

Advancing Innovative Digital E-Waste Management: A Preliminary Study of Economic Valuation Based on the TCCM Framework

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ABSTRACT

Digital waste or electronic waste (e-waste) has become one of the most important environmental problems all over the world as technology grows so quickly. E-waste is the most rapidly expanding waste stream, surpassing both population growth and urbanization. From this total e-waste production, it is also reported that only 22.3% was formally collected and recycled in 2022. Due to Indonesia's archipelagic nature and vast area of 1,905 million km², which is divided into 38 provinces, managing electronic waste efficiently using traditional methods is challenging. However, this disposal process from source to destination can be streamlined if there is a platform to manage the disposal, from collection to disposal. This integration and unification of systems can be achieved through an e-waste application. Disposers can place their e-waste on the application, and collectors or those benefiting from the waste can immediately meet with the disposers at a designated location. Additionally, what may attract consumers to use this system is the calculation of the value of the discarded items, and collectors can also determine the price and benefits of the e-waste items.

There is limited research that examines this in detail or develops a specific method for assessing the valuation process of e-waste. If the valuation of each e-waste component is precise, it can be mapped into the e-waste application. Given the existing e-waste issues, researchers attempted to develop an e-waste management application and successfully created an alpha prototype. However, before commercialization is carried out, the economic potential of the e-waste must first be calculated, both the value of the e-waste itself and the value obtained if the e-waste can be managed using the developed application

This study synthesizes previous research to fill this gap and improve the development of an innovative e-waste management application. Moreover, the TCCM framework and mapping theme through VOSviewer are applied to examine theoretical foundations, contextual factors, content, and methodologies, refining the valuation process and supporting robust digital solutions before full commercialization.

This study found that issues need to be explored in the dimension of e-waste analysis valuation. Research is still dominated by material valuation analysis, but few studies calculate the monetary value of e-waste disposal from upstream to downstream. We propose two models for future research contributions: 1) exploring hybrid models that integrate social preferences with economic valuation, particularly in urban mining and contingent valuation, and 2) integrating carbon pricing with the valuation analysis of e-waste. This study also contributes to academics, businesses, and policymakers analysing monetary valuation for e-waste, so that its disposal contributes not only less to environmental damage but also provides economic value to all actors.

Keywords: Contingent valuation, economic analysis, carbon pricing, e-waste, e-waste application, valuation analysis, techno-economic analysis, TCCM.

INTRODUCTION

Digital waste or electronic waste (e-waste) has become one of the most important environmental problems all over the world as technology grows so quickly. As more and more things become digital, it's important to know the problems and ways to solve them when it comes to managing e-waste so that it doesn't hurt the environment or people's health. Electronic waste includes all kinds of electronics that aren't being used anymore, like old cell phones, computers, TVs, and other home appliances.

In 2022, according to the United Nations Institute for Training and Research (UNITAR) report, global e-waste production reached 62 billion kg, with projections forecasting an astonishing 82 billion kg by 2030. E-waste is the most rapidly expanding waste stream, surpassing both population growth and urbanization Baldé *et al.* (2024). From this total e-waste production, Baldé *et al.* (2024) also reported that only 22.3% formally collected and recycled in 2022. The rest of the waste is either disposed of in landfills or recycled informally, which exposes millions of workers, including children, to dangerous chemicals. E-waste has valuable raw materials in it, like gold, silver, copper, and rare earth metals. However, a lot of these resources are

lost because of bad recycling and trash disposal. Although the environmental and health consequences of e-waste are well recognized, its financial assessment is still a largely uncharted area in waste management economics.

E-waste management in developing countries remains a challenge compared to developed countries (Baldé *et al.*, 2024). In developed countries, the separation of e-waste components is already advanced, with hydrometallurgical and biometallurgical processes carried out using robotics to maximise material recovery and minimise harmful emissions. In contrast, in developing countries, processing is still dominated by traditional methods and low-tech approaches, resulting in the loss of important resources and the release of toxins from improperly managed waste into the air, soil, and water (Reecolabb, n.d.). In developing countries in particular, the large amount of e-waste is not only due to electronic goods that are damaged and can no longer be used by citizens, but also due to the large number of used electronic goods entering from developed countries under the pretext of bridging the digital divide (Nnorom & Osibanjo, 2008)

Indonesia, as a developing country and the fourth most populous country in the world, is also using traditional methods and low-tech approaches to manage e-waste. In addition, due to Indonesia's archipelagic nature and vast area of 1,905 million km², which is divided into 38 provinces, managing electronic waste efficiently using traditional methods is challenging. To address e-waste, there is now a global Extended Producer Responsibility (EPR) policy that holds manufacturers accountable for collecting, transporting, recycling, and disposing of products at the end of their useful life cycle (Setiawan, 2023). At the global level, this concept was first introduced in 2002 at the World Summit on Sustainable Development. In Indonesia, EPR is enshrined in Law No. 18 of 2008 on Waste Management (Article 15), which was further detailed in Government Regulation No. 81/2012 (Article 1, point 5) and the Minister of Environment and Forestry Regulation No. P.75 of 2019 on the Roadmap for Waste Reduction by producers. The target of this roadmap is to reduce waste from goods and packaging, as well as containers made of plastic, paper, glass, and aluminium, by 30% of the total products and/or product packaging produced and marketed by 2029. Currently, only 15 businesses are recorded as implementing EPR, with a reduction of 1,145.5 tonnes of waste. E-waste management in developing countries is still largely carried out informally, without considering safety and health aspects. Parajuly *et al.*, (2019) provides an example of improper e-waste management, resulting in air, water, and soil pollution. Informal manner that does not consider safety and health aspects. These studies also provide examples of inappropriate e-waste management leading to severe air, water, and soil pollution in the areas of Agbogbloshie, Ghana, and Guiyu, China.

