First element i.e. $\{0\}$ represents the depot.
- $D = \{ d_i \mid \forall\, i,\ d_i \sim \mathcal{N}(\mu, \sigma^2) \}$ represents the demand associated with each customer. Values of demand are taken from a normal distribution.
- $E = \{ (i,j) \mid \forall\, (i,j) \subseteq N \times N \text{ and } i \neq j \text{ and } (i,j) \text{ are unordered} \}$ represents the set of edges, where each edge is an unordered pair of vertices.
- $C = \{ C_{ij} \mid \forall (i,j) \in E\}$ represents the set of cost associated with each edge which is taken as the map distance.
- $V = \{ k \mid k \in \mathbb{Z} \text{ and } 0 \leq k \leq v \}$ represents that v vehicles are used for servicing.

- Each vehicle is considered to have a capacity of b.

A decision variable x_{ijk} is defined as follows,

$$x_{ijk} = \begin{cases} 1 & \text{if vehicle } k \text{ travels from customer } i \text{ to customer } j \\ 0 & \text{otherwise} \end{cases}$$

Then, the following equation represents objective function for optimization.

$$Z = min \sum_{i=0}^{n} \sum_{j=0, j \neq i}^{n} \sum_{k=1}^{v} C_{ij} x_{ijk} \quad (7.1)$$

The equation for constraints are given as,

- Every customer is visited by only one vehicle only once.

$$\sum_{k=1}^{v} \sum_{j=0, j \neq i}^{n} x_{ijk} = 1 \qquad \forall\, i \in N \quad (7.2)$$

$$\sum_{k=1}^{v} \sum_{i=0, i \neq j}^{n} x_{ijk} = 1 \qquad \forall\, j \in N \quad (7.3)$$

- Volume of waste in each vehicle at given instance should not exceed the maximum capacity of the vehicle.

$$\sum_{i=0}^{n} d_i \sum_{j=0, j \neq i}^{n} x_{ijk} \leq b \qquad \forall\, k \in V \quad (7.4)$$

- All vehicles always start and end at the depot.

$$\sum_{j=1}^{n} \sum_{k=1}^{k} x_{0jk} = 1 \quad (7.5)$$

$$\sum_{i=1}^{n} \sum_{k=1}^{k} x_{i0k} = 1 \quad (7.6)$$

- Decision variable can only be 0 or 1.

$$x_{ijk} \in \{1, 0\} \quad (7.7)$$

7.3.2 Hybrid SGA-ACO algorithm

The proposed algorithm is based on evolutionary theorem and is a hybrid metaheuristic that combined SGA and ACO method. SGA is a population based method where initial population is randomly generated. After that, crossover and mutation operations generates new population. ACO is a stochastic optimization method that imitates the social behaviour of real ant colonies, which try to find shortest route to feeding sources and back. Real ants lay down some quantities of pheromone (chemical substance) marking the path that that keep accumulating as the next ant follow and hints towards the most preferred path. A flow chart of hybrid algorithm is presented in Figure 7.2.

7.3.2.1 SGA algorithm

Conventional SGA is employed to calculate the set of parameters of ACO. Steps of SGA as presented in Fig. 3 starts from creation of an initial population of n individuals and then evaluation of the fitness of all n individuals and loop to check if termination criteria are reached. The function of the crossover operator is to create new set children individuals by applying a mathematical function over two individuals of the parent generation. It performs local search in the vicinity of the two individuals by slightly modifying them. It also helps the algorithm to converge towards optimum value. Crossover is not initiated for every pair in generation, but it is controlled by user through a variable called crossover probability which is generally set a high value in the range 0.6-0.8 so that large number of cross overs keep happening but not 1 because then there is more chance of converge to a local optima.

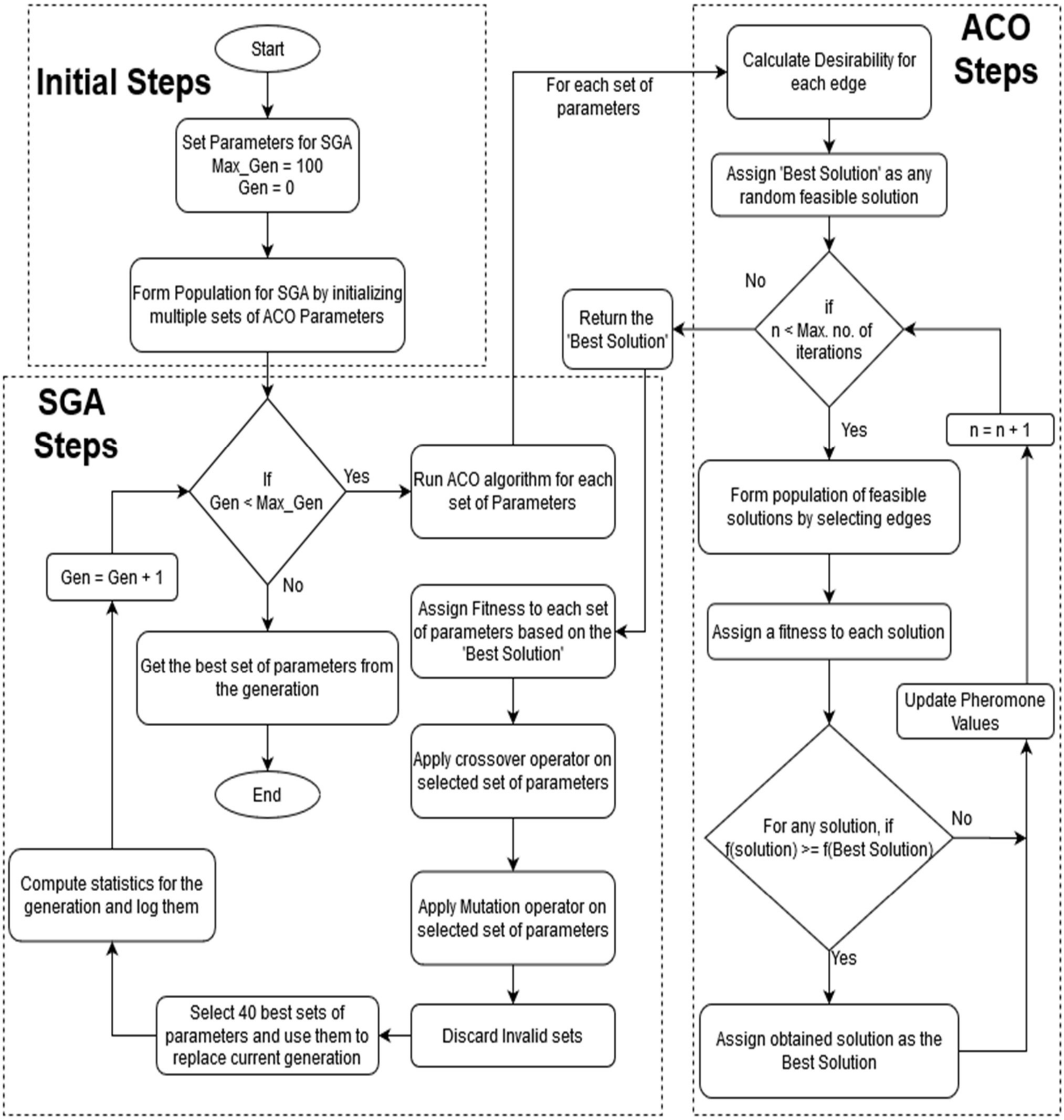


Figure 7.2: Flow chart of hybrid algorithm for e-waste collection optimization model

The function used here was proposed by Deb and Agrawal in 1994. Steps followed are:

- Generate a random number r $(0\ to\ 1)$
- Find the value of α' such that

$$\int_0^{\alpha'} C(\alpha)d\alpha = r \qquad if\ \ r\ <\ 0.5 \tag{7.8}$$

$$\int_0^{\alpha'} E(\alpha)d\alpha = r - 0.5 \qquad if\ \ r\ >\ 0.5 \tag{7.9}$$

Where,

$C(\alpha) = 0.5(q + 1)^{\alpha}$

$E(\alpha) = 0.5(q + 1)\frac{1}{\alpha^{(q+2)}}$ and q is a positive real exponent.

We get the two children individuals Ch_1 and Ch_2 as,

$$Ch_{1,2} = 0.5[(Pr_1 + Pr_2) \pm \alpha(Pr_1 - Pr_2)] \tag{7.10}$$

The purpose of mutation operator is to accomplish a global search to avoid premature loss of genetic material and to maintain diversity in population. It helps in exploring maximum of the search space and finding the global optimum. Mutation is again, a mathematical function implemented on an individual. Higher mutation probability results in a greater number of mutations, many of which may be infeasible solutions and may digress the search algorithm. Generally, it is kept low in the range 0.2-0.4. The mathematical function implemented for this project is Polynomial Mutation. Explained following:

- Generate a random number r $(0\ to\ 1)$
- Calculate the perturbation factor as,

$$\acute{\delta} = \begin{cases} (2r)^{\left(\frac{1}{q+1}\right)} - 1 & if\ r<0.5 \\ 1 - [2(1-r)]^{\left(\frac{1}{q+1}\right)} & if\ r>0.5 \end{cases} \tag{7.11}$$

- Mutated solution is given as,

$$Pr_{mutated} = Pr_{original} + (\acute{\delta} \times \delta_{max}) \quad (7.12)$$

Where, δ_{max} user defined maximum perturbation.

Penalty: Penalty is added only for the first five parameters when the values are out of the desired range. Penalty is calculated as the square of the difference with respect to upper or lower limit of the range.

$$P_i = (A_i - 0)^2 \quad \text{if } A_i < 0 \quad (7.13)$$

$$P_i = (A_i - 1)^2 \quad \text{if } A_i > 1 \quad (7.14)$$

Where, P_i is the value of penalty and A_i is the value of i^{th} parameter and $\in$ [1,5].

The final value of penalty is then calculated as,

$$Penalty = PenConst \times P_i \quad (7.15)$$

Where, *PenConst* is very large value of the order of $\sim 10^6$.

Fitness function of SGA is presented as following equation

$$F(parameters) = \frac{L_0}{L + Penalty} \quad (7.16)$$

Here, L_0 = Minimum distance required to cover all the customers

L = Minimum distance achieved by ACO for given set of parameters.

7.3.2.2 ACO algorithm

In application of Ant colony optimization, individual represents a set of route travelled by vehicles, such that all the customers are serviced and population is formed by a set of individuals. An edge has three attributes, other than the start node and end node.

- Cost (C_{ij}): Shortest map distance between the nodes.

- Pheromone (p_{ij}): Biologically, pheromones are chemicals which ants secrete to mark path to a given location. Shorter path or a frequently used path has a higher density of pheromones and the frequency of the path is considered, in the current study.
- Desirability (D_{ij}): Desirability of an edge is a combination of pheromones and cost as presented in following equation.

$D_{ij} = p_{ij}^{\delta}\left(\frac{1}{C_{ij}}\right)^{\epsilon}$ Here, δ and ϵ are tuning parameters. (7.17)

It is the value which represents how good an edge is, i.e. if an edge has higher desirability, then it will be selected more often in the best solution. Higher value of δ will tend to increase desirability as it increases the impact of pheromone value and higher value of ϵ tends to decrease desirability as it increases the impact of edge cost. The parameters of ACO are as follow:

- Initial value of pheromones (γ): The initial pheromone value of all edges is equal. Thus, for the first iteration, the selection of edge into the best solution purely depends on its cost.
- Learning rate α ($0 \le \alpha \le 1$): Whenever any edge is present in the best individual selected among the population, its pheromone value is increased as presented in following equation.

$$p'_{ij} = (1 - \alpha)p_{ij} + \alpha f(best\ individual) \tag{7.18}$$

Here, p'_{ij} is the final value of pheromone, p_{ij} is the initial value of pheromone and

$f(bestIndividual)$ is a function giving the fitness value of best individual solution. Based on distance covered by the vehicle in order to complete all scheduled pick-ups. Here, fitness is the ratio of actual distance covered by vehicle for a given solution and minimum distances between any two points including the central depot, such that all the points are covered.

$$f(individual) = \frac{L_0}{L} \tag{7.19}$$

Thus, an individual fitness value of 1 is the best individual and worst individual will have a fitness value of 0. α is the weight given to the ACO fitness value while updating the pheromone value of edges. Higher value of α (0.7 to 1) leads to selection of same edges in every ACO iteration which further increases its pheromone value and might result in a local optimum. If $\alpha = 0$, then ACO algorithm turns into a random search algorithm.

- Evaporation Rate β $(0 \leq \beta \leq 1)$: To avoid the algorithm getting stuck in local optima, evaporation rate decreases the pheromone value of all edges. The values of all the pheromones is decreased as follow Equation (7.20).

$$p'_{ij} = (1 - \beta)p_{ij} + \beta\gamma \tag{7.20}$$

Higher value of β (0.8 to 1) leads selection of different edges in every ACO iteration which results in further exploration of solution space looking for a global optimum. If $\beta = 1$, then pheromone value of all edges reduces to γ.