A comprehensive infrastructure strategy is necessary to manage the vast quantities of e-waste that are generated globally. In contrast to other products, these wastes contain health-threatening, hazardous materials and precious metals. Consequently, the economic values and environmental aspects of e-waste management render it a complex program (Ravichandran *et al.*, 2024). Currently, there are several institutions in Indonesia that manage e-waste, such as EwasteRJ, which has e-waste drop boxes at 20 locations in 12 districts/cities (Defitri, 2022b); The Jakarta Environment Agency, which provides e-waste drop boxes in every sub-district, the Octopus app, which initially promoted waste recycling, including e-waste, and the Bandung City Environmental Agency, which has provided 10 e-waste drop boxes (Defitri, 2022a). However, the management of all these initiatives is still not optimal. In response to the existing e-waste issues, researchers, through the first phase of research in 2023, have attempted to develop an e-waste management application and successfully created its alpha prototype. However, before commercialisation can proceed, the economic potential of the managed e-waste must first be calculated, including both the value of the e-waste itself and the value that can be obtained if the e-waste is managed using the application. It is estimated that Indonesia could gain USD 1.8 billion by recycling e-waste, with each tonne of recycled e-waste reducing 1.40 tonnes of CO₂ (Puspa, 2023). Within 1 tonne of telecommunications equipment e-waste, it can produce, among other things, 1.44 kg of gold, silver, copper, and other commodities with high resale value (Dinnata, 2017). The approach to obtaining economic value from e-waste is as simple as identifying which parts of an unused electronic device can still be utilised and determining their value. Currently, research on developing solutions for existing e-waste has not shown an analysis of its economic potential, so the estimated value of its benefits remains unmeasured. This is evident in the research by Sanito *et al.* (2021) proposing plasma technology Nnorom & Osibanjo (2008), which proposes several e-waste management policies, Nowakowski & Pamula (2020) which proposes the design of an application that can identify types of e-waste using photos, and Madhav *et al.* (2022) which proposes the application of mobile robots that identify e-waste. Nevertheless, previous research has also not been able to demonstrate a comprehensive method for measuring the economic potential of e-waste. Study of Islam & Huda, (2019) shows that there are 55 papers that use material flow analysis (MFA) in e-waste management as a tool to measure the flow and stock of materials or substances in a well-defined system, but it has not been able to explain how to measure the economic value of e-waste.

E-waste valuation is critical because it helps determine the economic viability of waste recovery and recycling. Understanding the financial worth of discarded electronic materials can incentivize businesses, governments, and organizations to invest in proper e-waste management systems. Therefore, this study aims to deliver advantages through a literature review that may serve as a reference for optimal practices in e-waste valuation. As previously said, several subjects pertain to e-waste and its processing; nonetheless, the optimal valuation of e-waste from upstream to downstream remains ambiguous. This study outlines findings on appropriate valuation methodologies, organised through systematically utilising content analysis grounded on the Theory-Context-Characteristics Methodology (TCCM) Framework. The mapping is accomplished thoroughly via VOS viewer to discern trends from literature released between 2012 and 2025. This research will offer both theoretical and practical advances. The theoretical advantages provide novel insights and concepts for further research, derived from the gaps identified

in the systematic literature review completed in this study. This paper provides a comprehensive review of optimal practices for applying suitable valuation methods for e-waste management, intended for application by e-waste managers, particularly in Indonesia.

Applying a systematic literature review from the Scopus database, this paper purposes to answer the following research questions (RQ):

RQ1: How are key factors in e-waste valuation mapped using the TCCM framework based on previous studies?

RQ2: What are the themes related to e-waste valuation to acknowledge the economic value of e-waste studied in previous studies?

RQ3: What model can be proposed to describe the trend of valuation analysis in e-waste management concerning monetization?

THEORY

This research conducted a systematic literature review (SLR) to explore insights into the economic valuation of e-waste by synthesising findings from previous studies. In addition, this study uses the TCCM framework to analyse the theoretical basis, contextual factors, content, and methodology of previous studies (Paul & Rosado-Serrano, 2019). Furthermore, this study uses VOS Viewer to conduct keyword analysis, ensuring a systematic and data-driven approach to mapping research cluster themes. VOSviewer is a tool that facilitates the process of researchers extracting themes from the content analysis that has been conducted. The theme clusters obtained from SLR are visually represented by VOSviewer (Anggadwita & Indarti, 2024). VOSviewer is a software application employed for bibliometric visualisation and analysis, particularly in creating network maps that illustrate the relationships between publications, authors, or keywords in scientific research. VOSviewer is employed in this research to assist in resolving research questions.

The database used here is the Scopus database and was retrieved in May 2025, with only articles published between 2012 and 2025 being considered. The process began by defining the research objectives and establishing a clear research protocol to ensure transparency and maintain research quality, employing terms. First of all, the search keywords are selected in terms of electronic waste and valuation analysis. Then the synonyms are added in order to make it more detail, i.e. electronic waste can be defined with “e-waste”, “Waste Electrical and Electronic Equipment”, “WEEE” and “recycling”; while valuation might be similar with “economic analysis”, “valuation analysis”, “discounted cash flow”, “npv” and “dcf”. Then by using Boolean, the keywords are inputted into Scopus as follows: “recycling” AND “Waste Electrical and Electronic Equipment” OR “WEEE” OR “e-waste” OR “electronic waste” AND valuation OR “economic analysis” OR “valuation analysis” OR “discounted cash flow” OR “dcf” OR “net present value” OR “npv”. This results in 203 documents. Further, the search is refined by article type and only uses English as the language, resulting in 149 documents. Third, the search is refined with the subject area of Accounting, Business, Economics, Econometrics, Finance, and Management, resulting in 43 documents. Even though the sample size is small, this study includes important and high-quality works in the field that were chosen through a strict process (Anggadwita & Indarti, 2024; Paul & Rosado-Serrano, 2019).

FINDING AND DISCUSSION

The analysis and discussion will be given in two sections. The initial section addresses RQ1 concerning the mapping of prior studies. RQ1 is addressed through an examination of the TCCM framework. The second section addresses RQ2 regarding the themes excluded from previous studies. VOS Viewer is employed to address RQ2.

The Mapping Of Studies On Valuation Analysis In Electronic Waste Studies

This section will answer the following research question, which is RQ1: How are key factors in e-waste valuation mapped using the TCCM framework based on previous studies?

This study will outline prior research in electronic waste and evaluation analysis within the TCCM framework. The primary advantage of employing the TCCM framework is to acquire a comprehensive understanding of the theoretical and empirical dimensions of a specific research domain (Paul & Rosado-Serrano, 2019). This section will examine the theoretical dimensions, context, characteristics, and methodology of 43 prior research articles.

Theoretical framework

As explained by Paul & Rosado-Serrano (2019) theories in TCCM represent the various theoretical foundations and paradigms employed in explaining the interconnections among the constructs. From the perspective of theoretical frameworks related to valuation analysis, 36 out of 43 papers explicitly provide monetary valuations. This includes seven theoretical frameworks, such as: Techno-Economic Analysis (TEA), Cost Benefit Analysis (CBA), Life Cycle Costing, Urban Mining, Willingness-to-Pay, Environmental Valuation, and Forecasting Based Valuation, see Table 1.

a. Techno-Economic Analysis (TEA)

The techno-economic analysis (TEA) framework is most used in e-waste value research. It combines technical process modelling with financial measures, such as present value (NPV), internal rate of return (IRR), return on investment (ROI), and capital and operational expenses. TEA is used to assess the economic feasibility of recycling technologies, such as black copper smelting (Ghodrat *et al.*, 2016), second-life battery systems (Rallo, Benveniste, *et al.*, 2020), and flue gas-

based leaching systems (Kim *et al.*, 2022). TEA lets researchers model real-world operations and look at how profitable they would be in different market and technological situations. This makes it very important for making investment decisions and building infrastructure (Chen & Hsieh, 2023; Wu *et al.*, 2023).

Table 1. The Mapping of Theoretical Framework

Theory Group	Authors (with Year)	Core Focus	Approach Tools	Number of Articles	Coverage
Techno-Economic Analysis (TEA)	Ghodrat (2016), Rallo (2020), Kim (2022, 2023), Reinhart (2023), Rautela (2024), Alipanah (2023), Mairizal (2023), Thompson (2021), D'Adamo (2019), Cucchiella (2016), Martins (2020), Deng (2023), Mukhlis (2021), Duarte Castro (2022), Chen (2023), Blömeke (2022), Wu (2023)	Evaluating technical feasibility and economic profitability	Process modeling, cost modeling, ROI, IRR, NPV, payback time	17	40%
Cost-Benefit Analysis (CBA)	Li (2023), Sun (2023), Faircloth (2019), Arain (2022), Yu (2021), Kim (2022), Ghodrat (2016), Deng (2023), Panchal (2021), Achillas (2012), Qiu (2019)	Comparing costs vs. benefits of recycling and recovery	Net benefit, avoided cost, environmental credit, economic trade-offs	11	26%
Urban Mining	Ravindra (2019), Panchal (2021), D'Adamo (2019), Cucchiella (2016), Sun (2023), Wu (2023), Deng (2023), Martins (2020), Ghodrat (2016)	Estimating monetary value of recoverable materials	Metal recovery value, secondary resource pricing, market-based valuation	9	21%
Life Cycle Costing (LCC)	Hischier (2021), Chen (2023), Blömeke (2022), Reinhart (2023), Duarte Castro (2022), Peeters (2017)	Assessing total cost across product lifecycle	Integration of LCA with monetary metrics, TCO, long-term cost implications	6	14%
Forecasting-Based Valuation	Tian (2023), Shafique (2022), Sun (2023), Gupta (2024), Qiu (2019), Zhou (2025)	Projecting future economic value of e-waste flows	Scenario modeling, revenue forecasting, dynamic MFA, learning curve economics	6	14%
Environmental valuation	Dato (2017), Levänen (2018), An (2023), Panchal (2021), Sun (2023)	Monetary implications of regulatory frameworks and policy incentives	EPR, ESG, subsidies, carbon pricing, market shaping through governance	5	12%
Willingness to Pay (WTP)	Achillas (2012), Islam (2016), Pekarkova (2021), Valente (2021)	Public valuation and economic preferences for e-waste services	Contingent valuation, survey-based WTP, socio-economic triggers	4	9%

b. Cost-Benefit Analysis (CBA)

Cost-benefit analysis (CBA) is an analysis to see whether the benefits of waste recycling are worth the costs. It is used mainly for policy-oriented research that supports recycling over dumping or throwing things away in an informal way. Li *et al.* (2023) used this analysis to compare solar waste's mechanical, chemical, and thermal recycling methods. In contrast, Sun *et al.* (2023) assessed the economic worth of uncontrolled WEEE in China. Cost-benefit analysis (CBA) is typically

used alongside environmental impact assessments to show the net societal benefits. This makes the case for subsidies and infrastructure development stronger (Faircloth *et al.*, 2019; Arain *et al.*, 2022).

c. Life Cycle Costing (LCC)

Life cycle costing (LCC) applies economic analysis to a product's whole life cycle, from manufacture to disposal. When integrated with Life Cycle Assessment (LCA), LCC combines environmental and financial performance evaluations, providing long-term environmental sustainability planning with economic incentives. Studies such as Chen & Hsieh (2023) and Duarte Castro *et al.* (2022) use LCC to assess the cost efficiency of lithium-ion battery recycling, considering carbon prices and resource scarcity.

d. Urban Mining & Resource Valuation

Urban mining theory views e-waste as a source of valuable secondary raw materials, emphasising the economic value of recovering metals such as copper, gold, lithium, and rare earth elements. Ravindra and Mor (2019) determined the recoverable value of metals from home e-waste in Chandigarh, whereas D'Adamo *et al.* (2019) and Cucchiella *et al.* (2016) investigated the economics of recycling printed circuit boards. This paradigm promotes circular economy concepts and offers a strong case for investment in sophisticated recovery technology and urban-scale resource exploitation.

e. Forecasting-Based Valuation

Forecasting-based value (FBV) uses predictive modelling to assess prospective economic flows resulting from e-waste creation and recovery. Methods include material flow analysis (MFA), Weibull distribution modelling, and learning curve economics, which are utilised to forecast resource availability, market value, and infrastructure requirements. This approach is very beneficial for strategic planning and policy formulation. Qiu and Suh (2019) studied the economic feasibility of rare earth metal oxide recycling on various scales and under various price scenarios. In contrast, Gupta *et al.* (2024) projected income from primary and secondary rare earth element sources.

f. Environmental Valuation

This framework analyses the impact of regulatory instruments, including extended producer responsibility (EPR), carbon pricing, and Environmental Social Governance (ESG) reporting, on the economic dynamics of e-waste management. This emphasises the function of institutions in establishing market incentives or obstacles for recycling and recovery. This lens is crucial for comprehending the macroeconomic and governance aspects of e-waste valuation. Ravindra and Mor (2019) investigated producer-centered accountability and determined producers' financial obligations under India's new Extended framework. Panchal *et al.* (2021) looked at fee-based take-back programs in Europe's EPR frameworks. Kim *et al.* (2023) and An & Mikhaylov (2023) investigated the impact of ESG criteria and blockchain technologies on the waste competitiveness of financial institutions.

g. Willingness to Pay (WTP)

Willingness to pay (WTP) is a stated or revealed preference tool for estimating the benefits of a change in the utility of non-tradable products and services for consumers. It is one of the most used contingent valuation methods (Paudel *et al.*, 2020). WTP studies use behavioural economics to determine how people and groups appreciate e-waste services. Researchers use contingent valuation methodologies to determine how willing the public is to pay for environmentally friendly e-waste handling. Achillas *et al.* (2012) and Islam *et al.* (2016) discovered that even if people do not always know about it, they are prepared to pay for better infrastructure and collection systems. This framework is essential for making rules based on demand and determining if recycling programs that charge fees are possible.