- Desirability tuning parameters δ, ϵ: The tuning parameter δ is the weight of pheromone value and ϵ is the weight of edge cost in calculating desirability.
- Exploit Allowance (0 to 1): This number helps decides which method will be frequently used in edge selection. If the value is higher (0.7 to 1), then tournament selection will have higher usage compared to selection based on desirability.
- Population size limit: Maximum number of individuals in any generation of ACO.
- No. of iterations: Number of iterations to perform for each vehicle.

7.4 Results and discussions

7.4.1 Getting the map and its conversion to a graph

The proposed model is applied on an area named VKI. Area is taken within 10 Km radius of center of VKI. The map and its data for roads and intersections was obtained through QGIS platform “OpenStreetMap”. The map is converted into a graph data structure using a library named “osmnx” where the nodes corresponded to intersections or terminals and the edges corresponded to the roads. This map is stored and accessed whenever shortest path and its length is to be calculated, as shown in Figure 7.3.

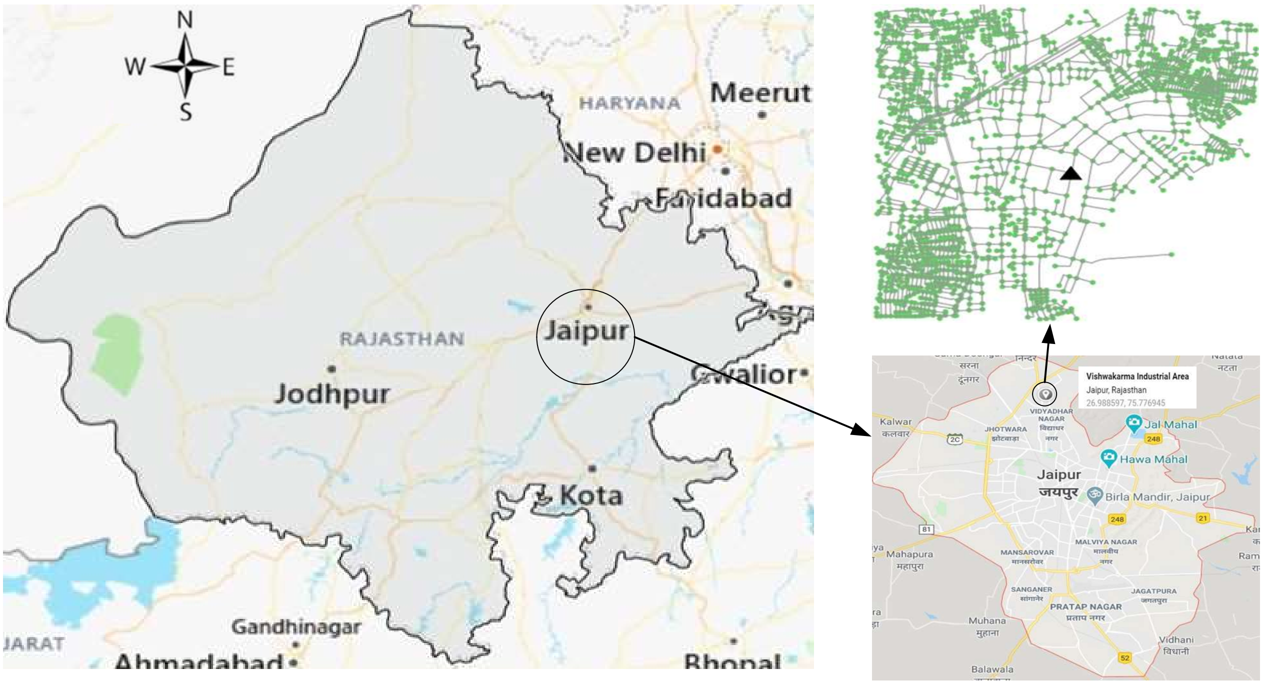


Figure 7.3: Location of X collection center (Black dots represent the collection depot)

7.4.2 Digitalization of demand data

Black colored dot represents the collection depot which is fixed. Nodes are customer site, selected randomly from anywhere on the map except the location of depot. Random number selection is based on normal distribution. Every call is associated with a location and demand. Location in terms of latitude and longitude and demand in terms of volume of discarded e-waste to be returned. The demand is also a normal distribution (data). Location of the depot is fixed. The nodes which are not reachable (isolated nodes) from the main depot are removed prior to implementation. Table 7.1 provides the parameters used for generating number of data calls. 'μ' gives the mean number of calls and 'σ' is the standard deviation. For example, in first case the number of calls will be generated taking 70 as the mean and 3 as the standard deviation.

Table 7.1: Normal distribution parameters

Parameters	**μ**	**σ**
No. of Calls	70	3
	80	
	90	
	100	
	110	
Demand (In units)	6	1

Table 7.2 gives examples of the demand data. For the same case of 70 calls, 70 random locations are selected from the map and each of them is assigned a demand. Table II represents the final form of data on which the optimization algorithm works.

Table 7.2: Demand data of calls (Example)

Customer Id.	**Latitude**	**Longitude**	**Demand (In units)**
1	26.98086	75.77371	4
2	27.00195	75.80179	6
3	26.98947	75.7758	7
4	26.9838	75.76662	6

When a vehicle reaches its limit, it has to return to the depot and unload before attending further scheduled customers. The values of the optimal parameters used in ACO to solve for 110 calls and 5 vehicles listed in Table 7.3. The optimal value of SGA algorithm is presented in Table 7.4.

Table 7.3: Value of ACO parameters for N110-V5

Parameters	**Values**
Learning Rate (α)	0.2316
Evaporation Rate (β)	0.3179
Tuning Parameter corresponding to Pheromones(δ)	0.0806
Tuning Parameter corresponding to cost (ε)	0.1743
Initial Value of Pheromones (γ)	0.2879
Exploit Allowance	0.8413
Population Size Limit	20
No. of iterations for a given vehicle	10

Table 7.4: Parameters for SGA

Parameters	Value
Number of Generations	100
Population Size	40
Crossover Probability	0.8
Mutation Probability	0.2
Exponent in Crossover and Mutation (q)	5
Maximum Perturbation Factor (δ max)	0.1
Penalty Coefficients	10^6

The algorithm was tested on five different number of calls for five vehicles. Since ACO and SGA both are non-deterministic algorithms and may give different results for different runs for the same input data. But repeatability was ensured by running the algorithm at least 10 times.

The fitness values are plotted against the number of calls for different number of vehicles. The value of fitness function clearly decreases with the increase in number of calls. This decrease in fitness value does not imply that the algorithm is performing poorly. It decreases due to the simple fact that as the number of calls increase, the travelling distance also increases and by definition, fitness value decreases. The graph helps us to choose optimum number of vehicles by running the algorithm for different quantity of vehicles, shown in Figure 7.4. For example, in the case of 70 calls, optimum number of vehicles could be 1,2 or 3. From the fitness values given in Table 7.5, we can confirm that if we use 2 vehicles, then we get the optimum solution. Similarly, for 110 calls, 4 vehicles clearly perform better than any other number of vehicles. Therefore, to assess the optimum number of vehicle, a range in discrete numbers above and below that is found from simulation as in Table 7.6, needs to be considered. The optimized shortest route for a case of 4 vehicles for 110 calls are presented in Figure 7.5.

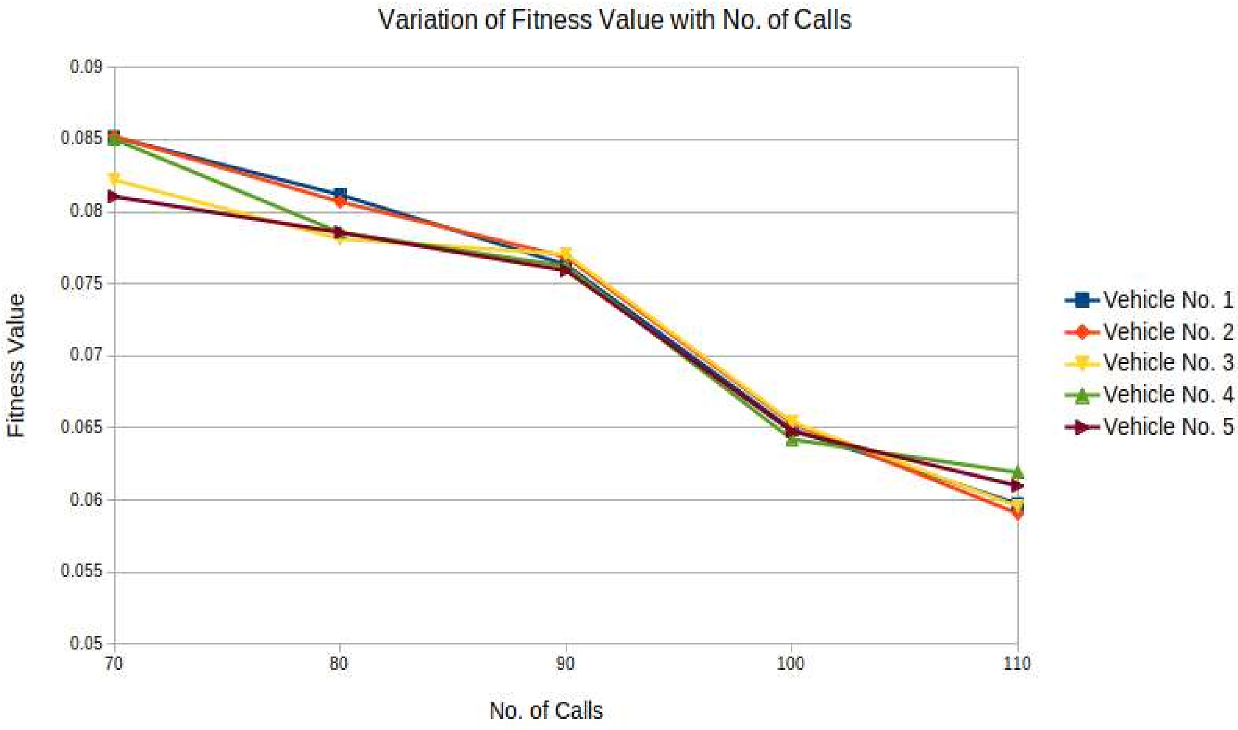


Figure 7.4: Variation of fitness values with no. of calls for different vehicles

Table 7.5: Maximum fitness value for a given vehicle and no. of calls

No. of Vehicles	70	80	90	100	110
1	0.085185973	0.081174706	0.076325022	0.064890886	0.0597343720
2	0.085211556	0.080684069	0.076858736	0.065311628	0.0590690140
3	0.082196168	0.078117553	0.077048555	0.065410016	0.0595604344
4	0.085027935	0.078547024	0.076222739	0.064208544	0.0619178430
5	0.081049459	0.078561651	0.075918392	0.064762891	0.0609841660

Table 7.6: Total distance travelled by all the vehicles in servicing customers (in Km)

No. of Vehicles Used	**No. of Calls**				
	70	**80**	**90**	**100**	**110**
	Distance travel in KM				
1	119.507	125.139	134.402	159.057	172.878
2	117.637	131.786	134.221	158.524	177.05
3	126.542	133.875	132.112	157.368	172.909
4	126.152	133.718	136.577	162.197	168.076
5	129.446	131.872	146.461	160.381	169.568
Optimal no. of vehicles requires	**2**	**2**	**3**	**3**	**4**