Table 1 shows that TEA and CBA are the predominant theoretical frameworks most researchers employ in the monetary valuation of e-waste economic analysis. Environmental valuation studies remain insufficient, although this domain requires additional development of policies and regulations that might explain the valuation process. Furthermore, research necessary for future development encompasses studies correlating carbon price with electronic waste, exemplified by those conducted by Chen & Hsieh (2023). Further for the last two frameworks theory in table 1, there are 7 that are excluded from monetary valuation, like forecasting WEEE generation (Tian *et al.*, 2023), classifying using graph transformer (Zhou *et al.*, 2025), developing an analytical framework for modelling the complex interactions between circular economy business model activities and the features of diverse institutional operating environments (Levänen *et al.*, 2018), monitoring e-waste market (Dato, 2017), discussing ESG reporting and competitiveness (An & Mikhaylov, 2023), studying cooperative logistics (Valente *et al.*, 2021), Lithium mining investment, not focused on e-waste valuation (Sterba *et al.*, 2019).

Context framework

In the TCCM structure, the Context refers to the empirical setting in which the research is conducted, such as the geographic focus where the study is applied, the category of object/device, and the involved stakeholders (consumers, industries, governments). Based on the 43 articles, here are the dominant contextual themes:

a. Geographic Focus

Asia dominates the dataset, mostly from China, where 65% of the articles were done. Followed by 4 articles done in India, three articles in South Korea, 2 articles each in Taiwan, Thailand, and Indonesia; and each article in Bangladesh, Iran, Malaysia, UAE, Nepal, Pakistan, and Srilanka

Furthermore, there are fourteen (14) articles that were done in Europe, which is around 32.60% of the total articles. Mostly done in Italy (three articles), then two articles each in Spain, Germany and European Uni, and others in Greeks, Poland, Finland, Swiss. There are 5 articles, mostly in the USA and Brazil (each for two articles), and one in Mexico. While in Australia, there are two articles. For global research, there are two articles. This description is depicted in Table 2.

Table 2 Mapping of Context Framework on Geographic Focus

Continent	Country	Number Articles	Percentage	Authors
Asia	China	11	25.60%	An & Mikhaylov, 2023; Deng <i>et al.</i> , 2023; Li <i>et al.</i> , 2023; Liu <i>et al.</i> , 2023; Shafique <i>et al.</i> , 2022; Sun <i>et al.</i> , 2023; Tian <i>et al.</i> , 2023; Wu <i>et al.</i> , 2023; Yu <i>et al.</i> , 2021; Zhou <i>et al.</i> , 2025
	India	4	9.30%	Gupta <i>et al.</i> , 2024; Panchal <i>et al.</i> , 2021; Rautela <i>et al.</i> , 2024; Ravindra & Mor, 2019
	South Korea	3	7.00%	An & Mikhaylov, 2023; Kim <i>et al.</i> , 2022, 2023
	Taiwan	2	4.70%	Chen & Hsieh, 2023; Wu <i>et al.</i> , 2023
	Thailand	2	4.70%	Arain <i>et al.</i> , 2022; Faircloth <i>et al.</i> , 2019
	Indonesia	1	2.30%	Mukhlis <i>et al.</i> , 2021
	Bangladesh	1	2.30%	Islam <i>et al.</i> (2016)
	Iran	1	2.30%	Alipanah <i>et al.</i> , 2023
	Malaysia	1	2.30%	Tian <i>et al.</i> (2023)
	Vietnam	1	2.30%	An & Mikhaylov (2023)
	UAE	1	2.30%	An & Mikhaylov (2023)
Nepal, Pakistan, Sri Lanka	1 (regional)	2.30%	An & Mikhaylov (2023)	
Subtotal Asia		28	65.10%	
Europe	Italy	3	7.00%	Duarte Castro <i>et al.</i> (2022), Cucchiella <i>et al.</i> (2016), D'Adamo <i>et al.</i> (2019)
	Spain	2	4.70%	Rallo <i>et al.</i> (2020), Rallo <i>et al.</i> (2022)
	Germany	2	4.70%	Blömeke <i>et al.</i> (2022), Reinhart <i>et al.</i> (2023)
	Greeks	1	2.30%	Achillas <i>et al.</i> (2012)
	Poland	1	2.30%	Sterba <i>et al.</i> (2019)
	Finland	1	2.30%	Levänen <i>et al.</i> (2018)
	Swiss	1	2.30%	Hischier & Böni (2021)
European Uni	2	4.70%	Peeters <i>et al.</i> (2017), Pekarkova <i>et al.</i> (2021)	
Subtotal Eropa		14	32.60%	
America	USA	2	4.70%	Qiu & Suh (2019), Thompson <i>et al.</i> (2021)
	Brazilia	2	4.70%	Martins <i>et al.</i> (2020), Valente <i>et al.</i> (2021)
	Mexico	1	2.30%	Sterba <i>et al.</i> (2019)
Subtotal America		5	11.60%	
Australia	Australia	2	4.70%	Ghodrat <i>et al.</i> (2016), Mairizal <i>et al.</i> (2023)
Global/ Multiregional	Global	3	7.00%	Sterba <i>et al.</i> (2019), Dato (2017), An & Mikhaylov (2023)

b. E-Waste Type

There are five (5) types of e-waste studied for monetary valuation, reflecting both technological relevance and economic recovery potential: Lithium-ion Batteries, Printed Circuit Boards (PCB), Photovoltaic Panels, Consumer Electronics, and Other Specialized E-waste.

1. **Lithium-ion Batteries (LIBs)**
The most frequently analyzed category, LIBs, dominates valuation studies due to their high recovery value and relevance to energy transition, with around 13 articles (30% coverage). Research focuses on techno-economic analysis, second-life applications, and carbon pricing mechanisms. Studies like Kim *et al.* (2022). Reinhart *et al.* (2023) and Wu *et al.* (2023) highlight innovative recycling systems and policy implications.
2. **Consumer Electronics**
There are 11 articles, covering 25% that studied items like TVs, refrigerators, and fans, which are central to urban mining and behavioral economics studies. Ravindra (2019), Sun (2023), and Islam (2016) explore willingness to pay (WTP), informal sector dynamics, and regional disparities in recycling infrastructure.
3. **Printed Circuit Boards (PCBs)**
There are 18% of studies (8 articles) that studied PCB. PCBs are valued for their rich metal content, especially gold, copper, and palladium. Studies such as Ghodrat (2016) and D'Adamo (2019) emphasize pyrometallurgical recovery and cost-benefit modeling, often within industrial-scale feasibility frameworks.
4. **Photovoltaic Panels**
There are 12% studies (5 articles) of Photovoltaic (PV) Panels. PV panels are gaining attention due to their growing waste stream and complex material composition. Li (2023) and Faircloth (2019) apply life cycle assessment (LCA) and cost-benefit analysis to evaluate recycling technologies and environmental trade-offs.
5. **Other Specialized E-Waste,**
This gives 15% of studies, such as LED bulbs, rare earth elements, and electric bicycles. Studies such as Martins (2020), Qiu (2019), and Liu (2023) use niche methodologies like mechanical processing, dynamic material flow analysis (MFA), and techno-economic evaluation to assess feasibility and recovery efficiency.

c. Stakeholder Perspective

There are three categories of stakeholders: households and consumers, industry and manufacturers, and policymakers and governance institutions.

1. Households and consumers are the primary focus of behavioural assessment and contingent assessment studies. Articles such as Achillas (2012), Islam (2016), and Ravindra (2019) highlight the limited public awareness of the dangers of electronic waste and the low awareness of e-waste collection.
2. Industries and manufacturers are pivotal in process innovation, battery reutilization, and circular design. Among other things, Rallo (2020), Kim (2022, 2023), Liu (2023), and Wu (2023) evaluated capital and operational expenditures, return on investment (ROI), and environmental compromises, presenting substantial data for valuation models.
3. Policymakers and governance institutions are studied by, e.g, Panchal (2021), An & Mikhaylov (2023), and Duarte Castro (2022), who examined the influence of extended producer responsibility (EPR), ESG reporting, and blockchain-enabled transparency on waste management results. These studies illustrate the monetization of policy instruments, including carbon pricing, externality valuation, and institutional willingness to pay, to represent wider societal costs and benefits.

Characteristics framework

Characteristics refer to the elements of a construct and their relationship with other variables of interest. From all 43 articles that we have, there are eight characteristics that can be synthesized here (see Table 3).

- a. **Cost Structure Analysis**
In valuation-focused e-waste research, the most prevalent characteristic is the emphasis on cost assessments, particularly capital and operating expenditure (CAPEX and OPEX). There are 14 articles in this category (around 33%), which signifies a substantial body of research on e-waste valuation, providing a comprehensive overview of the topic. For instance, Ghodrat (2016) investigates and quantifies the economic performance of recycling and recovering valuable metals from WPCBs through a base metal secondary pyrometallurgical operation, detailing cost structures, while Kim (2022) uses techno-economic analysis to investigate a new model of lithium-ion battery (LIB) recycling system. These studies show how scale and chemical efficiency directly affect economic viability, providing a deep understanding of the subject.
- b. **Revenue Potential Estimation**
There are 11 studies that use the revenue metrics, which are revenue and cost estimation analysis. Estimated potential revenue is used to complement cost analysis, offering a promising outlook. Potential revenue estimates and economic analysis always complement research related to cost analysis. For instance, Ravindra (2019) analyzed the annual

revenue from heavy metals, while Wu (2023) used economic analysis and indicated that the income from recycling LFP batteries can be nearly \$5,000 per ton processed.

Table 3 Mapping of Characteristics Category

Characteristic Category	Description	Number of Articles	Articles
Cost Structure Analysis	CAPEX, OPEX, and leveled cost metrics for the financial feasibility of recycling systems.	14	Ghodrat (2016), Kim (2022), Kim (2023), Liu (2023), Rallo (2020), Duarte Castro (2022), Chen (2023), Wu (2023), Sun (2023), Yu (2021), Qiu (2019), Sterba (2019), Ravindra (2019), An (2023)
Revenue Potential Estimation	Economic value from recovered materials based on recovery rate and market prices	11	Ravindra (2019), Wu (2023), Martins (2020), Sun (2023), Qiu (2019), Duarte Castro (2022), Kim (2022), Kim (2023), Liu (2023), Yu (2021), Chen (2023)
Benefit–Cost Indicators	Net benefit, cost-benefit ratio, and break-even price for summarizing economic justification	10	Li (2023), Qiu (2019), Sun (2023), Duarte Castro (2022), Kim (2022), Kim (2023), Liu (2023), Yu (2021), Ghodrat (2016), Chen (2023)
Financial Performance Metrics	NPV, IRR, ROI payback period for investment attractiveness, and process scale-up	9	Rallo (2020), Ghodrat (2016), Kim (2022), Kim (2023), Sterba (2019), Duarte Castro (2022), Chen (2023), Wu (2023), Sun (2023)
Technical Efficiency Variables	Recovery rate, separation efficiency, and purity as inputs to economic modeling	8	Martins (2020), Wu (2023), Kim (2022), Kim (2023), Ghodrat (2016), Liu (2023), Duarte Castro (2022), Yu (2021)
Environmental Externalities	Monetization of carbon footprint, water use, and toxicity via carbon pricing and Life-Cycle Assessment (CLA)	7	Chen (2023), Liu (2023), Yu (2021), Duarte Castro (2022), Kim (2022), Kim (2023), Sun (2023)
Price Forecasting and Learning Effects	Forecasting market prices and evaluating learning effects in cost reduction	5	Chen (2023), Qiu (2019), Sterba (2019), Tian (2023), Kim (2023)
Social Valuation through Willingness to Pay (WTP)	Public support and behavioral willingness to pay for improved e-waste management	3	Achillas (2012), Islam (2016), Levänen (2018)

c. **Benefit–Cost Indicators**

The indicators here are needed for decision-making, including net benefits, cost-benefit ratio, and break-even price. These indicators also describe the overall economic basis for the e-waste recycling system. There are 10 articles that use these metrics, e.g. Ghodrat *et al.* (2016) use these indicators to examine black-copper smelting recycling analysis, while Li (2023) and Qiu (2019) use these criteria to compare recycling systems and determine market profitability levels.

d. **Financial Performance Metrics**

Financial performance metrics are usually used in capital budgeting criteria. The metrics used are Net Present Value, Internal Rate of Return, Payback Period, Return on Investment, etc. These metrics are used in feasibility studies or investment decision-making, providing a quantitative basis for evaluating the economic viability of e-waste recycling. There are 9 articles found using these metrics, e.g., Rallo (2020) and Alipanah (2023) use these metrics by simulating scenarios to assess the valuation of used batteries.

- e. **Technical Efficiency Variables**
This characteristic uses variables such as recovery rate, separation efficiency, and purity, which are used as inputs for economic modeling. The output will be to show the recovery rate value of e-waste. Articles found by this characteristic are eight (8), which gives 19% of studies contributing to it. For instance, Martins (2020) and Wu (2023) did experimental and process-evaluation studies, which showed that high recovery rates will increase revenue and reduce costs.
- f. **Environmental Externalities**
This valuation refers to monetizing ecological impacts such as carbon emissions, water use, toxicity, and resource depletion. For instance, (Chen & Hsieh, 2023) studies carbon pricing that can offset battery reductions. At the same time, Liu *et al.* (2023) demonstrates how battery type influences toxicity and metal shortage. Meanwhile Yu *et al.* (2021) use this valuation to quantify the effects of ecological impacts. There are in total seven studies that use the construct of environmental externalities.
- g. **Price Forecasting and Learning Effects**
This model forecasts future raw material prices and simulates cost reductions. Studies by Chen & Hsieh (2023) and Qiu & Suh (2019) show that declining battery prices and scaling up recycling operations can significantly improve economic feasibility. In the other hand Chen & Hsieh (2023) also find result by monetizing a battery's carbon footprint may offset battery price reductions through learning effects. This characteristic is essential for forward-looking investment analysis and policy design in e-waste management.
- h. **Social Valuation**
This characteristic appears in three studies through willingness to pay (WTP) surveys, reflecting public support for improved e-waste management. Achillas *et al.* (2012) and Islam *et al.* (2016) use this valuation method to quantify household WTP for recycling services, which offers insights into behavioral economics and funding models.