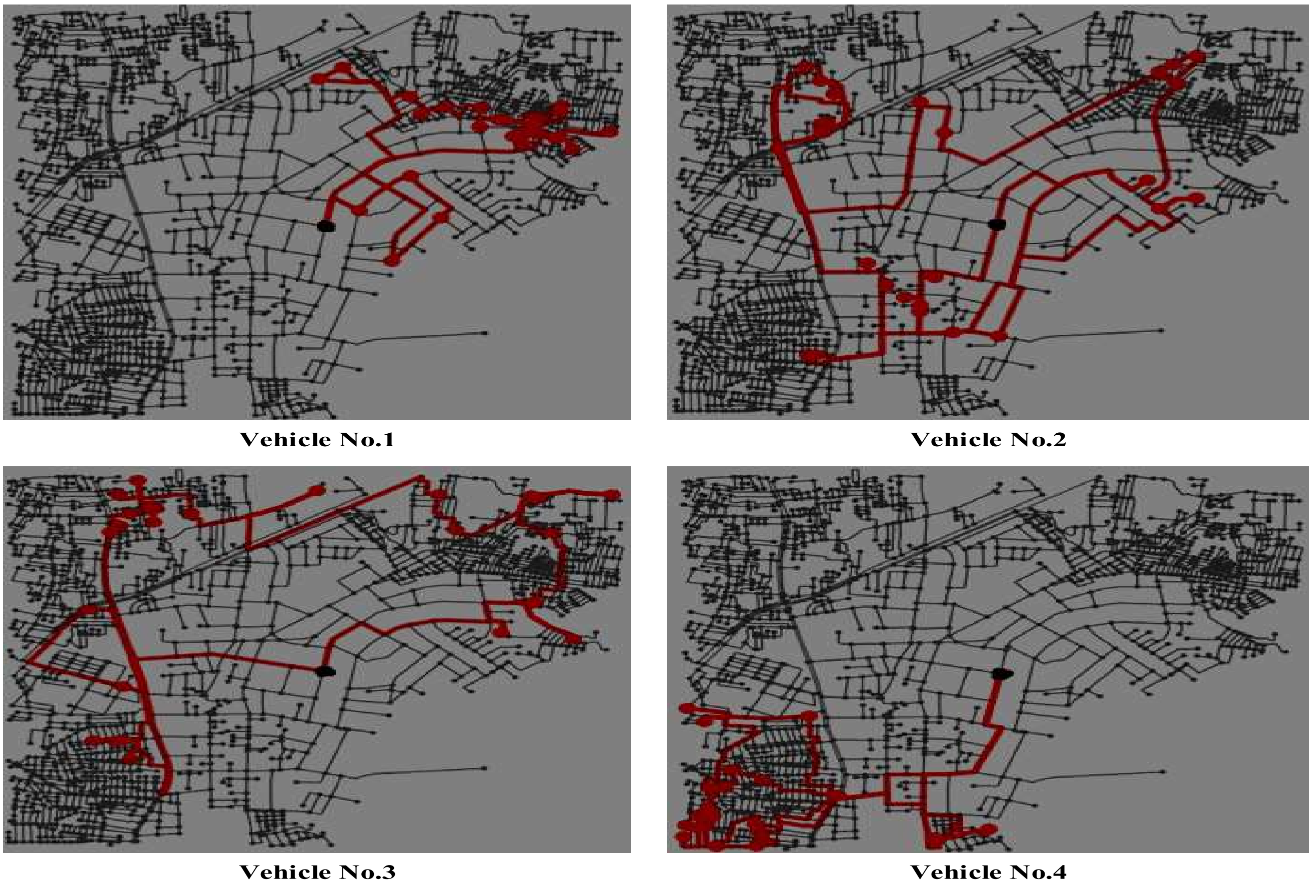


Figure 7.5: Optimized routes for vehicles

7.5 Sectional summary

This chapter presents a model for dynamic scheduling vehicle route for on-demand WEEE collection based on some assumptions, for a real location. This type of model can provide better service identifying shortest path based on number of calls and demand per call. The salient points are summarized as follows:

- It also leads to increased productivity and reduced fuel consumption as well as reduced GHG emission.
- The algorithm is validated using a case study in the city of Jaipur, India and is expected to scale with the growing size of area.
- The obtained results show that the model returns optimal routes for collection and also suggests the optimal number of vehicles required for given calls and their locations accounting for the capacity of vehicles and the workload on each vehicle.
- The proposed model is an efficient and hybrid algorithm, flexible and can be applied for any settlement area representable in a digital map.

CHAPTER 8 THESIS CONCLUSIONS AND CONTRIBUTIONS

E-waste management is a growing concern in developing countries such as India, and strict policies are required to be in place to ensure sustainable e-waste management. Stakeholders such as collectors and recyclers, however, face uncertainties regarding e-waste collection from consumers due to the various reasons. E-waste, if not treated and disposed of scientifically poses a severe environmental risk. This thesis comprehends and explains the major challenges in e-waste management including e-waste policy, collection system and consumer disposal behaviour that can act as barrier to a successful circular economy. Various challenges and opportunities are flagged in this doctoral thesis encompassing e-waste generation, reverse supply chain, circular economy concept, role of policies and participation of stakeholders. The phases and outcomes of research that are focused in this thesis are summarized in the chapter.

Chapter 2 employed bibliographic analysis tool for literature review to e-waste management research, including e-waste policy, disposal practices and collection systems. The relevant search string in the Scopus database is provided and total 678 articles are found, out of which 472 articles belongs to e-waste collection system, 104 were on e-waste policy and 102 articles from disposal behavior. It examined the dynamic development of related research during 1998-2022 (August 2022) to facilitate an overall measurement of the current status of e-waste research. The results from bibliography showed that an increasing number of research outcome are reported in standard journals and various hotspot keywords were also identified. Another clear outcome observed is that the United States, China and India are the top three countries contributing to e-waste management studies focused on policy, disposal behaviour and collection system.

The most frequently used hotspot keywords in e-waste policy research are EPR, Waste management, Laws & regulation, Regulatory framework, Informal recycling and Circular economy. While the frequently used hotspot keywords in consumer e-waste disposal research are Theory of planned behaviour, various statistical analysis methods and Structural equation modelling. The important keywords in e-waste collection research are Reverse logistic, Reuse, Material recovery, Urban mining, Informal collection, Material flow, Close loop supply chain and Collection location. Thus, using these identified hotspot keywords, in this study, a comprehensive literature review is achieved.

The conclusion derived from literature survey able summarized in terms of the review statements which clearly identifies the limited focus on e-waste management issues in developing nations. Further, issues relating to e-waste policy are reviewed from time to time and prominent factors are identified that contributed to e-waste policy development. Efficient e-waste collection system is also necessary to provide a better sustainable business model. For this it is deemed necessary to identify and evaluate the various sustainable e-waste collection methods for the specific regions. Match of disposal system of e-waste, with consumer intentions and likings are necessary for sustainable e-waste management. Understanding of current habits and identifying the relevant vulnerabilities of the e-waste disposal practices is found necessary also importance of targeted awareness campaigns and policies and schemes to encourage scientific disposal are required.

Chapter 3 explained the e-waste policy of India and identified important CSFs while reviewing the e-waste policy. This research explored twenty-three CSFs with the help of literature review and expert's opinion. A Fuzzy-DEMATEL method is applied to develop the interrelation among the CSFs and to examine the degree of prominence of the CSFs and categorisation into a cause group and an effect group. The research reveals that Technology involvement (K2) and Green practice (K1) are that factors have the highest importance among CSFs, implying that sustainable e-waste management practices require more responsiveness. So, the policymakers may give more attention to the proponents of research & development in e-waste handling. The stakeholders need to invest in these two areas for improving their existing methods. Moreover, awareness about the circular economy among stakeholders is an essential factor for sustainable economic benefit. Further findings are that the legislation & regulation CSFs fall under the cause group and are the most vital driver for designing of e-waste collection policy.

Chapter 4 emphasizes upon identification and evaluation of sustainable collection methods for urban and rural areas. Based on theoretical analysis and discussions with decision makers, four main attributes and thirteen sub-attributes were identified for sustainable e-waste collection under complex and challenging conditions within the local variables in the western region of India. These are reflected in the key features adopted: social awareness, economic sustainability, environmental impact and potential risks. FAHP is used to build a pairwise fuzzy comparison matrix and to determine the relative weight of the attributes as well as sub-attributes whereas FVIKOR is employed to rank the alternatives against the weighted attributes obtained from FAHP. The study shows that the take-back and retail store based collection system are better suited for the urban region while retail store and curbside collection are found most suitable for the rural region. The proposed evaluation method will enable a comprehensive overall evaluation of an e-waste collection method in the explicit situation by stakeholders.

The outcomes of the current study can provide a guideline for establishing the appropriate e-waste collection method(s) in different parts of the country as well as allocations for future development. The Government is expected to take steps for operationalizing the right e-waste collection system(s) in right customer segments for that maximization of volume of e-waste collection from the users both rural and urban and the practices will lead towards sustainability.

Chapter 5 presented an empirical assessment of the e-waste disposal behaviour of consumers living in India's urban, semi-urban and rural areas. It analyses the various aspects of e-waste generation, including consumption quantity, length of ownership, reason for replacement, reason for not disposing e-waste, the status of policy awareness and preference for e-waste disposal methods. A survey questionnaire was also developed to study these dimensions, and primary data were collected to elucidate e-waste flows from individuals and households in India. As per the survey outcomes, the average individual and household in India currently own 6 EEE as individuals and 4 EEE as households respectively, within average per capita income level of ₹5 lakhs to ₹25 lakhs ($6289 to $31295). Interestingly, many respondents informed that they attempted to replace an EEE when the same became non-functional or not repairable, however, the reason for not disposing off the same is that majority had no idea how to and where to dispose. Therefore, they gave it away to others or stored it. This is perceived to be a prominent reason why the informal sector thrives at the cost of the formal sector.

Overall, this study demonstrates that not only the education and awareness about e-waste is important, but also the implementation plan of the e-waste disposal system at the upstream level is essential for e-waste management. The policymakers need to work with the stakeholders and NGOs to identify the causes of particular e-waste disposal behaviour and establish a visible and robust e-waste collection system or plan acceptable to the general public. It is suggested that a robust collection system of region-wise (urban, semi-urban, rural) should be focused to have a targeted improvement in the e-waste collection infrastructure. A social campaign for e-waste disposal is the need of the hour, and every stakeholder should take responsibility for creating a social movement to enhance customer awareness at the domestic and institutional levels. Stakeholders should organize community collection campaigns to improve e-waste disposal habits and awareness levels. For e-waste management, there is a need to develop a common infrastructure for collection systems and augment the facility to meet the requirements of the EPR system. Stakeholders in the e-waste value chain need to adopt various sustainable collection methods and bring them to the consumers, which should provide an impetus to promote awareness. However, the main competitor of formal collectors is the informal sector, which at present has the advantage of greater reach in semi-urban and rural areas. There is a need to develop a roadmap for integrating the informal sector into the formal sector with the help of NGOs with an aim to ensure improvement in the e-waste collection rate to match the collection target that is defined in the e-waste policy. This will contribute to the conservation of natural resources and improve environmental sustainability, as well as the development of closed-loop supply chain leading to the circular economy.

Chapter 6 analyses the consumer behaviour intended towards widely accepted e-waste disposal system in Indian context. The research mainly focuses on the post-consumption disposal behaviour, which is related to sustainability and the circular economy concept. Research is conducted to identify important consumer psychological determinants of e-waste disposal behaviour. The current study uses a TPB framework to evaluate the consumer disposal behaviour towards the e-waste disposal system using the SEM method. The results highlight that the attitude and the perceived behavioral control are important psychological constructs towards disposal behaviour and that same significantly impact the selection of e-waste disposal modes. Consumer decisions (i.e. proximity, cost transparency, incentives for future purchases and documentation & legalization) act as mediators and significantly influence disposal behaviour and intention to select a particular e-waste disposal mode. As consumers are of utmost importance for success of any e-waste disposal scheme, it can be suggested, based on this study, that e-waste disposal infrastructure directly influences behaviour as well as affect the intention. Therefore, organizations must take the initiative to design infrastructure that facilitate and encourage the disposal modes.

Chapter 7 presented a model of WEEE collection on demand service on daily basis, where collectors have to pick up the discarded EEE from resident's source. It focuses on providing better service on schedule, identify shortest route path based on number of calls and reduced fuel consumption as well as GHG emission for sustainability. An algorithm is constructed which can assist the WEEE collector to schedule the collection, decide upon optimal number of vehicles required for collection and also provides the optimal route vehicles should follow to minimize travel cost. End users can place an order for a pickup using any communication channel, thus not needing any extra efforts for waste disposal and this also helps in reducing the waste going to un-organized sector. The algorithm is validated using a case study in the city of Jaipur, India and is expected to be scalable with the growing size of area. The obtained results show that the model returns optimal routes for collection and also suggests the optimal number of vehicles required for the given set of calls and their locations accounting for the capacity of vehicles and the workload on each vehicle.

Specific Research Contributions

- The literature was scientifically reviewed and explored focusing on e-waste policy, collection system and e-waste disposal behaviour. The deliberated research impacts the development of e-waste management issues of developing countries like India.
- A hierarchical structured is developed to evaluate the e-waste collection policy related to CSFs.
- Evaluated sustainable e-waste collection methods of urban and rural region of India, based on an empirical study of 491 Indian households.
- The above study analysed the various aspects of EEE cycle, including consumption quantity, length of ownership, reason for replacement, reason for not disposing e-waste, the status of policy awareness and preference of e-waste disposal methods.
- The study also describes that not only the education and awareness about e-waste is lacking, but also the implementation plan of the e-waste disposal system at the upstream level require improvement.
- This study models and measures the influencing factors of consumer behaviour and preference towards e-waste disposal mode. It also explores subjective knowledge from literature and theory to develop hypotheses using the TPB framework to improve the explanatory power.
- The study develops a SEM model and investigates to predict the consumer's disposal behaviour towards e-waste disposal modes with mediation effect of consumer's decisions.

- This thesis presents a case study on development of an intelligent collection system with GA based vehicle routing for reduction of GHG emission.