Overall, the characteristics framework reveals a strong orientation toward cost economic analysis rigor, revenue potential with cost benefit analysis growing interest in integrating environmental and social dimensions. However, the limited use of environmental externalities such as carbon pricing, price forecasting, and social valuation modeling suggests more interdisciplinary and forward-looking valuation research opportunities.

Methodology framework

As we focus on the methodological framework for e-waste valuation analysis, we divide this methodology into five paradigms: quantitative, qualitative, mixed methods, case studies, and big data/AI models (see Table 4).

- a. **Quantitative Paradigm**
There are 34 articles (about 80% studies) that use this paradigm for valuation by using numerical data, modelling, and statistical analysis to measure valuation outcomes. Focused methods in this paradigm are seven (see table 5).
 1. First of all return on ROI and IRR both are frequently employed in techno-economic analyses to evaluate the profitability of recycling e-waste and infrastructure. For instance Rallo *et al.* (2020) valued ROI for second-life lithium-ion batteries that used in stationary energy storage systems, while (Ghodrat *et al.*, 2016) used IRR for black dopersmelting of waste printed circuit boards, demonstrating the financial viability of large-scale operations, see Table 5.
 2. Secondly, net benefit and cost analysis are integrated to quantify the economic gain from processing specific e-waste streams. (Martins *et al.*, 2020b) valued a profit of \$639.82 per ton from LED bulb recycling using mechanical separation, highlighting the potential of material recovery as a revenue-generating strategy.
 3. Next is Cost-Benefit Analysis (CBA) integrated with Life Cycle Assessment (LCA) to compare the total costs and environmental benefits of different recycling technologies. Li *et al.* (2023) applied CBA to photovoltaic module recycling, showing that mechanical, chemical, and thermal methods outperform landfilling in both cost and environmental impact.
 4. Next construct is Willingness to Pay (WTP), which is derived from contingent valuation methods and captures the behavioral dimension of e-waste valuation. Achillas *et al.* (2012) found that public WTP in Greece exceeded current recycling fees.
 5. Furthermore, environmental metrics such as greenhouse gas reduction, water consumption and energy efficiency are increasingly monetized to support eco-efficiency arguments. Yu *et al.* (2021) demonstrated that direct physical recycling of lithium-ion batteries could reduce GHG emissions by up to 38% and water consumption by over 40%, while also lowering production costs.
 6. Material Recovery Value is another key metric, especially in urban mining contexts. Ravindra & Mor (2019) estimated an annual economic potential of \$65,000 from household e-waste in Chandigarh, based on the recovery of precious metals like copper, silver, and gold.
 7. Finally, Scenario-Based Valuation is used to test the robustness of economic outcomes under varying conditions. Li *et al.* (2023) conducted sensitivity analyses on transport distances, technology efficiency, and subsidies, revealing how policy and operational changes can significantly influence valuation results.

Table 4 Mapping of Methodology Paradigm

Paradigm	Description	Valuation Metrics Used	Number of Articles
Quantitative	Uses numerical data, modeling, and statistical analysis to measure valuation outcomes	ROI, IRR, Net Benefit, Cost/ton, WTP (structured), GHG reduction, Water savings	34
Case Study	In-depth analysis of specific regions, technologies, or systems to derive localized insights	ROI, Net Benefit, feasibility analysis, localized cost modeling	6
Mixed Methods	Combines quantitative modeling with qualitative surveys or contextual analysis	WTP + extrapolated cost/benefit, behavioral insights + TEA, LCA + survey	4
Qualitative	Explores perceptions, informal practices, and behavioral insights through interviews and thematic analysis	WTP (open-ended), protest vote interpretation, informal sector dynamics	3
Big Data / AI Models	Uses machine learning, ANN, hybrid forecasting, and large datasets for predictive modeling	Forecasted e-waste volume, infrastructure cost projections, regional valuation	2

Table 5 Mapping Methodological Framework of Quantitative Paradigm

Life Cycle Assessment (LCA)	17	Li <i>et al.</i> (2023), Liu <i>et al.</i> (2023), Yu <i>et al.</i> (2021), Kim <i>et al.</i> (2022), Ghodrat <i>et al.</i> (2016), Rallo <i>et al.</i> (2020), Martins <i>et al.</i> (2020), Jing Li <i>et al.</i> (2023), Min Liu <i>et al.</i> (2023)
Techno-Economic Analysis (TEA)	14	Ghodrat <i>et al.</i> (2016), Kim <i>et al.</i> (2022) Rallo <i>et al.</i> (2020), Yu <i>et al.</i> (2021) Li <i>et al.</i> (2023), Liu <i>et al.</i> (2023)
Forecasting Models	5	Tian <i>et al.</i> (2023)
Process Modeling & Simulation	6	Kim <i>et al.</i> (2022), Ghodrat <i>et al.</i> (2016) Martins <i>et al.</i> (2020)
Scenario & Sensitivity Analysis	8	Li <i>et al.</i> (2023), Liu <i>et al.</i> (2023), Yu <i>et al.</i> (2021)
Material Characterization	5	Martins <i>et al.</i> (2020), Liu <i>et al.</i> (2023), Kim <i>et al.</i> (2022)
Structured Surveys	3	Ravindra & Mor (2019), Achillas <i>et al.</i> (2012)

b. Case Study Paradigm

There are 6 studies incorporating case study paradigm. For instance Rallo *et al.* (2022) use ROI and cost savings in real installations to evaluate second-life lithium-ion batteries used in Spanish energy storage systems for their electricity bill savings and investment returns, while (Martins *et al.*, 2020a) are studying material recovery and profit per ton on LED bulb recycling, which showed that mechanical separation can yield high-purity materials and generate substantial profits. These studies often incorporate local variables such as labor costs, infrastructure availability, and policy context. This is ideal for tailoring solutions to specific geographies.

c. Mixed Methods

This paradigm combines quantitative analysis with depth of qualitative insights to get holistic valuations. The studies are done, for instance, combining LCA and CBA, both evaluate environmental impacts and economic feasibility, such as recycling technologies are assessed for their carbon footprint, water use, and cost efficiency (Li *et al.*, 2023). Furthermore, combining scenario analysis, risk analysis, and sensitivity testing (Adamo *et al.*, 2019). These tools explore how changes in transport distances, energy sources, or subsidies affect valuation outcomes, helping policymakers identify leverage points.