Limitations and Future Scope

This study points out a few important limitations in existing and reported research, which can be viewed as a future scope. The present study is based on a limited expert's input that are also subjective in nature. An alternative technique of ISM-MICMAC be utilised to develop hierarchical relations between factors. Further, the authors also recommend empirical analysis, i.e. structural equation modelling that can be employed to conduct quantitative evaluation from a large sample to validate interrelation among CSFs. This study is conducted in the western part of India. The results of similar study may differ from others that are conducted at a differ region of India and in a different country. One of the limitations of this study is the presence of local variables which are diverse for a large country such as India. Therefore, a global prescription of e-waste collection methods may not be appropriate for the whole country. The DM's conclusion in this study is obtained for the western part of the country, specifically northern Rajasthan. Further, the study can be extended to other parts of India and other MADM methods can also be applied to obtain different perspectives. The present study provides valuable information on the consumption and disposal pattern among consumers in various sectors in India, certain limitations are present in the study: the observations regarding the use of EEE are based on a limited sample size, with a minimum household income level of ₹5 lakhs. Future data analysts should use a larger sample size to capture the true EEE disposal status in India. The ownership of EEEs will increase with time, and so is e-waste generation, therefore, such a study should be conducted at regular intervals. The future works may concentrate on comparative studies among different countries, which will provide a comprehensive picture of e-waste consumption and disposal patterns across countries as well as help in benchmarking.

There are some limitations of this study that can be addressed in future. The data is collected from certain individual consumers for this study having connection to educational institutional, but there are other individual groups, including farmer, business population, labour, which has minimal representation here. All of them contribute to e-waste generation in large volumes. It may be considered in further study and may also use this proposed model to investigate the disposal behaviour including those groups. The mediation effect could be changed in the different situations considered such as access to online exchange schemes and collection centres that may impact of e-waste collection. These factors may be studied to address the problem in a better way. The outcomes of this study probes country-specific behaviour and culture related to preference in disposal behaviour. As an improvement, validation process of this model can be generalized in a wider and cross-country study.

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APPENDIX A

Questionnaires of Electronics Waste Disposal Behaviour

Dear respondents,

We would like to hear from you about your current e-waste disposal habits and get some ideas about what will you do with your discarded e-waste. Please take a few minutes and fill out this anonymous survey. This work is purely for academic purpose only. Thanks!

Table (a): Respondents demographic profile

S.No.	Demographic variables		Tick mark
1.	**Age**	18-27	
		28-37	
		38-47	
		48-57	

2.	**Gender**	Male	
		Female	

3.	**Education Level**	Graduate	
		Post Graduate and above	
		Other (High school, School, Diploma)	

4.	**Annual income level**	Less than 6 lakhs	
		6 lakh - 12 lakhs	
		12 lakh - 24 lakhs	
		More than 24 lakh	

5.	**Profession**	Student	
		Govt. employee	
		Private employee	
		Entrepreneur	

6.	**Living Area**	Urban	
		Semi-urban	
		Rural	

7.	**Family size (numbers)**	Single	
		2-4	
		5-8	
		8-12	
		Above 12	

8.	**No. of family members (age wise)**	below 18	
		18-27	
		28-37	
		38-47	
		48-57	
		Above 58	

9.	**Family income level**	Same as my personal income	
		6 lakh - 12 lakhs	
		12 lakh - 24 lakhs	
		More than 24 lakh	

10.	**Family Living Area**	Urban	
		Semi-urban	
		Rural	

Table (b): EEE quantity, reason of disposal, awareness and disposal methods

1. Specify quantity of EEEs owned by you				
EEE Items	0	1	2	≥ 2
Mobile				
Laptop				
Tablet				
Desktop				
Computer accessories				
Bluetooth speakers				
Smart watches				

2. Specify quantity of EEEs owned by your family members					
EEE Items	0	1	2	3	≥ 3

Mobile					
Laptop					
Tablet					
Desktop					
TV/Monitors					
Refrigerators					
Washing machines					
Microwaves					
Air condition					

3. How frequently you replace EEEs by you and your family members						
EEE Items		NA	≤ 1 year	1-2 year	2-3 year	≥ 3
Mobile	Individual					
	Household					
Laptop	Individual					
	Household					
Tablet	Individual					
	Household					
Desktop	Individual					
	Household					
Computer accessories	Individual					
Bluetooth speakers	Individual					
Smart watches	Individual					
TV/Monitors	Household					
Refrigerators	Household					
Washing machines	Household					
Microwaves	Household					
Air condition	Household					

4. Mention most probable cause of replacement	
The old one has become non functional	
The old one cannot be repaired	

Considering the cost of repair, it is wiser to buy a new one than repairing the old one	
The latest models have attractive and features	
Possessing the latest model will increase my status in the society	
All my colleagues/friends are buying the latest models, so do I	
Monetary gain when sell old one	
Other reasons	

5. Where did you hear about the term "e-waste"	
School/college	
From friends/relatives	
Social media	
TV	
Print media	
Public domain	
Government sponsored initiatives	
Others	

6. Mention all the options for not disposing e-waste	
I keep as I do not know how to and where to dispose	
I give away to children/relatives/domestic servants	
I keep as I have sense of belonging with them	
I leave them at the store when buying a new one	
I dispose them with mixed waste	
Other	

7. Do you know about e-waste policy	
Yes	

No	

8. How do you dispose e-waste	
Door to Door service (from kawariwalas/rag pickers)	
Door to Door service by formal collectors/recyclers/dismantlers	
Community collection drive by local Recycler/Municipalities	
Take-back collection by producers	
Exchange schemes by retail store	
Curbside drop box	
Other	

9. Rank e-waste disposal option	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
Door to Door service (from kawariwalas/rag pickers)						
Door to Door service by formal collectors/recyclers/dismantlers						
Community collection drive by local Recycler/Municipalities						
Take-back collection by producers						
Exchange schemes by retail store						
Curbside drop box						

Table (c): Rate the e-waste disposal behaviour on five point Likert scale

Attitude	1 - strongly disagree	2 - somewhat agree	3 - neutral	4 - agree	5 - strongly agree
Feel good about myself when I choose a standard e-waste disposal system					
e-waste disposal system is helpful for environmental protection					
e-waste disposal system will help to conserve natural resources					
e-waste disposal system will make living environment better					
Subjective Norms (Social pressure)					
Society (and/or government) should encourage me to participate in e-waste disposal system					
The community where I live will influence me to participate in the e-waste disposal system					
People whose opinion is valuable to me would prefer that I use the e-waste disposal system					
If I did not choose an e-waste disposal system, the government or the community should have punitive (punishable) measures					
Perceived behavioral control (PBC)					
It is not difficult for me to access an appropriate e-waste disposal system					
I would like use of IT platform such as Mobile Apps, recyclers website for e-waste disposal					
There are several e-waste disposal agencies nearby for e-waste recycling					
I think it is easier to send e-waste to e-waste disposal agencies					
Behavioural intention towards e-waste disposal modes					
I would recommend others to use the e-waste disposal system					
I would like to participate in the e-waste disposal drive in future					

If I get opportunity to use the e-waste disposal system, I will utilize it maximum					
I strongly intend to return my e-waste through e-waste disposal system					
Rate the following factors while selecting the e-waste collection mode					
Brand (organized)					
Proximity (Distance)					
Transparency in cost					
Incentives for future purchase					
Documentation and legal considerations					

APPENDIX B

Peer-Reviewed International Journal Publication

1. Singh, S., Routroy, S. and Dasgupta, M.S., 2023. Electrical and Electronic Equipment Consumption pattern and e-waste disposal behaviour of individuals and households in India. *Journal of Material Cycles and Waste Management*, pp.1-17
2. Singh, S., Dasgupta, M.S. and Routroy, S., 2022. Analysis of critical success factors to design e-waste collection policy in India: A fuzzy DEMATEL approach. *Environmental Science and Pollution Research, 29*(7), pp.10585-10604.
3. Singh, S., Dasgupta, M.S. and Routroy, S., 2022. Evaluation of sustainable e-waste collection method for urban and rural region of India. *Waste Management & Research*, *40*(5), pp.545-555.
4. Singh, S., Trivedi, B., Dasgupta, M.S. and Routroy, S., 2021. A bibliometric analysis of circular economy concept in E-waste research during the period 2008–2020. *Materials Today: Proceedings*, *46*, pp.8519-8524.

Book chapter

5. Singh, S., Tidke, M., Dasgupta, M.S. and Routroy, S., 2021. An Intelligent Solution for E-Waste Collection: Vehicle Routing Optimization. In *Operations Management and Data Analytics Modelling* (pp. 59-73). CRC Press.

Conferences

6. Shailender Singh, Mani Sankar Dasgupta, and Srikanta Routroy (2021). Disposal behavior of e-waste amongst university students: a descriptive study. *International*

Conference on Industrial Engineering and Management (ICIEM) 2021 organized by MNIT Jaipur, Rajasthan, 17th-19th December, 2021

7. Singh, S., Routroy, S. and Dasgupta, M.S., Estimation of e-waste generation in India using logistic and Gompertz models: A comparative study. 9*th International Conference on Business Analytics and Intelligence*, organized by Data Centre and Analytics Lab (DCAL) at IIM Bangalore, 13th-14th December, 2022.

Papers under review/To be communicated

8. Singh, S., Routroy, S. and Dasgupta, M.S., Consumer behaviour towards e-waste disposal mode: an application of the theory of planned behaviour. *Journal of Environmental Planning and Management*, Taylor and Francis Online *[Under review]*

9. Singh, S., Routroy, S. and Dasgupta, M.S., Assessment of Risk propagation in E-Waste Collection System using Bayesian Networks. *[To be communicated]*

10. Singh, S., Routroy, S. and Dasgupta, M.S., E-waste management issues–A review of policy, collection system and consumer disposal behaviour in the context of circular economy transition. *[To be communicated]*

Brief biography of the candidate (Mr. Shailender Singh)

Shailender Singh is currently a Research scholar in Birla Institute of Technology & Science, Pilani. He received the BE Degree in Production and Industrial Engineering and the ME Degree in Industrial Management and Engineering from MBM Engineering College, Jodhpur, India. The topic of his master's thesis is product improvement using Quality Function Deployment and Target Costing. His doctoral dissertation is on the Development of E-waste management strategies for selected E-products in India. His research of areas is sustainable supply chain management, waste management, MCDM techniques, lean manufacturing, sustainable manufacturing and quality engineering. He has published many research paper in international Journals and conferences.

Brief Biography of the Supervisor (Prof. Mani Sankar Dasgupta)

Prof. M.S Dasgupta received his PhD degree from BITS Pilani in 2000 and his ME degree in Design specialization from Jadvpur University, Kolkata in 1991 and BE in Mechanical Engineering from Regional Engineering College, Silcher in 1989. Prof. Dasgupta is working as full professor at Pilani campus of BITS Pilani in Mechanical Engineering Department and has taken up many administrative positions. He teaches courses in Advanced Mechanics, Machine Design, Sport engineering, etc. areas. He has several publications in International Journals of repute and had delivered keynote address at various national and international conferences. He received various sponsored projects from national and international Institutions like UGC, DBT, DST, Norwegian Ministry of Foreign Affairs (INDEE+) and, Research Council of Norway (INTPART). He has guided 04 Ph.D. and currently 06 Ph.D. students are working with him. He is currently working in the area of E-waste management, Trans-critical CO_2 systems for refrigeration, Solar geothermal integration and various other environment friendly technologies, He has developed the Smart Building Laboratory in BITS Pilani with support from JCI. The details about Professor M. S. Dasgupta is available in the web link: https://www.bits-pilani.ac.in/pilani/dasgupta/profile.

Brief Biography of the Co-Supervisor (Prof. Srikanta Routroy)

Srikanta Routroy has received B Tech in Mechanical Engineering from CET, Bhubaneswar and Master of Technology in Industrial Engineering and Management from IIT, Kharagpur. He has completed his Ph.D. in the area of Supply Chain Management from BITS, Pilani. At present, he is working as Professor and Head of Mechanical Engineering Department at BITS Pilani, Pilani Campus. He has more than twenty-two years of teaching experience both in under graduate and post graduate level. He has authored and co-authored more than 175 research papers in refereed Journals and Conferences; 03 book chapters and 02 case studies in the area of supply chain management. He has also authored two case studies in the area of Supply Chain Management. He received sponsored projects from UGC, DBT, ICSSR, DST, Ministry of Steel (India), DST Rajasthan and Department of Food & Public Distribution, New Delhi. He has guided 07 Ph.D. and currently 08 Ph.D. students are working with him. He is currently working in the area of Supply Chain Analytics, Value Added Products, Life Cycle Assessment and Supplier Development. He has developed the Supply Chain Analytics Laboratory and minor program in supply chain analytics in BITS Pilani. The details about Professor Srikanta Routroy are available in the web link: https://www.bits-pilani.ac.in/pilani/srikanta/profile.