d. Qualitative Methods

Furthermore, in this case, the qualitative paradigm shows there are three valuations, including public perception and behavioral intent, social equity, and informal sector dynamics, and a narrative-based assessment. Qualitative studies emphasize the human and institutional dimensions of e-waste management. Study on public perception and behavioral intent is one of the studies found using a qualitative paradigm, for instance Achillas *et al.* (2012) which uses surveys

and interviews to examine how awareness, trust, and cultural norms shape recycling behavior. Furthermore, social equity and informal sector dynamics is used by Pekarkova *et al.* (2021) to study how informal recyclers operate under hazardous conditions, framing valuation in terms of health risks, labor justice, and environmental ethics. Lastly, there are also assessments based on narrative valuations (e.g Islam & Huda (2016)), which are used to uncover barriers to formal recycling, such as a lack of infrastructure or regulatory enforcement, which are critical for designing inclusive policies.

e. AI Model and Big Data

AI and big data are used to forecast and optimize the transformation of e-waste systems. Study by Tian *et al.* (2023) applied forecasting model such as grey model and artificial neural to predict WEEE generation from a country perspective. Using Big data and AI model can forecast regional demand for recycling infrastructure with high accuracy

Theme Studies in Valuation Analysis in Electronic Waste Studies

This section will address RQ2: What are the themes related to e-waste valuation to acknowledge the economic value of e-waste studied in previous studies? We will generate themes from the previous researches in valuation analysis from a monetary perspective and e-waste management using VOSviewer. Furthermore, VOSviewer is also used for co-word analysis to discern topic clusters and research trajectories about valuation analysis in e-waste management from a monetary perspective. Co-word analysis investigated the links among frequently occurring words to reveal related concepts (Fauzi *et al.*, 2022). Keywords were derived from the titles and abstracts of the articles in this study, employing a co-occurrence threshold of three articles to improve analytical precision.

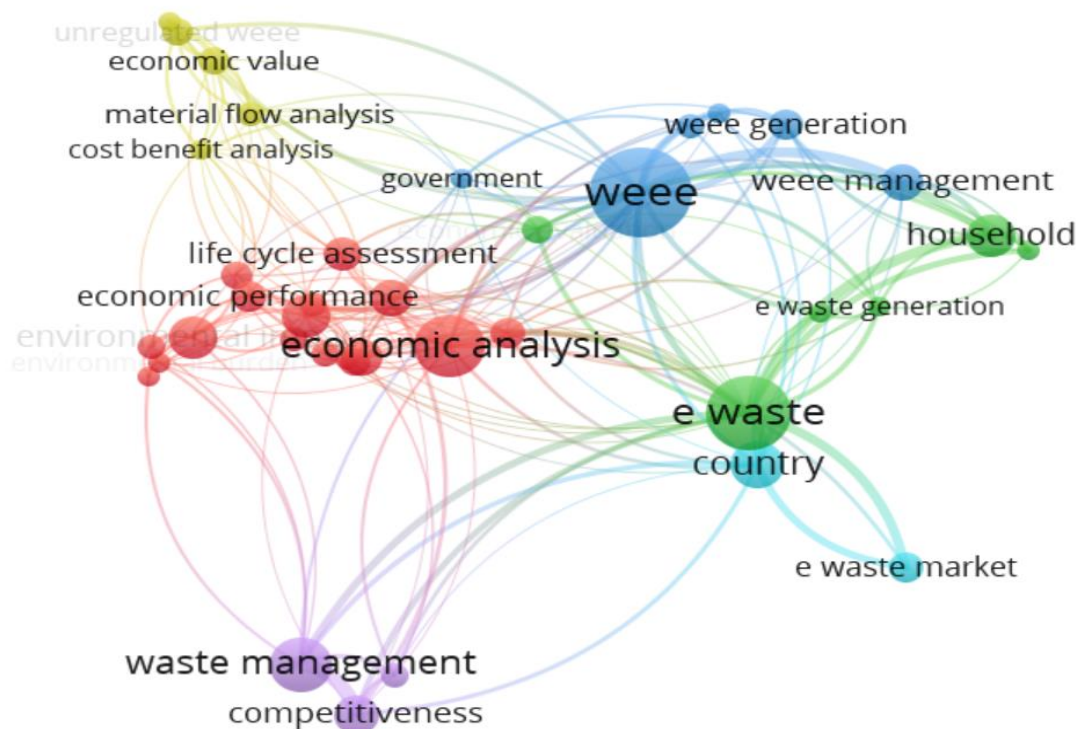


Figure 1. Themes Mapping Related to Valuation Analysis and Electronic Waste (E-waste)

A mapping of the results of drawing themes from this study using VOSviewer is depicted in Figure 1. The result shows that there are six (6) clusters which are distinguished in colors of red, blue, green, yellow, purple, and light-blue. The first cluster, coloured red, consists of seventeen (17) items, namely carbon footprint, circular economy, economic analysis, economic feasibility, economic impact, economic performance, environmental burden, environmental impact, life cycle assessment, net present value, NPV, profit, recycling methods, recycling processes, sensitivity analysis, and technological-economic analysis. The largest cluster is in economic analysis and environmental impact. Although there is a connection between NPV and profitability, it is unclear in this red cluster diagram, indicating that there is still limited literature linking economic analysis and environmental impact with NPV and profitability. It is evident in this red cluster that there is a significant gap in the relationship between economic analysis, environmental impact, carbon footprint, circular economy, and e-waste/WEEE, as well as its connection to government, indicating a research gap that can be addressed through future research.

The second cluster is blue, with six (6) items: government, municipality, recycled materials, Waste from Electrical and Electronic Equipment (WEEE), WEEE generation, and WEEE management. It is evident that studies on WEEE, from a management perspective, have a strong connection with the central and local government. These studies are related to WEEE

management policies and policies regarding recycled materials. However, there is no apparent connection between WEEE, government, and economic analysis, nor from the evaluation theme related to monetary evaluation. This represents a research gap and could be proposed as future research on evaluation analysis in WEEE management, WEEE generation, and recycled materials, which are specific policies for the government.

The next cluster, coloured green, shows six (6) items, including e-waste, e-waste generation, economic evaluation, household, management practice, recovery economy, and potential. Between the green and blue clusters are words with the same meaning, namely e-waste and WEEE, with WEEE being a synonym or extension of the term e-waste. There is a research gap between e-waste households and economic analysis, and no connection with the government. Additionally, there is no connection between e-waste and households with recycling methods, environmental burden, and cost-benefit analysis.

The fourth cluster, coloured yellow, contains five (5) items: cost-benefit analysis, economic value, material flow analysis, unregulated WEEE, and valuable resource components. Among the 43 pieces of literature found, one study in China on unregulated WEEE about economic value and cost-benefit analysis (Sun *et al.*, 2023). There appears to be a research gap in that this issue has not been discussed by any country other than China. Additionally, the government should already regulate unregulated WEEE, and economic analysis, environmental burden, and environmental impact should be considered. There is also no classification for unregulated WEEE within the scope of households, industries, and countries.

The fifth sector, coloured purple, contains three (3) items: competitiveness, e-waste, and waste management. This is only found in one study of An & Mikhaylov (2023) which focuses on the significance of addressing the rising problem of e-waste in Asia and the need for better collection and analysis of waste data in banks, whether it be paper waste or e-waste found in banks in Asia. The data used in this study is e-waste data from banks in developing countries. This indicates that there is still a gap, as many industries besides banks could be studied, as well as in countries outside Asia, particularly developing countries.

The last sector, light blue, only has two (2) items: country and e-waste market. This is only seen in one study, Dato, which examines the economic analysis of the e-waste market. They propose an economic analysis of a standard e-waste market that they compare with an alternative market of a joint trade in reusable and non-reusable e-wastes. The result is that their alternative market is better for developing countries. From this, we see no relationship between the e-waste market and the circular economy or economic analysis, nor is there any regulatory connection the government can fill. This can also be used as a separate future research topic.

FUTURE RESEARCH

This section will address RQ3: What model can be proposed to describe the trend of valuation analysis in e-waste management concerning monetization? It represents the preliminary study phase concerning valuation analysis for e-waste regarding monetisation. There are two proposed model frameworks, developed from the TCCM framework and themes analysed using VOSviewer, namely:

1. Most studies rely on Techno Economic Analysis (TEA), Cost Benefit Analysis (CBA) and Life Cycle Assessment (LCA) while willingness-to-pay (WTP) and contingent valuation are rarely applied. The opportunity for this gap is to explore hybrid models that integrate social preferences with economic valuation, especially in urban mining context and contingent valuation context.

From this, we can see that WTP can be applied to studies related to objects ranging from households, including starting this research from the flow of e-waste collection from door-to-door collection, delivery costs, collection costs, then calculating revenue and valuation for both e-waste owners and collectors, and the industry that is the final downstream of e-waste collection. Additionally, we propose implementing theories such as economic analysis, circular economy, contingent valuation method (CVM), or extended producer responsibility (EPR) as theoretical frameworks to explain the importance of valuation analysis for e-waste. These theories serve as the foundation for questions and research.

Furthermore, the scope and boundaries of this study can be defined geographically, whether limited to a city or province, the national level, or an industrial zone. The analysis level can range from households (micro level), recycling firms (meso level), and policy (macro level). Finally, the research context can be within the scope of stakeholders, namely local/national government, electronic producers, or collectors, both formal and informal.

Conceptual constructs, variables, and operational methodologies that we can conceptualise include:

- 1) Material flows with operational variables of total e-waste volume per type of e-waste and material composition. The method used is material flow analysis, which quantifies stocks and flows to estimate recoverable and base volumes.
- 2) Process efficiency with operational variables such as recovery rates for each e-waste component, then calculating the capex/opex per unit.

The operational methodology for techno-economic assessment involves comparing CapEx/OpEx using capital budgeting criteria and adding scenario analysis to these criteria, where the expected outcomes will be the total economic valuation of e-waste, policy recommendations, and business model proposals.

- Another interesting finding from our SLR analysis is the missing link between carbon pricing and monetary valuation. Only a few studies have incorporated carbon footprint monetisation into electronic waste valuation. In our database, only Chen & Hsieh (2023) integrated carbon pricing mechanisms into TEA to assess the trade-off between recycling costs and climate benefits. This is a topic for further in-depth research related to the carbon market. We propose a conceptual framework by identifying electronic waste streams, such as metal fractions, polymer portions, and geographical flows. Using carbon pricing theory, we may conduct life-cycle and techno-economic assessments to measure environmental effects, including greenhouse gas (GHG) emissions, water usage, and toxicity. We can also identify the economic costs, like CAPEX and OPEX.

Furthermore, the scope can be geographic, conducted at the city, provincial, or national level. Electronic waste flows through formal and informal channels, each with distinct processing technologies and carbon footprints. Regional logistics and spatial distribution influence transportation emissions and collection costs.

The construct is carbon pricing, with variables such as market ETS price, social cost of carbon, green subsidies, and government carbon tax rates. The methodology involves integrating techno-economic analysis by combining CAPEX and OPEX with carbon costs, with the expected outcome being carbon incentives. Sensitivity analysis can also be added by applying upper and lower limits on carbon prices and employing Monte-Carlo analysis or scenario-based modelling to assess BEP and ROI impacts, thereby determining a broader range of carbon incentives for e-waste.

CONCLUSION

The combined analysis of the TCCM framework and theme visualisation using VOSviewer resulted in the grouping of findings into four categories based on the dimensions of the TCCM framework and six themes in the VOSviewer visualisation. In terms of theory, we obtained seven theoretical frameworks, with willingness to pay (WTP) and environmental valuation being the two least implemented theories. For Context, there are three frameworks: geographical focus, e-waste type, and stakeholder perspective. From the geographical focus, it is evident that most research is still concentrated in China, while other countries have no more than three studies, and for Asia, most have only one study. Similarly, Indonesia has only one study. For the characteristic framework, eight frameworks were identified, showing that environmental valuation is limited, such as carbon pricing, price forecasting, and social valuation. Regarding methodology, we identified five paradigms: quantitative research being the most common, and qualitative research, big data, and machine learning technology being the least common.

Meanwhile, the results of the theme mapping through the VOS Viewer show that, in general, e-waste is not closely related to economic analysis, and there are still few studies related to valuation analysis involving NPV, IRR, and ROI. In other aspects, the focus remains on government-related topics, which are still very limited, especially household and municipal-level analyses, which are not yet sufficiently integrated into e-waste valuation analysis.

Based on the overall results we obtained, we propose two models. The first is exploring hybrid models that integrate social preferences with economic valuation, particularly in urban mining and contingent valuation, which can be explicitly applied to Indonesia as part of an extension of our previous research. In addition to Indonesia, this could also be the scope of research in various countries, from the central government to municipal and village levels. The second proposed model is 2) integrating carbon pricing with the valuation analysis of e-waste. This could be another breakthrough as it is expected to generate carbon incentives from e-waste for all categories.

This study can contribute theoretically in the form of new ideas for future research, and the findings of this study can also provide practical recommendations for communities disposing of e-waste, enabling them to derive benefits from e-waste. This also applies to industries, both waste collectors and those generating e-waste, who can implement solutions to benefit from the e-waste they receive through carbon incentive applications. Meanwhile, for the government as a policy maker, this study can help establish a useful management system for e-waste, from obtaining benefits to protecting the environment from further exposure to e-waste.

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